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Malaise trap sampling efficiency for bees (Hymenoptera: Apoidea) in a restored tallgrass prairie

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Pollination is an essential ecological function, and bees (Hymenoptera: Apoidea) are among the most important pollinators. However, there is growing evidence of decline in some bee populations, with habitat alteration playing an important role, particularly in heavily cultivated regions such as the midwestern USA (Byrne & Fitzpatrick 2009; Grixti et al. 2009; Cameron et al. 2011). Monitoring of bee abundance and diversity is essential for effective bee conservation. Bees are commonly monitored by using sampling devices such as bowl traps, or "bee bowls," which are colored bowls that are placed on the ground, or occasionally elevated, and filled with a liquid such as soapy water (Leong & Thorp 1999; Droege et al. 2010; Grundel et al. 2011; Shapiro et al. 2014). These traps are often referred to as "pan traps" in the literature, but "bowl trap" seems more appropriate because actual aluminum pans are sometimes used as pan traps (Martin 1977). Other trap types used in bee monitoring include vane traps, which consist of 2 plastic cross vanes with a collection container underneath, into which the insects fall upon contact with the vanes (Stephen & Rao 2005; Kimoto et al. 2012), and Malaise traps (Malaise 1937; Townes 1972), which are large, mesh fabric flight interception traps that collect flying insects when they contact a vertical central portion and move up a sloping roof to a collection container. The usefulness of Malaise traps for collecting bees and other insects has been demonstrated in several studies (Matthews & Matthews 1971; Noyes 1989; Bartholomew & Prowell 2005; Ngo et al. 2013), although Malaise traps were less effective than bowl traps in collecting pollinating insects in southeastern U.S. forests (Campbell & Hanula 2007). Recently, Geroff et al. (2014) assessed the effectiveness of the above methods in a west-central Illinois tallgrass prairie and found that Malaise trap captures identified the greatest bee abundance and species richness. This finding suggests that Malaise traps may be useful in assessing bee diversity in this system. In this paper, we further investigate the effectiveness of Malaise traps in assessing bee species richness, using the Chao1 statistical richness estimator (Chao et al. 2009).

Data for this study were collected as part of a larger evaluation of bee sampling methods done from early Jun to early Oct 2010 by Geroff et al. (2014). That study was done in an approximately 12 ha restored prairie at Western Illinois University's Alice L. Kibbe Life Science Station (40.3658°N, 91.4067°W). More detailed information on the study location is given in Geroff et al. (2014). For the present study, data from 5 Townes-style Malaise traps (Sante Traps, Lexington, Kentucky), spaced 50 to 100 m apart, were used. Only Jun and Jul samples were used to ensure sufficient sample sizes. In each month, trapping was done on 6 d within a 10 d period, based on weather conditions (clear, calm, sunny days). In Jun, data were collected on 3 Jun, 6 Jun, 7 Jun, 9 Jun, 10 Jun, and 11 Jun; in Jul, data were collected on 16 Jul, 17 Jul, 19 Jul, 20 Jul, 21 Jul, and 22 Jul 2010. Trapping was done from 0900 to 1800 h on each collection date.

For each month, total numbers and species richness of bees were determined for each trap and for all traps combined. To get an indication of the potential effects of additional sampling dates on species richness totals, we calculated the mean number of unique species per sampling date (species collected only on a particular sampling date) for each month. We used the Chao1 richness estimator to estimate asymptotic bee species richness and evaluate the completeness with which Malaise traps sampled the bee richness present. The Chao1 analysis estimates the minimum total number of species present based on the frequency of rare species collected, in particular the relative numbers of singletons (1 individual of a species collected) and doubletons (2 individuals of a species collected) (Chao et al. 2009). The individual-based Chao1 estimator was chosen rather than the sample-based Chao2 estimator because of small sample sizes (n = 6, using each collection date as a sample) and potential lack of independence of these samples, because these dates were clustered within a short time frame within each month. The Chao calculator (Ecological Archives E090-073-S1, Chao et al. 2009) was used to calculate Chao1 estimates, and estimated sample sizes needed to achieve 80, 90, 95, and 100% of Chao1 estimates. For each Chao1 estimate, the proportion of singletons was less than 50% (i.e., $f_1/n < 0.5$), as recommended by Anne Chao (cited in Colwell 2013).

In Jun, numbers of bees collected by individual traps ranged from 60 to 1,180, and the observed species richness collected per trap ranged from 20 to 37, with 1,882 bees and 68 species collected by the 5 traps combined (Table 1). The mean number (± SE) of unique species per sampling date was 4.33 ± 0.80 (min. = 2, max. = 7). In Jul, numbers of bees collected by individual traps ranged from 20 to 542. The observed species richness collected per trap ranged from 6 to 30, with 899 bees and 40 species collected by the 5 traps combined (Table 2). The mean number (± SE) of unique species per sampling date was 2.83 ± 0.83 (min. = 0, max. = 5). Jun Chao1 estimates of minimum species richness for individual traps ranged from 35.79 to 53.60, with an estimate of 92.05 for the 5 traps combined. Jul estimates for individual traps ranged from 7.00 to 78.17, with an estimate of 58.75 for the 5 traps combined. Estimated sample size increases required to achieve given percentages of the Chao1 estimates are given in Tables 1 and 2. For a complete list of bee species collected at the site, including type of trap and month of collection, see Geroff et al. (2014).

Our results suggest that substantial additional trapping effort (increase in number of traps and/or sampling dates) would be needed to approach asymptotic bee species richness at this site. The combined trap

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Table 1. Abundance, species richness, Chao1 estimates, and sample sizes needed to achieve a given percentage of the Chao1 estimate for 5 Malaise traps operated from 3 to 11 Jun 2010 at Alice L. Kibbe Life Science Station, Hancock County, Illinois.

Trap #	No. of bees collected (mean ± SE)	Observed species richness (mean ± SE)	Chao1 estimate	Estimated no. of bees (and fold increase) required to achieve given % of Chao1			
				80%	90%	95%	100%
Trap #1	1,180 (196.7 ± 35.1)	34 (12.2 ± 1.97)	53.60	2,177 (1.8)	3,322 (2.8)	4,467 (3.8)	10,257 (8.7)
Trap #2	351 (58.5 ± 10.7)	37 (12.7 ± 0.95)	53.06	488 (1.4)	718 (2.0)	948 (2.7)	2,115 (6.0)
Trap #3	60 (10.0 ± 1.03)	20 (6.67 ± 0.71)	40.25	185 (3.1)	278 (4.6)	372 (6.2)	800 (13.3)
Trap #4	108 (18.0 ± 2.37)	30 (9.67 ± 0.56)	42.07	144 (1.3)	214 (2.0)	283 (2.6)	608 (5.6)
Trap #5	183 (30.5 ± 6.27)	30 (12.8 ± 1.58)	35.79	—[a]	240 (1.3)	321 (1.8)	677 (3.7)
Total	1,882 (313.7 ± 46.3)	68 (29.5 ± 2.43)	92.05	2,408 (1.3)	3,771 (2.0)	5,135 (2.7)	13,256 (7.0)

[a]The observed species richness was greater than 80% of the Chao1 estimate.

results for each month suggest that a 7- to 8-fold greater sampling effort would have been required for a complete inventory based on Chao1 values, and about a 3-fold increase in sampling effort to achieve 95% of Chao1 values (Tables 1 and 2). One factor affecting these results may be the patchiness of bees in this restored prairie, along with the localized effective trapping area of the Malaise traps, which is suggested by the great variation in bee abundance and species richness among the individual traps. In a more uniform environment and/or smaller area, fewer traps might be sufficient for detecting a higher proportion of bee species. But in environments where floral resources and bees are patchy (which is probably almost always the case in non-cultivated environments), limitations on the number of Malaise traps that can be deployed are a concern, because high spatial variation would require increased replication. Considering the cost of Malaise traps (about US$230), greater numbers of traps would be cost prohibitive for many bee monitoring programs, but the collection of 1 or more unique species on all but 1 sampling date suggests that an increase in sampling dates could effectively provide at least some of this increased sampling effort.

It is important to note that in the study by Geroff et al. (2014) (in which bowl traps were operated at the same study site for the same time periods as the Malaise traps), the Chao1 estimate of bee richness for bowl traps placed at ground level (69.13) was about 64% of the Chao1 richness estimate (108.00) and about 83% of the observed species richness (83) collected by Malaise traps. These results were based on 15 bowl traps, but analyses indicated that a 12-fold increase in bowl trap sampling effort would have been needed to achieve this Chao1 estimate. In their study of optimal sampling number for bowl traps, Shapiro et al. (2014) concluded that, in general, transects of greater than 30 bowls added little to species richness estimates obtained with 30-bowl transects. It thus appears that Malaise traps may collect bee species that are unlikely to be collected by bowl traps, even if extremely large numbers of bowl traps are used. Malaise traps do collect somewhat different bee species composition than bowl traps (Geroff et al. 2014). As Shapiro et al. (2014) pointed out, bowl traps are probably sufficient for detecting major changes in local bee communities over time, but a combination of trapping methods is likely required for synoptic inventories of bee richness. The addition of even 1 or 2 Malaise traps to bee inventory efforts could improve completeness substantially and provide a better estimate of how many undiscovered species may be present. This would be especially true if Malaise traps were relocated between sampling dates, given the great variation in bee collections among individual traps found in this study. The availability of relatively portable types of Malaise traps such as SLAM traps (MegaView Science, Taichung City, Taiwan) could facilitate more complete coverage of patchy environments by making it easier to relocate traps within a study site during inventory.

Studies of the potential impacts of lethal sampling on bee abundance and diversity are also needed for Malaise traps, as has been done for bowl traps and netting (Gezon et al. 2015). Another consideration with regard to Malaise traps is the large numbers of incidental captures, or "bycatch," that typically occur. Such incidental captures can include taxa of research and conservation interest (Hung et al. 2015) but can also lead to storage challenges and wasted specimens if they are not made available to appropriate taxonomic specialists (Spears & Ramirez 2015).

Bowl traps are an inexpensive and convenient method of quickly assessing bee species richness, but inventories based on bowl traps alone may be far from complete (Cane et al. 2000), and other methods should be used to supplement bowl trapping whenever possible. Malaise traps offer one possibility, but further studies are needed to assess the effectiveness of Malaise traps in various environments and to clarify the trapping intensity needed to achieve an acceptable inventory.

Table 2. Abundance, species richness, Chao1 estimates, and sample sizes needed to achieve a given percentage of the Chao1 estimate for 5 Malaise traps operated from 16 to 22 Jul 2010 at Alice L. Kibbe Life Science Station, Hancock County, Illinois.

Trap #	No. of bees collected (mean ± SE)	Observed species richness (mean ± SE)	Chao1 estimate	Estimated no. of bees (and fold increase) required to achieve given % of Chao1			
				80%	90%	95%	100%
Trap #1	542 (90.3 ± 22.7)	30 (9.67 ± 2.32)	78.17	2,270 (4.2)	3,334 (6.2)	4,399 (8.1)	10,510 (19.4)
Trap #2	214 (35.7 ± 11.2)	24 (8.17 ± 2.39)	32.33	259 (1.2)	383 (1.8)	506 (2.4)	1,028 (4.8)
Trap #3	27 (4.50 ± 1.59)	6 (2.33 ± 0.67)	7.00	—[a]	—[a]	—[a]	—[a]
Trap #4	96 (16.0 ± 5.56)	15 (5.83 ± 1.30)	21.00	130 (1.4)	197 (2.1)	263 (2.7)	491 (5.1)
Trap #5	20 (3.33 ± 1.09)	6 (1.83 ± 0.60)	10.50	43 (2.2)	64 (3.2)	84 (4.2)	130 (6.5)
Total	899 (149.8 ± 36.9)	40 (15.0 ± 3.30)	58.75	1,424 (1.6)	2,203 (2.5)	2,982 (3.3)	7,033 (7.8)

[a]Could not be calculated because no doubletons were collected.

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Summary

Effective assessment of bee (Hymenoptera: Apoidea) diversity is essential for informed bee conservation policies. In this study, the effectiveness of Malaise traps in assessing bee species richness in a west-central Illinois restored prairie was examined using the Chao1 nonparametric richness estimator. Individual traps varied greatly in abundance and species richness of bees collected, and substantially greater trapping effort would have been needed to achieve Chao1 estimates. Malaise traps provide a potentially effective means of augmenting bowl trap inventories, but more studies on Malaise trap performance and comparisons with bowl traps are needed, particularly in heterogeneous environments.

Key Words: insect monitoring; spatial variation; species richness; trapping effort

Sumario

La evaluación eficaz de la diversidad de abejas (Hymenoptera: Apoidea) es esencial para ser informado de las políticas de conservación de abejas. En este estudio, se examinó la eficacia de trampas Malaise en la evaluación de la riqueza de especies de abejas en una pradera restaurada de centro-oeste del estado de Illinois utilizando el estimador de riqueza Chao1 no paramétrico. Las trampas individuales variaron en gran medida en la abundancia y riqueza de especies de abejas recolectadas, y se habrían necesitado sustancialmente mayor esfuerzo de captura para lograr estimaciones Chao1. Las trampas Malaise proveen un medio potencialmente eficaz para aumentar el inventario en las trampas cuencos, pero se necesitan más estudios sobre el rendimiento de las trampas Malaise y las comparaciones con trampas cuencos, sobre todo en ambientes heterogéneos.

Palabras Clave: monitoreo de insectos; variación espacial; riqueza de especies; esfuerzo de captura

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