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Sampling Bee Communities (Hymenoptera: Apiformes) in a Desert Landscape: Are Pan Traps Sufficient?

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ABSTRACT: Pan traps (colored plastic bowls) are frequently used as an efficient standardized method of sampling bee faunas. We explored the utility of pan traps in three colors compared to net collecting using simultaneous sampling at biweekly intervals throughout the flowering season (May–Sep) at 11 sites in the eastern Great Basin Desert. Pan traps deployed for one day (9:00–16:00) on average captured significantly larger samples than net collections (2 hr.) at all intervals except the latter half of May. Average species richness for net collections exceeded pan traps only during late May and late September, periods with abundant floral resources. Capture rates were similar between colors. The composition of bees was also similar; Sørensen's similarity values exceeded 0.7. Color preferences for pollen specialists did not match flower color of their hosts. There were significant differences in species composition between net collections and pan trap collections. Almost one-third of the species showed a strong bias toward one method and in some cases between pan trap colors. The methods appear complementary: Halictinae and *Perdita* were predominantly collected in pan traps (85%); three genera, *Anthidium*, *Colletes*, *Epeolus* were largely or entirely detected by netting. Net collecting should be used in addition to pan traps if comprehensive inventories are desired. Though pan trapping constitutes a standardized method that avoids collector bias, it may not be unbiased; capture rates were lowest when flowering plant richness was greatest.

KEY WORDS: UV reflective traps, bee diversity, Great Basin, sand dunes

Pollination is an essential ecosystem service bees provide in natural and agricultural systems (Nabhan and Buchmann, 1997). Increased awareness of the important role native bees play as pollinators has led to recent collaborative efforts between researchers and land managers to document bee faunas in North America (Griswold *et al.*, 1998; Messinger and Griswold, 2002; Gardner and Ascher, 2006; Giles and Ascher, 2006; Messinger, 2006; Brosi *et al.*, 2007). Pan traps (colored plastic bowls filled with soapy water) have been employed as tools to evaluate the diversity of pollinators, so that informed management decisions can be made (Aizen and Feinsinger, 1994). Pan trapping is viewed as an attractive alternative to traditional net collecting because it is cheaper, requires fewer man-hours, is not dependent on trained collectors, and presumably eliminates collector bias.

Some studies, however, have cautioned against using pan traps alone to estimate the relative abundance of bee species (Leong and Thorp, 1999; Cane *et al.*, 2000; Toler *et al.*, 2005; Roulston *et al.*, 2007). Pan traps may not collect bees in an unbiased manner; some species are rarely collected in pan traps. There are also indications that pan trap color influences relative abundance (Barker *et al.*, 1997;

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Leong and Thorp, 1999). Leong and Thorp (1999) proposed that specialist bees may be attracted to traps that have a similar color to their host flower, thus resulting in a biased sample. Toler *et al.* (2005) addressed the issue of insect color preference by comparing the bees collected by blue, yellow, and white pan traps in Dugway Proving Grounds (DPG) in the Great Basin Desert of western Utah during the spring flowering period. They concluded that the majority of bees showed no significant color preference, and that pan traps were useful in measuring the bee richness of an area. However, there was no comparison with traditional collecting methods such as net collecting.

Here we address the issue of pan trap efficacy using data from a two year study in DPG with simultaneous pan trap and net collecting. Our work adds to the previous studies in three ways: 1) we deployed pan traps bi-weekly from May through September for two years; this larger data set permits investigation of the complete bee fauna, including the distinctive late season as well as early season bee faunas; 2) we used fluorescent colored pan traps which capture more bees than non-fluorescent pan traps (Droege, 2005); 3) we collected with nets from all available flowering plants so we can compare differences not only among pan trap colors but between pan traps and net collections.

A further element of our study was a test of novel pan trap colors. Traditional pan trap colors have been blue, yellow, and white. In order to test the superiority of these colors we periodically deployed three alternative fluorescent colors of pan traps (orange, green, and pink), along with our standard fluorescent blue, fluorescent yellow and white.

Materials and Methods

This study was conducted during the 2003 and 2005 flowering seasons in Dugway Proving Grounds, in Tooele County, Utah (40.2°N 112.7°W). Because of limited public access, DPG provided many relatively pristine desert environments for collecting, including large sand dune systems. A total of 11 one ha sites in a variety of habitats, including active sand dunes, vegetated dunes, and riparian areas, were sampled using pan traps and aerial nets. In both years, collections began at the beginning of May and continued bi-weekly through the end of September. To capture the active flight period for most bees, pan traps were set out before 9:00 and were picked up after 16:00. Droege (2005) found that there was no statistical difference in number of bees collected in pan traps deployed for 24 hr and those deployed for only eight hours. Thirty pan traps, equally divided between fluorescent blue, fluorescent yellow, and white were deployed either in a single linear transect, or as two 15 bowl transects forming an "X". In each transect, bowls were organized in a repeating color sequence (e.g., B, W, Y, B, W, Y, etc.). In 2003 pan traps were made from white eight oz bowls that were colored with fluorescent spray paint. In 2005 pan traps were colored the same way, but traps were made from 3.25 oz cups rather than eight oz bowls to reduce the amount of water needed. Droege (2005) found that there was no difference in capture rate between eight oz bowls and 3.25 oz bowls. Net collecting was conducted by two trained collectors for two 30-minute periods on each sampling day, once before noon and once after noon. A total collection time of two hours was spent net collecting each plot per day. In order to promote even sampling throughout plots, they were divided in half with both collectors sampling each half for 15 min. Collectors traversed the entire plot capturing bees as encountered on all blooming plants. All sites were geo-referenced using Garmin 12XL GPS units. Insect specimens were mounted, and labeled with site, date, and collection information, as well as a unique barcode. Specimens were identified to the species level where possible at the USDA-ARS Bee Biology and Systematics Laboratory (BBSL) in Logan, Utah. Where species could not be assigned to a published name, as in some unrevised genera, they were given alphanumeric names to distinguish them as morphospecies (i.e., *Perdita* sp. D2). Morphospecies without a "D" preceding the number designate specimens matching morphospecies from other faunal surveys. Except for a synoptic set of vouchers returned to DPG, specimens are deposited in the BBSL's U.S. National Pollinating Insects Collection.

To compare bee richness and relative abundance between different collecting techniques we used two versions of the Sørensen's similarity index, one that includes abundance (Bray and Curtis, 1957), and one that only uses presence/absence (Southwood, 1978). Similarities were determined using EstimateS (Colwell, 2005). The closer the Sørensen's similarity value is to one, the more similar the collecting techniques. An analysis of estimated species richness was performed using the program Specrich which is available online at: http://www.mbr-pwrc.usgs.gov/software.html (Last accessed: April 2008).

To test the effectiveness of the traditional pan trap colors (fluorescent blue, fluorescent yellow, and white), alternative colors (fluorescent orange, fluorescent green and fluorescent pink) were deployed along with the traditional colors at sites additional to our standard plots. Alternative colors were tested five times throughout the 2005 field season. Five traps of each of the six colors were placed at one meter intervals along a single transect line deployed before 9:00 h and collected after 16:00 h.

Results

A total of 104 collections were made using both nets and pan traps, yielding 9,119 individuals representing 146 species (Appendix 1). Traditional colored pan traps accounted for the vast majority (86%) of specimens collected. Bee abundance in pan traps was evenly distributed across the three colors (35.2% in white, 32.5% in fluorescent yellow, and 32.3% in fluorescent blue). Richness for the two methods was similar; 114 species in pan traps and 109 species collected with nets.

Bees that dominated net collections were different than those most abundant in pan traps. *Hesperapis* n. sp. (nr. *elegantula* Cockerell) was the most numerous species collected with nets (83 specimens), followed by *Perdita idonea* (81 specimens) and *Protandrena aurifodinae* (67 specimens). For pan traps *Perdita idonea* was the most abundant bee in all three standard colors (fluorescent yellow, 630 specimens; fluorescent blue, 458; white, 418). The next most abundant species in fluorescent yellow pan traps were *Lasioglossum* sp. 23 (539 specimens) and *Perdita aridella* (343 specimens). In white pan traps *Perdita aridella* (398 specimens) and *Lasioglossum* sp. 23 (382 specimens) dominated. Finally, in fluorescent blue pan traps, *Perdita aridella* (383 specimens) and *Perdita albonotata* (295 specimens) were most abundant. *Lasioglossum* sp. 23 was also abundant in fluorescent blue with 285 specimens collected.

Sørensen's similarity values calculated using only presence/absence data show that all three colors of pan trap are highly similar to each other, with values ranging from

Table 1. Sørensen's similarity values of the bee faunas collected in pan traps and nets, using only presence/absence data.

	Net	Fluorescent yellow	White	Fluorescent blue
Net	—	0.621	0.634	0.656
Fluorescent yellow		—	0.735	0.744
White			—	0.739
Fluorescent blue				—

0.735 to 0.744 (Table 1). Net collections were less similar to individual colors of pan trap than between color similarities, with similarity values from 0.621 to 0.656 (Table 1). Similarity of net collections to total pan trap collections based on presence/absence was 0.663. When abundance is included in the similarity analysis, pan trap colors remain very similar to each other, with values ranging from 0.722 to 0.829 (Table 2). Similarities between net collections and pan traps, however, dropped dramatically; values range from 0.346 to 0.397 for individual pan trap colors, and 0.203 for total pan trap collections.

Estimated species richness for net collections was 145 ± 10.0, and 150 ± 9.8 for pan traps. Estimates for individual pan trap colors was 127 ± 12.2 for florescent yellow, 93 ± 6.2 for white, and 102 ± 6.3 for florescent blue. Overall estimated species richness was 185 ± 9.5.

Thirty-one species are disparate across collecting methods (Table 3). Some of these species were collected more often in pan traps, or a specific pan trap color, while others show patters which suggest avoidance of pan traps (fifteen species). Sixteen species were collected in much higher numbers in pan traps than with nets. Four of these species were abundant in all three pan trap colors. Three species showed a preference for white and fluorescent blue pan traps. Two species preferred white, two species preferred fluorescent yellow, and fluorescent blue was preferred by five species (Table 3).

Pan traps, when compared to net collections, consistently captured higher numbers of bee specimens across the season with one exception, the latter half of May (Fig. 1). Similarly, pan traps collected a richer bee fauna than net collections except for the second half of May and the second half of September (Fig. 2).

Alternative colors

Using alternate colors (fluorescent orange, fluorescent green and fluorescent pink) along with the traditional colors yielded a total of 720 specimens representing 36

Table 2. Sørensen's similarity values of the bee faunas collected in pan traps and nets, using abundance data and presence/absence data.

	Net	Fluorescent yellow	White	Fluorescent blue
Net	—	0.346	0.346	0.397
Fluorescent yellow		—	0.733	0.722
White			—	0.829
Fluorescent blue				—

Table 3. Bee species that show strong disparities across collecting methods. Percentages collected by net and pan trap are proportions of total sample (N). For different pan trap colors, the percentages are also proportions of total sample (N). Best collecting method for each species is marked in bold type. Specialist pollinators are marked with bold type.

	Species	Net	Pan	Fluorescent yellow	White	Fluorescent blue
Andrenidae	*Andrena nigricula*	**100%**				
	***Perdita* n.sp.** (nr. *arenaria* Timberlake)	1.30%	**98.70%**	11.80%	**67.50%**	19.40%
	Perdita albonotata	6.20%	**93.80%**	1.30%	**44.60%**	**47.90%**
	Perdita aridella	4.30%	**95.70%**	29.20%	33.90%	32.60%
	Perdita dilecta	11.00%	**89.00%**	**56.10%**	17.10%	15.90%
	Perdita haigi	**100%**				
	Perdita idonea	5.10%	**94.90%**	39.70%	26.30%	28.90%
	Perdita jucunda	**83.30%**	16.70%		16.70%	
	Perdita lepidosparti	2.90%	**97.10%**	**54.30%**	20.00%	22.90%
	Perdita nuda	**60.90%**	39.10%	13.00%	13.00%	13.00%
Apidae	*Anthophora flexipes*	**93.90%**	6.10%	3.00%		3.00%
	Anthophora maculifrons	**100%**				
	Anthophora petrophila	**89.30%**	10.70%	3.60%		7.10%
	Anthophora urbana	19.20%	**80.80%**	7.20%	**32.00%**	**41.60%**
	Diadasia australis	5.00%	**95.00%**	10.00%	15.00%	**70.00%**
	Diadasia diminuta	5.20%	**94.80%**	10.30%	20.70%	**63.80%**
	Epeolus pusillus	**100%**				
	Eucera fulvitarsis	17.40%	**82.60%**	8.70%	13.00%	**60.90%**
	Melissodes agilis	**66.70%**	33.30%	5.60%		27.80%
	Melissodes dagosa	12.70%	**87.30%**	21.10%	11.30%	**54.90%**
Colletidae	*Colletes gypsicolens*	**100%**				
	Colletes phaceliae	**100%**				
	Colletes simulans	**97.00%**	3.00%		3.00%	
Halictidae	*Agapostemon angelicus/texanus*	8.50%	**91.50%**	36.30%	27.40%	27.80%
	Lasioglossum hudsoniellus	8.20%	**91.80%**	25.80%	**40.20%**	25.80%
	Lasioglossum sp. 23	4.10%	**95.90%**	**42.90%**	30.40%	22.70%
Megachilidae	*Anthidium rodecki*	**96.20%**	3.80%			3.80%
	***Megachile* n.sp.** (nr. *umatillensis* Mitchell)	11.10%	**88.90%**	11.10%	**31.10%**	**46.70%**
Melittidae	***Hesperapis* n.sp.** (nr. *elegantula* Cockerell)	31.80%	**68.20%**	16.10%	11.90%	**40.20%**
	Hesperapis carinata	**82.40%**	17.60%	17.60%		
	Hesperapis oliviae	**78.30%**	21.70%	4.30%	15.20%	2.20%

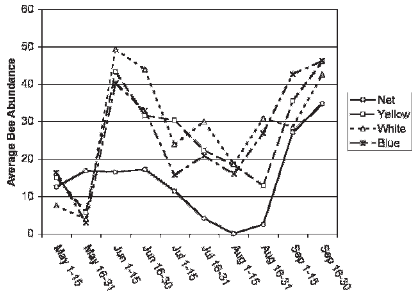

Fig. 1. Average bee abundance of sites in bi-weekly collections for both years for each of the collecting methods (Net, florescent yellow pan traps, white pan traps and florescent blue pan traps).

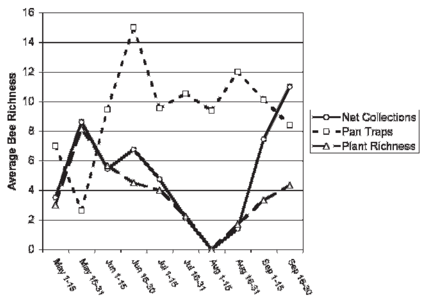

Fig. 2. Average bee species richness of sites by bi-weekly collection for net collecting and pan-trapping, as well as average plant richness data from the 2005 collecting season.

species. Traditional bowl colors captured more bee species than did the alternate colors (Table 4). Traditional bowl colors also captured bees in greater abundance than alternate colors with one exception: fluorescent green traps collected a higher abundance than fluorescent blue and white traps (Table 4). This was due in large part to high numbers of *Halictus tripartitus* and *Lasioglossum* (*Dialictus*) *hudsoniellus* specimens.

Discussion

Our results, like those of previous studies (Toler *et al.*, 2005; Roulston *et al.*, 2007), did not show any overall difference in capture rates between colors of pan traps

Table 4. Bee species richness and abundance data for the collections using both traditional pan trap colors (florescent yellow, white, and florescent blue) and alternate colors (florescent green, florescent orange, and florescent pink).

	Richness	Abundance
Fluorescent yellow	22	299
White	19	105
Fluorescent blue	22	77
Fluorescent green	18	119
Fluorescent orange	13	81
Fluorescent pink	12	39

(Table 1). Even when abundance is included in the similarity analysis, there is no significant difference between pan trap colors (Table 2). Many individual species, however, do exhibit some color preference (Table 3). Leong and Thorp (1999) suggest that specialist pollinators are attracted to pan traps similar in color to their host plant. Our data does not support this hypothesis. An interesting example is *Diadasia*, a genus consisting entirely of specialist pollinators. The two *Diadasia* species represented in DPG by over ten specimens (*Diadasia australis* and *D. diminuta*) show a preference for fluorescent blue pan traps. This is surprising because these species are specialists on *Opuntia* (Cactaceae; prickly pear cactus) and *Sphaeralcea* (Malvaceae; globe mallow), respectively (Sipes and Tepedino, 2005). The blooms of neither of these host plants is blue; *Opuntia* flowers in DPG are pink and yellow, while *Sphaeralcea* is orange. Interestingly, all eight specimens of *Diadasia* reported by Cane *et al.* (2000) were collected in blue pan traps.

Other specialist bees showed some degree of color preference (Table 3). *Megachile* n. sp. (nr. *umatillensis* Mitchell) specializes on white-flowered *Oenothera* (Onagraceae; evening primrose), yet it was collected in fluorescent blue as well as white pan traps. *Perdita* n. sp. (nr. *arenaria* Timberlake) specializes on *Tiquilia* (Boraginaceae; crinklemat) and *P. albonotata*, specializes on *Stephanomeria* (Asteraceae; wirelettuce). Both of these plants have pale pink blooms. *Perdita* n. sp. (nr. *arenaria* Timberlake) preferred white pan traps, and *P. albonotata* preferred blue and white.

While specialist bees make up a significant portion of Table 3 (15 of the 31 species), only a handful of these were collected most frequently in pan traps with colors that matched the color of the bees preferred host plant. Many of the specialists (six species) were collected more often in nets than in any color of pan trap. Six other specialists were collected more often in fluorescent blue traps than any other trap, yet none of these specialized on plants with blue flowers.

Strong biases in capture rate are evident at the generic level. Pan traps captured 85% or more of the Halictinae (*Agapostemon*, *Halictus*, *Lasioglossum*) and *Perdita* specimens. Pan traps largely failed to detect other genera; nets excelled in collecting *Colletes* (99%), its cleptoparasite *Epeolus* (100%), and *Anthidium* (93%). Results also suggest pan traps are poor at capturing *Bombus*, as observed elsewhere (only 6% of all *Bombus* in plots in Zion National Park were from pan traps; TG unpubl.). In DPG seven out of eight specimens were net collected.

The test of alternate colors suggests pan trap colors traditionally used (white, fluorescent blue, and fluorescent yellow) are optimal for sampling bees; they capture a greater diversity of bees than the alternate colors (fluorescent green, fluorescent orange, and fluorescent pink) (Table 4).

Our results lead us to agree with others whose studies suggest that pan trap collections may not accurately represent relative abundances of bee species (Leong and Thorp, 1999; Cane *et al.*, 2000; and Toler *et al.*, 2005; Roulston *et al.*, 2007). This problem is especially apparent in five species. *Agapostemon angelicus*/*texanus* females were collected in abundance with pan traps (658 specimens) while they were not particularly abundant in net collections (61 specimens). Similarly, for *Lasioglossum* (*Dialictus*) sp. 23, a total of 1,206 specimens were collected in pan traps, while only 51 specimens were collected with nets. *Perdita aridella* is represented by 1,124 specimens in pan traps, and 50 specimens collected with nets. *Perdita idonea* is represented by 1,506 specimens in pan traps, and 81 specimens that were net-collected. Lastly, 550 *Perdita* n. sp. (nr. *arenaria* Timberlake) were collected with pan traps, while only seven specimens were collected with nets.

It is difficult to ascertain if these species are over-represented by pan traps, or if they are under-represented in net collections. However, it seems more likely that pan traps are inordinately attractive to some species; two trained collectors would not be expected to miss seeing even the smallest of these bees on flowers, let alone bright green, medium-sized *Agapostemon*, especially if present in the high numbers suggested by pan traps.

While pan-trapping probably does not result in accurate abundance data, net collecting likely yields inaccurate estimates of relative abundance of bee species as well. Net collections consistently recorded lower abundances across the collecting season. Indeed, no bees were collected with nets during the first two weeks of August in either year (Fig. 1). Additional studies are needed to determine how best to reliably estimate the populations extant on the landscape.

Net collections yield a richer bee fauna in the spring and in the late summer (Fig. 2), when floral bloom (richness in the spring, abundance in the fall) is at its peak (pers. obs.). Our data suggest that background bloom greatly affects pan trap effectiveness. In the mid summer of both years (July 16th through August 15th) pan traps caught more bee species, as well as more bee specimens than net collections did. This is likely because there were few or no blooming plants so pan traps were very attractive to those bees that were flying. Furthermore, the lowest bee diversity in pan traps was during the second half of May when floral diversity reached its peak (Fig. 2). Similarly, bee richness in pan traps declined in the late summer, likely as a result of large numbers of available flowers. While average floral richness was not particularly high in the late season (Fig. 2), the plants that were blooming were abundant, over 100 individuals per plot. Additionally, the late season flora was dominated by shrubs like *Chrysothamnus* (Asteraceae; Rabbitbrush) and *Eriogonum nummulare* Jones (Polygonaceae; Money Buckwheat), which produce an abundance of blooms on each plant, thus providing an attractive alternative to pan traps.

Toler *et al.* (2005) suggest that pan traps are an appropriate tool for measuring species richness. They suggest that the use of multiple colors of pan traps can offset any color preference exhibited by some bees. Cane *et al.* (2000) and Roulston *et al.* (2007), suggest the opposite, that pan trapping should be used as a complement to net collections. Our results support the conclusions reached by the latter. If pan traps alone were used in this study, the 23% (35 species) of the bee fauna that were only collected with nets would have been undetected; six of these were represented by ten specimens or more. Additionally, 16 species were collected much more abundantly with nets than with pan traps (Table 3). Alternatively, if collections were made by nets alone, 17% (26 species) of the fauna would have been missed. All 26 of these species collected by pan traps only, however, were poorly represented (three or fewer specimens). This is surprising since pan traps were deployed for at least eight hours, while net collections were made by two collectors for a total of only two hours a day. It is possible that additional net collecting effort, either extending the period of collecting, or adding collectors, would have yielded some of these 26 species. Additional evidence for the complementarity of these two methods comes from the richness estimates: those for nets (145 spp.) and pan traps (150 spp.) are much less than the richness estimate for the methods combined (185 spp.).

In summary, pan traps are useful tools to passively collect bees in natural and agricultural landscapes, but they should be combined with net collecting to yield a more complete portrait of the richness and abundance of bee communities. Pan traps do, however, represent a standardized method that can be useful for comparison across sites, albeit with some known biases. While pan traps have been attractive to researchers partially due to their apparent cost efficiency, we suggest that because pan traps collect a much greater abundance of specimens than nets, much more processing and curating time is required, negating any cost efficiency experienced in the field collecting. Standardized collecting methods like those suggested by LeBuhn *et al.* (2003), which incorporate pan trapping as well as net collecting, collect a more diverse bee fauna and should be implemented where possible. While there was no overall color preference in the bee community in DPG, we suggest, as did Toler *et al.* (2005), that the use of multiple colors will be more successful in correctly representing the bee fauna than would a single color. If pan traps alone are used to measure the diversity of bee communities in a natural or an agricultural setting, especially if only one color is deployed, the resulting incomplete assessment of bee richness and abundance could reduce the effectiveness of efforts to conserve native pollinators.

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Literature Cited

Aizen, M. A., and P. Feinsinger. 1994. Habitat fragmentation, native insect pollinators, and feral honey bees in Argentine 'Chaco Serrano'. Ecological Applications 4:378–392.

Barker, A. M., K. J. Sanbrooke, and N. J. Aebischer. 1997. The water trap colour preferences of farmland sawflies. Entomologia Experimentalis et Applicata 85:83–86.

Bray, J. R., and J. T. Curtis. 1957. An ordination of the upland forest communities of Southern Wisconsin. Ecological Monographs 27:325–349.

Brosi, B. J., G. C. Daily, and P. R. Ehrlich. 2007. Bee community shifts with landscape context in a tropical countryside. Ecological Applications 17:418–430.

Cane, J. H., R. L. Minckley, and L. J. Kervin. 2000. Sampling Bees (Hymenoptera: Apiformes) for pollinator community studies; pitfalls of pan-trapping. Journal of the Kansas Entomological Society 73:225–231.

Colwell, R. K. 2005. EstimateS: Statistical estimation of species richness and shared species from samples. Version 7.5. User's Guide and application published at: http://purl.oclc.org/estimates (Last accessed: April 2008).

Droege, S. 2005. The Bee Inventory Plot. http://online.sfsu.edu/~beeplot (Last accessed: April 2008).

Gardner, K. E., and J. S. Ascher. 2006. Notes on the native bee pollinators in New York apple orchards. Journal of the New York Entomological Society 114:86–91.

Giles, V., and J. S. Ascher. 2006. A survey of the bees of the Black Rock Forest preserve, New York (Hymenoptera: Apoidea). Journal of Hymenoptera Research 15:208–231.

Griswold T., F. D. Parker, and V. J. Tepedino. 1998. The bees of the San Rafael Desert: Implications for the bee faunas of the Grand Staircase-Escalante National Monument. *In* L. M. Hill and J. J. Koselak (eds.). Learning from the land. Grand Staircase-Escalante National Monument Science

Symposium Proceedings, pp. 175–186. Bureau of Land Management, Salt Lake City, Utah. iii + 518 pp.

LeBuhn, G., T. Griswold, R. Minckley, S. Droege, T. Roulston, J. Cane, F. Parker, S. Buchmann, V. Tepedino, N. Williams, C. Kremen, and O. J. Messinger. 2003. A standardized method of monitoring Bee Populations—The Bee Inventory (BI) Plot. Available from http://online.sfsu.edu/~beeplot/ (Last accessed: April 2008).

Leong, J. M., and R. W. Thorp. 1999. Colour-coded sampling: the pan trap colour preferences of oligolectic and nonoligolectic bees associated with a vernal pool plant. Ecological Entomology 24:329–335.

Messinger, O., and T. L. Griswold. 2002. A pinnacle of bees. Fremontia 30:32–40.

Messinger, O. J. 2006. A survey of the bees of Grand Staircase-Escalante National Monument, Southern Utah: Incidence, abundance, and community dynamics. M.S. Thesis. Utah State University, Logan, Utah. 147 pp.

Nabhan, G. P., and S. Buchmann. 1997. Services provided by pollinators. *In* G. C. Daily (ed.). Nature's Services: Societal Dependence on Natural Ecosystems, pp. 133–150. Island Press, Washington DC. 412 pp.

Roulston, T. H., S. A. Smith, and A. L. Brewster. 2007. A comparison of pan trap and intensive net sampling techniques for documenting a bee (Hymenoptera: Apiformes) fauna. Journal of the Kansas Entomological Society 80:179–181.

Sipes, S. D., and V. J. Tepedino. 2005. Pollen-host specificity and evolutionary patterns of host switching in a clade of specialist bees (Apoidea: *Diadasia*). Biological Journal of the Linnean Society 86:487–505.

Southwood, T. R. E. 1978. Ecological methods with particular reference to the study of insect populations. John Wiley and Sons, New York, New York. 524 pp.

Toler, T. R., E. W. Evans, and V. J. Tepedino. 2005. Pan-trapping for bees (Hymenoptera: Apiformes) in Utah's West Desert: the importance of color diversity. The Pan-Pacific Entomologist 81:103–113.

Appendix 1. List of bee species and abundances collected with each method. Collecting methods are: net, florescent yellow pan trap, white pan trap, and florescent blue pan trap.

Family	Species	Net	Yellow	White	Blue	Total
Andrenidae						
	Andrena nigricula Laberge & Bouseman	26				26
	Andrena piperi Viereck	4	4	2		10
	Andrena scurra Viereck		3			3
	Calliopsis barri (Rozen)	1		1		2
	Calliopsis puellae (Cockerell)	2	5	1	2	10
	Calliopsis scutellaris (Fowler)			1	1	2
	Perdita n.sp. (nr. *arenaria* Timberlake)	7	66	376	108	557
	Perdita albipennis Cresson	2	6	5	7	20
	Perdita albonotata Timberlake	38	8	275	295	616
	Perdita aridella Timberlake	50	343	398	383	1174
	Perdita dilecta Timberlake	9	46	14	13	82
	Perdita dolichocephala Swenk & Cockerell	3			4	7
	Perdita gutierreziae Cockerell		1	1		2
	Perdita haigi Timberlake	11				11
	Perdita idonea Timberlake	81	630	418	458	1587
	Perdita jucunda Timberlake	10		2		12
	Perdita lepidosparti Timberlake	1	19	7	8	35
	Perdita luteola Cockerell	13	10	6	3	32
	Perdita nuda Cockerell	42	9	9	9	69
	Perdita phymatae Cockerell		7	8	12	27
	Perdita similis Timberlake	3				3
	Perdita sp.	1				1
	Perdita sp. D1		2			2
	Perdita sp. D2		1			1
	Perdita subfasciata Cockerell	9				9
	Perdita tortifoliae Cockerell			1		1
	Perdita xanthisma Cockerell		1			1
	Perdita zebrata Cresson				1	1
	Protandrena aurifodinae (Michener)	67	67	53	46	233
Apidae						
	Anthophora affabilis Cresson	28	9	8	17	62
	Anthophora flexipes Cresson	31	1		1	33
	Anthophora maculifrons Cresson	10				10
	Anthophora mortuaria Timberlake	1				1
	Anthophora neglecta Timberlake & Cockerell	1				1
	Anthophora pachyodonta Cockerell	1				1
	Anthophora petrophila Cockerell	25	1		2	28
	Anthophora porterae Cockerell	4			3	7
	Anthophora urbana Cresson	24	9	40	52	125
	Bombus morrisoni Cresson	7			1	8
	Ceratina nanula Cockerell		1	4	5	10
	Ceratina pacifica Smith	1				1
	Diadasia australis (Cresson)	1	2	3	14	20
	Diadasia diminuta (Cresson)	3	6	12	37	58
	Diadasia lutzi Cockerell		1		2	3
	Diadasia rinconis Cockerell				2	2
	Epeolus minimus (Robertson)	2				2
	Epeolus pusillus Cresson	11				11
	Eucera fulvitarsis (Cresson)	4	2	3	14	23

Appendix 1. Continued.

Family	Species	Net	Yellow	White	Blue	Total
	Eucera lutziana (Cockerell)	9	2	1	1	13
	Eucera sp.	2				2
	Melecta alexanderi Griswold & Parker	3	1	2	2	8
	Melecta pacifica Cresson				1	1
	Melissodes nr. *Utahensis* LaBerge	1	1		1	3
	Melissodes agilis Cresson	12	1		5	18
	Melissodes bimatris LaBerge	1				1
	Melissodes dagosa Cockerell	9	15	8	39	71
	Melissodes semilupina Cockerell		1			1
	Melissodes sp.	16	3	8	8	35
	Melissodes sp. 10		1	1		2
	Melissodes sp. D10			1		1
	Melissodes sp. D14			1		1
	Melissodes sp. D3				1	1
	Melissodes sp. D5				1	1
	Melissodes sp. D7		1			1
	Melissodes tristis Cockerell			2		2
	Neolarra nr. *vigilans* (Cockerell)	1				1
	Neolarra n. sp. (nr. *clavigera* Shanks)		1			1
	Neolarra vigilans (Cockerell)	1	1		1	3
	Nomada (*Micronomada*) n.sp. 1	3				3
	Nomada n.sp.	2				2
	Svastra obliqua (Say)	1		2	1	4
	Triepeolus grindeliae (Cockerell)	5		1		6
	Triepeolus helianthi (Robertson)	1				1
	Triepeolus sarothrinus (Cockerell)	1	2	2	1	6
	Triepeolus sp. D7	1				1
	Triepeolus sp. D8	2				2
	Triepeolus sp. D9		1			1
	Triepeolus timberlakei (Cockerell)	2			1	3
	Xeromelecta californica (Cresson)	1	1			2
Colletidae						
	Colletes gypsicolens Cockerell	46				46
	Colletes louisae Cockerell	4				4
	Colletes mandibularis Smith	1				1
	Colletes phaceliae Cockerell	21				21
	Colletes simulans Cresson	32		1		33
	Colletes slevini Cockerell	1				1
	Colletes sphaeralceae Timberlake	3				3
Halictidae						
	Agapostemon angelicus Cockerell (males)	37	19	13	12	81
	Agapostemon angelicus/texanus (females)	61	261	197	200	719
	Agapostemon coloradinus Crawford		1			1
	Agapostemon femoratus Crawford	4	6	7	9	26
	Agapostemon melliventris Cresson			1		1
	Agapostemon texanus Cresson (males)	2		2	5	9
	Dieunomia triangulifera Vachal	4				4
	Halictus ligatus Say	7	5	2	9	23
	Halictus tripartitus Cockerell	27	93	62	18	200
	Lasioglossum nr. *pruinosiforme* (Crawford)		1			1
	Lasioglossum nr. *pruinosum* (Robertson)	2	9	6	5	22
	Lasioglossum albohirtum (Crawford)	6	1	4	4	15
	Lasioglossum hudsoniellum (Cockerell)	24	75	117	75	291

Appendix 1. Continued.

Family	Species	Net	Yellow	White	Blue	Total
	Lasioglossum hunteri (Crawford)	1	1	1	5	8
	Lasioglossum hyalinum (Crawford)	25	13	25	14	77
	Lasioglossum incompletum (Crawford)	12	20	23	19	74
	Lasioglossum nr.sp.A	2	1		2	5
	Lasioglossum pruinosiforme (Crawford)	1	5	6	4	16
	Lasioglossum pruinosum (Robertson)	38	14	20	28	100
	Lasioglossum sedi (Sandhouse)		2	2		4
	Lasioglossum sisymbrii (Cockerell)	7	6	4	3	20
	Lasioglossum sp.	55	92	97	69	313
	Lasioglossum sp. 2	4	1	8	5	18
	Lasioglossum sp. 23	51	539	382	285	1257
	Lasioglossum sp. C	1	3	4	7	15
	Lasioglossum sp. D		3		2	5
	Lasioglossum sp. D1		1	2	3	6
Megachilidae						
	Anthidium emarginatum (Cockerell)	3			1	4
	Anthidium rodecki Schwarz	25			1	26
	Ashmeadiella aridula Cockerell	3	2			5
	Ashmeadiella bigeloviae (Cockerell)			1	2	3
	Ashmeadiella bucconis (Say)	7	1	2		10
	Ashmeadiella foveata Michener	1		2	1	4
	Ashmeadiella gillettei Titus	6	4	2	4	16
	Ashmeadiella meliloti (Cockerell)	3	2	1	3	9
	Ashmeadiella sonora Michener		1		1	2
	Ashmeadiella sp. 1				1	1
	Coelioxys hunteri Crawford	1				1
	Coelioxys mesae Cockerell	1				1
	Coelioxys sodalis Cresson			1		1
	Dianthidium n. sp.		1			1
	Dianthidium parvum Cresson	1		1		2
	Dianthidium pudicum (Cresson)	10	3	8	14	35
	Dioxys productus (Cresson)	4	4	7	6	21
	Hoplitis grinnelli (Cockerell)	5	2	1	3	11
	Hoplitis hypocrita Cockerell	2				2
	Megachile nr. *laurita* Mitchell	1				1
	Megachile n.sp. (nr. *umatillensis* (Mitchell))	5	5	14	21	45
	Megachile brevis onobrychidis Cockerell	2	1	3	2	8
	Megachile inimica Cresson	3	1			4
	Megachile montivaga Cresson				3	3
	Megachile subanograe Mitchell		1	1	4	6
	Osmia (*Melanosmia*) sp.	1				1
	Osmia (*Melanosmia*) n. sp.				2	2
	Osmia crassa Rust & Bohart			2	2	4
	Osmia gaudiosa Cockerell	1				1
	Osmia titusi Cockerell	4			1	5
Melittidae						
	Hesperapis n.sp. (nr. *elegantula* Cockerell)	83	42	31	105	261
	Hesperapis carinata Stevens	14	3			17
	Hesperapis oliviae (Cockerell)	36	2	7	1	46
	Total	1309	2539	2747	2542	9119