J Insect Conserv (2007) 11:399–408
DOI 10.1007/s10841-006-9055-4

ORIGINAL PAPER

Efficiency of Malaise traps and colored pan traps for collecting flower visiting insects from three forested ecosystems

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Received: 8 May 2006 / Accepted: 20 November 2006 / Published online: 8 February 2007

Abstract Pan and Malaise traps have been used widely to sample insect abundance and diversity, but no studies have compared their performance for sampling pollinators in forested ecosystems. Malaise trap design and color of pan traps are important parameters that influence insect pollinator catches. We compared pan trap (blue, yellow, white, and red) and Malaise trap catches from forests in three physiographic provinces (Piedmont, Coastal Plain, and Blue Ridge) of the southeastern United States. Similarities in trap performance between sites were observed with blue pan traps being most effective overall. Our results showed that various pollinator groups preferred certain pan trap colors and that adding color to Malaise traps influenced insect pollinator catches. However, pan traps generally caught more pollinators than Malaise traps. Because of their low cost and simplicity, using several colors of pan traps is an effective way to sample relative abundance and species richness of flower-visiting insects.

Keywords Pan trap · Malaise trap · Pollinator · Insect vision

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Introduction

Studying pollinators in forested environments presents numerous sampling challenges. Forests are structurally and biologically diverse often containing a herbaceous plant community, a shrub layer, midstory trees, and a dominant overstory tree canopy. Even in fairly simple even-aged forests, understory communities may have a mixture of woody shrubs and herbaceous plants making sampling with sweep nets or vacuum samplers impractical. Studies on the effects of various forest management treatments that alter stand structure and/or composition further complicate sampling. Therefore, we were interested in developing a simple and effective sampling procedure for assessing the relative abundance and species richness of pollinators in forested habitats.

Flowering plants use color, fragrances, rewards (pollen/nectar), and size or shape to attract pollinators (Niesenbaum et al. 1998), with color being one of the more important attractants (Kevan 1972). Therefore, color traps are a potential method of surveying and monitoring pollinator diversity and abundance in forests. Color traps have been used to capture many different types of insects. For example, various yellow traps have been used to catch a wide variety of phytophagous insects (Kirk 1984) and predators (Leksono et al. 2005), blue pan traps catch various Hymenoptera (Aguiar and Sharkov 1997), and white or yellow traps catch many Diptera (Disney et al. 1982). Bees and various other flower-visiting insects respond to common floral colors (Kirk 1984) associated with floral rewards (pollen/nectar) (Leong and Thorp 1999).

Pan traps consisting of colored pans filled with water and an additive (e.g. soap) to help break surface tension are the most common type of colored traps and yellow has been the most widely used color because it attracts a diversity of insects (Leong and Thorp 1999). Few studies have used pan traps to estimate relative abundances of bees or other pollinators in different habitats, despite their usefulness in such studies with other insects (Southwood 1978) and their potential for comparing species richness and diversity (Leong and Thorp 1999). However, Cane et al. (2001) cautioned that pan traps may not accurately reflect the pollinator fauna because samples from such traps poorly represented native bee fauna that visited flowering shrubs in their study area.

Malaise traps capture large numbers and high diversities of flying insects including Hymenoptera (Matthews and Matthews 1970; Noyes 1989; Darling and Packer 1988) and have been used widely in surveys of insect abundance and diversity. Many different Malaise trap designs have been used by past researchers, including Townes (1972) who noted that different colored parts of the trap can cause differences in catches. We compared four colors of pan traps at ground level to modified Malaise traps to determine which captured the greatest number and species richness of flower-visiting insects in three forested habitats located in the Gulf Coastal Plain, Piedmont and Blue Ridge provinces.

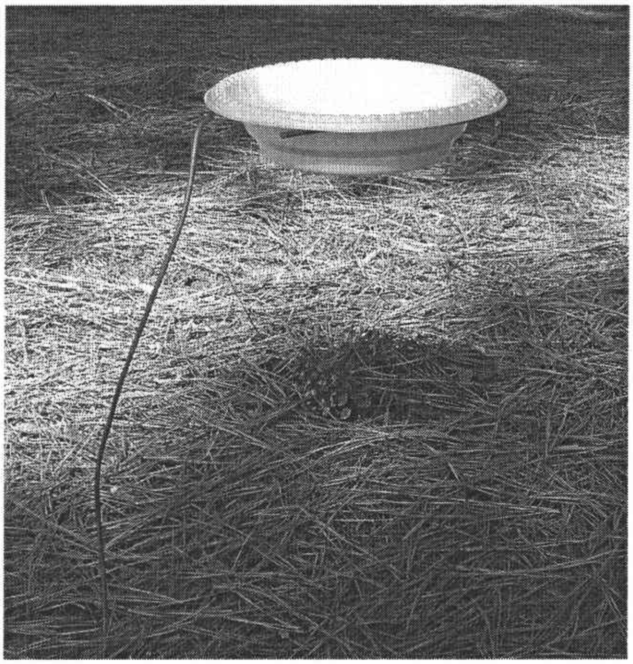

Fig. 1 Example of a colored pan trap used for capturing pollinators. Pan traps were approximately 0.5 m above the ground and 18 cm in diameter

Methods

We trapped at three locations: (1) Clemson Experimental Forest, near Clemson, SC in the Piedmont region, (2) Solon Dixon Experimental Forest, near Andalusia, AL within the Coastal Plain region, and (3) Green River Game Management Area, near Hendersonville, NC in the southern Appalachian Mountains (Blue Ridge region). Traps were placed on 10 ha (24.7 acre) plots at each location. The Piedmont location had 14 plots, the Coastal Plain location had 15 plots and the Blue Ridge location had 12 plots. Each plot was marked by grid points, which were 50 m apart.

The pan traps consisted of red ($\lambda \sim 650$ nm), blue ($\lambda \sim 475$ nm), yellow ($\lambda \sim 580$nm), or white plastic bowls (Solo^{TM}, 532 ml, approximately 18 cm diameter) filled approximately three-fourths full with water, to which several drops of unscented Ajax^{TM} dishwashing detergent were added (Fig. 1). These colors were chosen because they are widely used, represent a range of wavelengths found in the visual spectrum, and are similar to flower colors. We compared the pan traps with a visible light spectrum chart (Curtis 1983) to obtain approximate wavelengths reflected from the colored pans. The pan traps were held approximately 0.5 m above the ground with heavy gauge aluminum wire. The wire was inserted into the ground with the other end bent into a loop that supported the pan (Fig. 1).

We also used canopy Malaise traps from Santee Traps (Lexington, KY) with or without color panels (Fig. 2). Canopy Malaise traps differed from the traditional Malaise trap in that an insect could be caught from any direction and the traps had collecting containers at the top and bottom. The Malaise trap measured approximately 2.7 m tall and 1.2 m in width. Three-meter tall, metal conduit poles were used to suspend the traps. A 0.5 m length of pipe with a larger diameter than the conduit was inserted into the ground and the trap support poles were then inserted into the metal pipe to hold the trap in place. Collecting containers were filled approximately one-third full with a soapy water solution. The colored Malaise traps had four cotton cloth (red, white, blue, and yellow) color panels (0.3 m^2 each) pinned onto Malaise traps so that each collection panel had a different color. We compared the panels to the visible light spectrum chart and found that they reflected similar wavelengths as the pan traps. Samples from the pan traps and Malaise traps were immediately stored in 70% alcohol, sorted to morphologically similar groups and identified.

Fig. 2 Malaise trap (height = 2.7 m, width = 1.2 m) with color panels added (arrow). Colored panels (0.3 m^2) were located on one side of each partition

The Piedmont site was used as a pilot study during the summer of 2002. It was dominated by loblolly (*Pinus taeda*), shortleaf (*Pinus echinata*), and Virginia (*Pinus virginiana*) pines. We used red, white, and blue pan traps, a Malaise trap, and a Malaise trap with red, white, blue, and yellow panels (0.3 m^2 each) attached. We trapped seven times from May to September, with each trapping period lasting seven days. Within each 10 ha plot five groups of pan traps were used with each group consisting of one of each color spaced approximately one meter apart. At each plot we also operated one Malaise and one Malaise trap with color panels. Malaise traps and groups of pan traps were placed near the center of each plot at different grid points 50 m apart.

The Coastal Plain and Blue Ridge sites were sampled during the spring and summers of 2003 and 2004. The Coastal Plain site was dominated by mature longleaf (*Pinus palustris*) and slash pine (*Pinus eliottii*), whereas the Blue Ridge site was dominated by mature hardwood trees which were primarily various oaks (*Quercus* spp.). The Blue Ridge site was sampled 11 times between April and October, and the Coastal Plain site was sampled 10 times between March and September during the 2 years. We used the same traps at the Coastal Plain and Blue Ridge sites as in the Piedmont, but we added yellow pan traps and omitted red pan traps and Malaise traps without color panels. On each plot, a single Malaise trap was operated near plot center and five sets of pan traps were placed at randomly selected grid points also in the central part of each plot.

Because we did not measure pollination effectiveness among the plants and insects, the insects captured can be thought of as flower visitors instead of pollinators. We selected insects for inclusion in our analyses based on published literature and field observations. Numerous insects (other than pollinators/flower visitors) were caught in the Malaise and pan traps. We selected flower visitors we thought also were likely to be involved in pollination to some extent. If species were observed actively visiting flowers on the plots we included them in the analysis even though we were unable to find published references to this behavior. Voucher specimens are currently housed in the USDA Forest Service's collection in Athens, Georgia but they will be placed in the University of Georgia, Natural History Museum upon completion of our studies.

Data were analyzed using a one-way ANOVA with traps as the independent variable and the various pollinator groups as dependent variables. A square-root transformation was used to assure normality and homogeneity of variance. Data were analyzed with PROC GLM in SAS (SAS Institute 1985), and the Ryan-Einot-Gabriel-Welsch Multiple Range Test (REGWQ) was used to determine differences in relative abundances and diversities of pollinators between trap types. Overlap of flower visitor communities captured by the various trap types was compared using the Simplified Morisita Index (Horn 1966) to determine if different traps captured different groups of insects. Morisita's index takes into consideration both species and abundance. We compared overlap of species only among trap types by using Sørenson's quotients of similarity (Sørenson 1948; Southwood 1978). Both Sørenson and Morisita's index calculate values between 0 (no overlap) and 1 (complete overlap).

Results

Piedmont

We collected 6265 flower visitors in four orders and 21 families. Hymenoptera was the most abundant order and Halictidae was the most common family. We included 28 species from five families of Hymenoptera as potential pollinators. Blue pan traps caught significantly more Hymenoptera than any other trap type (Table 1). They also worked best for the two most abundant families Halictidae and Anthophoridae. Overall, Lepidoptera was the most diverse order sampled, with nine families and 34 species of potential pollinators caught. Coleoptera was the second most diverse order with four families and 17 species of flower visitors. Diptera was the least abundant and diverse of the orders, comprising only three families and 10 species that we considered as potential pollinators.

Malaise traps with color panels caught 781 total pollinators compared to Malaise traps without color panels, which caught 526 pollinators. Colored Malaise traps caught more Lepidoptera than all other trap types except blue pan traps (Table 1). Hesperiidae, the most common family of Lepidoptera captured, were caught more frequently with blue pan traps compared to the other traps. However, Papilionidae, the second most abundant family of Lepidoptera, were captured in significantly higher numbers only in colored Malaise traps. The number of Lepidoptera caught in Malaise traps without colored panels was low and did not significantly differ from the white and red pan traps.

The highest numbers of Diptera were caught in blue pan traps, whereas red pan traps caught the fewest (Table 1). The two types of Malaise traps did not differ significantly in numbers of Diptera caught although Malaise traps with color panels caught more than red pan traps. Twice as many Syrphidae were caught in blue pan traps compared to any other trap type.

A total of 89 species of flower visitors were captured (34 Lepidoptera, 28 Hymenoptera, 17 Coleoptera, and 10 Diptera). White pan traps, colored Malaise, and Malaise traps were the most effective for Coleoptera species (Table 2). However, both types of Malaise traps were more successful than all three pan colors tested for the family Mordellidae (one of the more common families). Conversely, colored Malaise and Malaise traps did not yield a single specimen of Buprestidae, another common flower-visiting Coleoptera we caught. Blue and white pan traps caught the most species of Hymenoptera, and the colored Malaise and blue pan traps were the most effective for Lepidoptera.

Blue and white pan traps had the highest flower visitor overlap with a Morisita's index of overlap of 0.95, whereas red and colored Malaise traps had the lowest with a value of 0.16 (Table 3). We compared the combined captures from all three pan colors to Malaise traps. Pan traps and colored Malaise had a Morisita's index value of 0.48, and pan traps and Malaise without color panels had a 0.38 overlap. Species overlap between pan traps and Malaise without color panels as measured by Sørenson's index was 0.74 while Sorenson's index was 0.77 for comparison of pan traps to Malaise traps with color panels.

Table 1 Mean number (SE) of flower-visiting insects from four orders, and the two most numerous families from each order, caught per plot in five different traps used on the Clemson Experimental Forest, near Clemson, SC 2002 (Piedmont, $n = 14$)

Order and family[a]	Trap type[b]				
	CM	M	B	W	R
Hymenoptera	15.1 (4.0)$_c$	9.6 (2.1)$_c$	152.8 (24)$_a$	85.6 (16.9)$_b$	1.6 (0.37)$_c$
Halictidae	11.9 (3.7)$_c$	7.1 (1.7)$_c$	141 (22.9)$_a$	79.4 (16)$_b$	1.3 (0.30)$_c$
Anthophoridae	0.86 (0.35)$_b$	0.21 (0.11)$_b$	8.2 (1.6)$_a$	2.4 (0.43)$_b$	0.14 (0.10)$_b$
Lepidoptera	18.7 (4.2)$_a$	5.6 (0.98)$_b$	20.3 (2.0)$_a$	8.5 (1.2)$_b$	1.7 (0.44)$_b$
Hesperiidae	12.4 (2.8)$_b$	2.6 (0.49)$_{cd}$	18.8 (1.8)$_a$	7.0 (0.97)$_c$	0.21 (0.15)$_d$
Papilionidae	3.6 (1.1)$_a$	0.36 (0.17)$_b$	1.1 (0.38)$_b$	0.71 (0.38)$_b$	0.29 (0.13)$_b$
Diptera	5.5 (1.5)$_b$	3.2 (0.84)$_{bc}$	11.1 (2.4)$_a$	5.4 (1.1)$_b$	0.07 (0.07)$_c$
Syrphidae	1.6 (0.44)$_b$	1.3 (0.49)$_b$	10.7 (2.3)$_a$	3.3 (0.66)$_b$	0.07 (0.07)$_b$
Bombyliidae	3.8 (1.6)$_a$	1.9 (0.65)$_{ab}$	0$_b$	1.9 (0.59)$_{ab}$	0$_b$
Coleoptera	16.4 (3.2)$_{ab}$	19.1 (3.1)$_{ab}$	26.1 (8.9)$_a$	34.7 (8.6)$_a$	6.0 (1.8)$_b$
Mordellidae	12.0 (2.0)$_{ab}$	15.3 (2.9)$_a$	5.1 (1.1)$_{cd}$	8.6 (1.5)$_{cb}$	1.4 (0.32)$_d$
Buprestidae	0$_b$	0$_b$	19.8 (8.1)$_a$	19.4 (7.8)$_a$	3.9 (1.6)$_b$

[a] Within each order or family, means followed by the same letter(s) are not significantly different at $P \leq 0.05$ according to the Ryan-Enoit-Gabrell-Welch multiple comparison test (REGWQ, SAS 1985)

[b] CM = malaise traps with color panels; M = malaise traps without color panels; B = blue pan trap; W = white pan traps; R = red pan traps

Table 2 Mean number (SE) of species from four orders of flower visitors caught per plot in various trap types tested on the Clemson Experimental Forest, near Clemson, SC 2002 (Piedmont Region, $n = 14$)

Order[a]	Trap type[b]				
	CM	M	B	W	R
Hymenoptera	4.9 (0.79)$_b$	4.1 (0.65)$_b$	8.5 (0.87)$_a$	7.8 (0.66)$_a$	1.3 (0.30)$_c$
Lepidoptera	6.6 (0.96)$_a$	3.7 (0.55)$_b$	5.0 (0.54)$_{ab}$	3.5 (0.50)$_b$	1.4 (0.32)$_c$
Diptera	2.1 (0.29)$_{ab}$	1.9 (0.40)$_b$	2.9 (0.34)$_a$	2.5 (0.37)$_{ab}$	0.07 (0.07)$_c$
Coleoptera	5.1 (0.59)$_a$	5.3 (0.34)$_a$	3.4 (0.43)$_b$	5.2 (0.52)$_a$	2.1 (0.21)$_b$

[a] Within each order, means followed by the same letter(s) are not significantly different at $P \leq 0.05$ according to the Ryan-Enoit-Gabrell-Welch multiple comparison test (REGWQ, SAS 1985)

[b] CM = malaise traps with color panels; M = malaise traps without color panels; B = blue pan trap; W = white pan traps; R = red pan traps

Table 3 Comparison of the similarity of flower visitors captured in a Piedmont forest near Clemson, SC by various pan traps (red, white or blue) or Malaise traps (with or without color panels added) using the Simplified Morisita Index. Numbers indicate amount of overlap of the communities captured among trap types (0 = no overlap, 1 = complete overlap)

Trap type	Trap type				
	Red	Blue	White	Malaise	All pan traps
Red					
Blue	0.40				
White	0.47	0.95			
Malaise	0.20	0.37	0.38		0.38
Colored Malaise	0.16	0.47	0.46	0.79	0.48

Coastal Plain

We caught 10,908 flower visitors representing four orders and 27 families on the Coastal Plain. Hymenoptera was the most abundant and diverse order captured in our traps, with the largest number captured from the Halictidae. Eight families and 57 species of Hymenoptera were caught, along with six families and 26 species of Coleoptera, ten families and 45 species of Lepidoptera, and three families and 16 species of Diptera.

Colored Malaise traps captured 870 pollinators, blue pan traps 5017, white pan traps 3126, and yellow pan traps 1895. Blue pan traps were the most successful trap overall for Hymenoptera (Table 4). They also worked best for capturing Halictidae and Anthophoridae. However, colored Malaise traps, white pan traps and blue pan traps were similar in effectiveness for capturing Apidae.

Lepidopterans, primarily Hesperiidae, were also caught in higher numbers with blue pan traps (Table 4). For Papilionidae, however, colored Malaise, white pan traps and blue pan traps were equally effective.

Blue pan traps were also the most effective traps for Diptera that consisted primarily of Syrphidae. However, Bombyliidae were caught in higher numbers with colored Malaise traps (Table 4).

Overall, Coleoptera were caught most effectively with white pan traps (Table 4). White and blue pan traps captured Buprestidae with similar success, whereas, Mordellidae were captured with the greatest success in yellow pan traps.

A total of 144 species of flower visitors was captured (57 Hymenoptera, 45 Lepidoptera, 26 Coleoptera, and 16 Diptera). Blue pan traps caught the greater species richness of Hymenoptera and colored Malaise traps captured the most Diptera species (Table 5). All traps except yellow pan traps captured equal numbers of species of Lepidoptera, while no one trap was more effective than others for Coleoptera. Blue and white pan traps had the highest Morisita's index of overlap at 0.68, but blue pan traps and colored Malaise traps were comparable with a Morisita's index of 0.62 (Table 6). White and colored Malaise had the lowest overlap at 0.18. All three pan trap colors combined and compared to Malaise traps with color panels only had a Morisita's index of 0.51. Species overlap (Sørenson's Index) between pan traps and Malaise traps with color panels was 0.82.

Table 4 Mean number (SE) per plot of flower-visiting insects from four orders and the common families captured in four trap types on the Solon Dixon Experimental Forest, Alabama (Coastal Plain, $n = 15$) and the Green River Game Management Area, near Hendersonville, NC (Blue Ridge, $n = 12$) 2003–2004

Location	Order and family[a]	Trap type[b]			
		CM	B	W	Y
Coastal plain	Hymenoptera	22.9 (2.8)$_c$	158.9 (18.3)$_a$	57.5 (8.6)$_b$	35.9 (3.9)$_{bc}$
	Halictidae	13.9 (2.6)$_b$	116.1 (17.5)$_a$	22.9 (3.5)$_b$	25.7 (3.4)$_b$
	Anthophoridae	1.0 (0.29)$_b$	11.5 (1.5)$_a$	1.5 (0.41)$_b$	0.6 (0.19)$_b$
	Apidae	6.5 (1.3)$_a$	7.3 (0.98)$_a$	5.2 (0.85)$_a$	0.93 (0.21)$_b$
	Sphecidae	0.67 (0.29)$_c$	7.4 (1.2)$_{ab}$	11.9 (3.4)$_a$	2.7 (0.76)$_{bc}$
	Lepidoptera	14.3 (1.7)$_b$	38.2 (2.9)$_a$	15.7 (2.0)$_b$	7.6 (1.2)$_c$
	Hesperiidae	6.3 (0.96)$_b$	30.7 (2.4)$_a$	5.9 (0.72)$_b$	2.9 (0.56)$_b$
	Papilionidae	3.7 (0.83)$_a$	5.5 (0.90)$_a$	3.9 (0.68)$_a$	0.53 (0.24)$_b$
	Diptera	10.1 (0.87)$_b$	45.6 (6.1)$_a$	7.5 (0.87)$_b$	3.4 (0.83)$_b$
	Syrphidae	4.1 (0.76)$_b$	45 (6.1)$_a$	6.4 (0.83)$_b$	3.3 (0.84)$_b$
	Bombyliidae	5.5 (0.82)$_a$	0.07 (0.07)$_b$	1.1 (0.24)$_b$	0.07 (0.07)$_b$
	Coleoptera	10.7 (1.8)$_c$	91.8 (12.0)$_b$	127.7 (21.8)$_a$	79.4 (8.7)$_b$
	Mordellidae	8.7 (1.6)$_b$	20.9 (2.9)$_b$	24.3 (3.9)$_b$	67.9 (9.1)$_a$
	Buprestidae	1.3 (0.30)$_b$	69.5 (12.2)$_a$	98.8 (20.7)$_a$	10.7 (2.2)$_b$
Blue ridge	Hymenoptera	12.7 (5.5)$_c$	198.1 (38.3)$_a$	86.8 (17.5)$_b$	77.6 (12.6)$_b$
	Halictidae	11.2 (5.5)$_c$	182.9 (35.4)$_a$	69.4 (13.3)$_b$	65.1 (10.6)$_b$
	Anthophoridae	0.58 (0.26)$_b$	6.3 (1.5)$_a$	4.7 (1.3)$_a$	7.0 (2.0)$_a$
	Apidae	0.83 (0.34)$_b$	6.4 (1.7)$_a$	5.3 (1.4)$_a$	0.83 (0.34)$_b$
	Sphecidae	0.083 (0.083)$_b$	0.25 (0.25)$_b$	5.1 (2.1)$_a$	2.2 (0.74)$_{ab}$
	Lepidoptera	6.3 (1.6)$_{bc}$	26.2 (3.9)$_a$	11.5 (1.7)$_b$	2.5 (0.62)$_c$
	Hesperiidae	2.8 (0.75)$_c$	21.1 (3.0)$_a$	7.3 (1.0)$_b$	1.7 (0.40)$_c$
	Papilionidae	2.8 (1.1)$_a$	3.7 (0.78)$_a$	3.1 (0.69)$_a$	0.33 (0.14)$_b$
	Diptera	17 (4.5)$_b$	99.3 (33.4)$_a$	23.5 (7.9)$_b$	15.8 (4.2)$_b$
	Syrphidae	16 (4.5)$_b$	98.8 (33.4)$_a$	23.2 (7.9)$_b$	15.7 (4.2)$_b$
	Coleoptera	14.3 (1.5)$_b$	15.3 (3.1)$_b$	29.5 (8.4)$_a$	23.8 (5.6)$_{ab}$
	Mordellidae	8.0 (1.3)$_a$	8.7 (1.7)$_a$	5.4 (1.5)$_a$	8.0 (1.8)$_a$
	Buprestidae	1.4 (0.40)$_b$	3.7 (1.3)$_a$	3.0 (0.67)$_{ab}$	0.92 (0.31)$_b$
	Scarabaeidae	0.50 (0.50)$_b$	0.67 (0.36)$_b$	11.8 (5.5)$_a$	11.8 (4.1)$_a$
	Cerambycidae	4.0 (0.83)$_b$	2.3 (0.61)$_b$	9.3 (2.9)$_a$	3.0 (0.95)$_b$

[a] Within each order or family, means followed by the same letter(s) are not significantly different at $P \leq 0.05$ according to the Ryan-Enoit-Gabrell-Welch multiple comparison test (REGWQ, SAS 1985)

[b] CM = malaise traps with color panels; B = blue pan trap; W = white pan traps; Y = yellow pan traps

Table 5 Mean number (SE) of species of four orders of flower visitors caught per plot in various trap types on the Solon Dixon Experimental Forest, Alabama 2003–2004 (Coastal Plain, $n = 15$) and the Green River Game Management Area, near Hendersonville, NC (Blue Ridge, $n = 12$)

Location	Order[a]	Trap Type[b]			
		CM	B	W	Y
Coastal plain	Hymenoptera	8.2 (0.68)$_c$	17.6 (0.67)$_a$	12.7 (0.90)$_b$	8.4 (0.54)$_c$
	Lepidoptera	7.2 (0.54)$_a$	8.5 (0.48)$_a$	8.4 (0.65)$_a$	5.1 (0.62)$_b$
	Diptera	4.6 (0.34)$_a$	3.1 (0.25)$_b$	2.9 (0.22)$_b$	1.8 (0.31)$_c$
	Coleoptera	4.4 (0.46)$_a$	5.1 (0.41)$_a$	5.1 (0.28)$_a$	4.1 (0.31)$_a$
Blue ridge	Hymenoptera	3.4 (0.31)$_b$	10.8 (1.0)$_a$	13.1 (1.3)$_a$	11.1 (1.1)$_a$
	Lepidoptera	3.6 (0.70)$_c$	8.4 (0.81)$_a$	5.8 (0.60)$_b$	2.2 (0.53)$_c$
	Diptera	3.6 (0.43)$_a$	3.3 (0.28)$_a$	3.1 (0.43)$_a$	1.6 (0.23)$_b$
	Coleoptera	7.2 (0.53)$_a$	5.5 (0.74)$_{ab}$	6.8 (0.91)$_a$	4.7 (0.45)$_b$

[a] Within each order, means followed by the same letter(s) are not significantly different at $P \leq 0.05$ according to the Ryan-Enoit-Gabrell-Welch multiple comparison test (REGWQ, SAS 1985)

[b] CM = malaise traps with color panels; B = blue pan trap; W = white pan traps; Y = yellow pan traps

Table 6 Comparison of the similarity of flower visitors captured by various traps on a Coastal Plain site near Andalusia, AL and a Blue Ridge site near Hendersonville, NC using the Simplified Morisita Index. Numbers indicate amount of overlap of the communities captured (0 = no overlap, 1 = complete overlap)

Location	Trap Type	Trap Type			
		Blue	White	Yellow	All Bowls
Coastal plain	Blue				
	White	0.68			
	Yellow	0.36	0.38		
	Colored Malaise	0.62	0.18	0.34	0.51
Blue ridge	Blue				
	White	0.88			
	Yellow	0.85	0.97		
	Colored Malaise	0.72	0.78	0.76	0.77

Blue Ridge

We caught 7921 flower visitors representing four orders and 21 families. Like the Piedmont and Coastal Plain, Hymenoptera was the most abundant order, with Halictidae being the most abundant family. We caught six families and 45 species of Hymenoptera, seven families and 35 species of Lepidoptera and six families and 33 species of Coleoptera. Diptera was the second most abundant order but, like the other two sites, were the least diverse, comprising only two families and 13 species.

The colored Malaise traps captured 603 pollinators, blue pan traps 4067, white pan traps 1816, and yellow pan traps 1435. Blue pan traps were the most effective traps for Hymenoptera in general and for Halictidae and Anthophoridae specifically (Table 4). However, blue and white pan traps captured similar numbers of Apidae. White pan traps were the most successful traps for Sphecidae.

Blue pan traps were most effective for Lepidoptera, which were predominantly Hesperiidae, while colored Malaise and blue or white pan traps captured Papilionidae with similar success. Blue pan traps were also the most effective traps for Diptera, which were primarily syrphid flies (Table 4).

Overall, Coleoptera were caught best with white pan traps although yellow pan traps performed equally well (Table 4). White pan traps captured the greatest number of Cerambycidae while equal numbers of flower visiting Scarabaeidae were caught in white and yellow pan traps. Buprestids were captured most often with blue or white pan traps; while Mordellidae were captured in equal numbers in all trap types.

A total of 126 species of flower visitors were captured (45 Hymenoptera, 35 Lepidoptera, 33 Coleoptera, and 13 Diptera). Blue pan traps captured the greater species richness of Lepidoptera (Table 5). Blue, white, and yellow pan traps captured similar diversities of Hymenoptera. Similar numbers of Diptera and Coleoptera species were caught with colored Malaise, and blue and white pan traps. All trap types had a relatively high flower visitor overlap, with blue pan traps and colored Malaise having the lowest Morisita's index of 0.72 (Table 6). Catches from all three pan colors combined and compared with colored Malaise traps had a Morisita's index of 0.77. Sørenson's Index of species overlap between all three pan traps combined and Malaise traps with color panels was also high at 0.70.

Discussion

The type and color of the trap clearly influenced abundances and diversities of catches for various insect groups. Many Hymenoptera are able to discern shorter wavelengths of visible light better than longer wavelengths and many are also able to detect wavelengths in the ultra-violent (Jones and Buchmann 1974; Kevan 1979; Peitsch et al. 1992). The color blue is the lowest wavelength that we used, which may explain why Hymenoptera overall preferred the blue pan traps at all three sites. Kevan (1978) showed that bumblebees preferred flowers that reflected blue light and some bee species see white as a blue–green color (Leong and Thorp 1999). Therefore, the attraction of various groups of Hymenoptera to both white and blue pan traps may be because they cannot distinguish the difference or do not discriminate between the colors. Peitsch et al. (1992) found that many bee species can recognize the color yellow; however, fewer bees were caught in yellow pan traps at the Blue Ridge and Coastal Plain sites. Even though many bee species are attracted to the color yellow (Leong and Thorp 1999), there may be few yellow flowered plants that provide floral rewards in these areas, possibly making yellow pan traps less effective. Red pan traps were almost completely ineffective for Hymenoptera. Most Hymenoptera are considered "red blind" so they see the color red as black or dark colored (Frisch 1971). Therefore, many red flowers are tubular in shape and emit no odor, favoring pollination by birds with long beaks (Kevan and Baker 1983; Buchmann and Nabhan 1996). The Malaise traps (from the Piedmont) with and without color panels were also relatively ineffective for capturing a diversity or large numbers of Hymenoptera, which may indicate some Hymenoptera were able to avoid capture in the traps. We noticed on occasion that some bees that flew into Malaise traps were able to escape. Therefore, the hovering and flight ability of many bees may allow them to avoid the design of Malaise traps we used. In addition, the trapping surface of our traps was approximately 0.5 m above the forest floor so bees foraging or flying close to the ground would be less likely to be captured.

Butterflies visit a wide variety of colored flowers (Kevin and Baker 1983; Buchmann and Nabhan 1996; Kinoshita and Arikawa 2000) and are considered to have the widest visual range of any animal (Bernard 1979). Color has been shown to be an important criterion for butterflies searching for nectar (Ghoulson and Cory 1993; Weiss 1995, 1997). However, because our results indicate they have a strong preference for blue (and white in the Coastal Plain and Blue Ridge) when given a choice, they may be able to discern the color blue better than others despite the fact that other researchers have found they prefer the color yellow in their feeding behavior (Swihart and Gordon 1971). Many butterflies see the color red, which is uncommon among insects (Bernard 1979; Kevan and Baker 1983), while other butterflies lack sensitivity to red (Bandai et al. 1992; Briscoe 2000; Briscoe and Chittka 2001). Some plants have flowers that change from yellow to red after being pollinated to direct butterflies and other pollinators to unpollinated flowers (Weiss 1995; Nisenbaum 1998), indicating that some plants use red as an avoidance color. Visually seeing red may be used only as part of courtship behavior for some butterflies (Swihart and Gordon 1971), which may also explain the low catches among the red pan traps when we tested them in the Piedmont. Members of the Papilionidae were also captured with color Malaise at all three sites with similar success. In the field, several papilionids were viewed visiting pan traps, but were not captured. Their large size appeared to help them avoid capture in our relatively small pan traps, which may explain why colored Malaise traps outperformed pan traps for capturing these butterflies at the Piedmont site. However, that was not the case in subsequent trials where pan traps and Malaise traps performed equally.

Diptera are considered to be the second most important order of insects that visit and pollinate flowers (Larson et al. 2001). However, despite a high diversity of Diptera documented to visit flowers, the majority of flower visiting flies we sampled were syrphids and bombyliids. These two families are considered to be the most important flower visitors among flies and their attraction to flowers is well documented (Larson et. al. 2001). It appears that syrphid flies are highly attracted to blue colors based upon our results. This contradicts the fact that most flies, in general, have been shown to visit white, pink, and yellow flowers with constancy (Proctor et al. 1996). However, other groups of Diptera, such as biting flies, are attracted to dark colors (Kirk 1984). Syrphids have been caught in yellow pan traps (MacLeod 1999), while various syrphid genera also were attracted to yellow, blue or white traps (Haslett 1989). However, Chen et al. (2004) captured large numbers of syrphid flies with blue sticky traps, which support our findings. Beeflies (Bombyliidae) are commonly associated with blue flowers (Kevan 1978), so we expected blue pan traps to be more successful. However, Bombyliidae were captured in higher numbers with Malaise traps with or without color panels in the Piedmont, with very few being collected with pan traps. Likewise, Malaise traps with color panels caught more Bombyliidae than color pan traps in the Coastal Plain, while few beeflies were caught with any trap on the Blue Ridge site. Perhaps, bee flies were able to escape the pan traps. However, relatively few bombyliids were collected, which may indicate that all trap types we tested were somewhat inefficient for them or they have low populations within forests.

We found few similarities in Coleoptera captured among the different trapping sites or trap types. The species of beetles varied among the three sites more than any other order of insect we studied, which could explain why their response to the traps varied more. Beetle species have been shown to respond to colors differently. Chrysomelidae and Scarabaeidae are able to distinguish among yellows, oranges, and blues while others can discern red (Proctor et al. 1996). Responses to yellow by some beetles may imply that they are foliage seekers (Prokopy and Owens 1983). Very few beetles we considered flower visitors were attracted to the red pan traps, which may indicate they were unable to discern the color red. Our trap captures of Buprestidae included large numbers of *Acmaeodera* spp. that were attracted to blue and white pan traps at all three sites. Buprestids of the genus *Agrilus* have been caught successfully with purple and navy blue traps (Francese et. al. 2005) so buprestids in general may be attracted to shorter wavelengths of visible light such as blue.

Morisita's index of similarity indicated that captures of flower-visiting insects were most similar in blue and white pan traps on all three sites. Overall, this is fairly consistent with our species richness and abundance results that showed many groups preferred blue and white pan traps equally well. Although blue and white pan traps were most similar at all sites, a number of differences in similiarity of trap catches among trap types existed between sites. For example, similiarity was high among all trap types at the Blue Ridge study area where white and yellow pan traps had a similarity of 0.97. In contrast, white and yellow bowls in the Coastal Plain forest had a similarity in captures of only 0.38. Why similarity of trap catch varied among locations is unclear but it emphasizes the need to use all three colors to insure a broad sampling of the flower-visiting insect communities in these forest habitats. Morisita's index of overlap between all pan traps and Malaise traps was low in the Piedmont and Coastal Plain, but Sorenson's index, which only considers presence or absence of species, was relatively high at all three sites. Therefore, pan traps and Malaise traps were similar in effectiveness for sampling pollinator richness but they differed in abundance of the various species sampled. These data suggest that the pan traps we used can effectively sample a wide range of flower-visiting insects including many large butterflies. Droege (Tips on how to use bee bowls to collect bees. http://online.sfsu.edu/~beeplot/pdfs/bee%20bowl%20%20tip%20sheet2.doc) found pan size did not affect catch of bees a great deal and suggested that smaller pans were easier to handle and maintain in the field. However, if the goal is to capture large flower visitors like butterflies in addition to other pollinators then large bowls work as well as the canopy Malaise traps we tested.

Our study demonstrates that a combination of blue, white, and yellow pan traps were effective for assessing the abundance and species richness of diverse communities of flower visitors in three forests. Other parameters (i.e. trap height, duration of trap placement, etc.) may influence trap captures and could prove useful in insect pollinator sampling, so exploring their effects on trap captures could prove useful for maximizing insect pollinator sampling, in these habitats. However, our results show that pan traps were an easy, effective and inexpensive method that worked as well or better than Malaise traps for sampling pollinators in three different forest habitats. In addition, a recent study (Hanula, unpublished data) shows that pan traps in forests captured most of the bee species that were collected by net while visiting flowers in nearby roadside habitats.

Acknowledgements This is Contribution Number 87 of the National Fire and Fire Surrogate Project (FFS), funded by the U.S. Joint Fire Science Program. We thank Danny Dyer, Ryan Malloy, Mike Ulyshen, and Scott Horn for field assistance. James Pitts provided identifications of many of our Hymenoptera.

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