Wild Bee Pollinators Foraging in Peanut and Cotton Adjacent to Native Wildflower Strips

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Wild bee pollinators foraging in peanut and cotton adjacent to native wildflower strips

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Abstract

Wild bees are major contributors to pollination of economically important crops. However, widespread habitat conversion to agriculture and pesticide exposure are associated with declines in wild bee abundance and biodiversity. A growing number of studies have investigated the incorporation of a variety of flower species in agroecosystems to augment resource and habitat availability to wild bees and pollination of nearby crops. Here we investigated if wildflower strips containing *Gaillardia pulchella* Foug. (Asteraceae) in 2018 and *G. pulchella*, *Rudbeckia hirta* L. (Asteraceae), and *Monarda citriodora* Cerv. ex Lag. (Lamiaceae) in 2019 could promote pollinator abundance and pollination of nearby peanut and cotton. We used bee bowls in crop fields to capture bees and identified the pollen on the bees. We captured a total of 291 bees in peanut and 89 bees in cotton that were comprised of 2 families (Apidae and Halictidae) with 10 species represented from these families. The species in peanut were comprised mostly of *Melissodes communis* Cresson and *Melissodes bimaculatus* Lepeletier (Apidae). The bee species in cotton was comprised of mostly *Lasioglossum reticulatum* Robertson (Halictidae), *M. communis*, and *M. bimaculatus*. At peak abundance in peanut, 48% of bees bore both *G. pulchella* and peanut pollen. At peak abundance in cotton, 37% of bees bore 1 or more wildflower strip pollen and cotton pollen. Throughout the season, 62% of the bees captured in cotton had unidentified pollen from surrounding sources. These results indicate that the wildflower buffers had provided pollinators and bee foragers to these crops in early season. By studying bee foraging between crop fields and wildflower strips based on identification of pollen grain on bee bodies, we showed the potential to increase pollination in crop fields through the provision of floral resources throughout the growing season.

Key Words: *Arachis hypogaea*; *Gossypium hirsutum*; Asteraceae; floral resources; native bees

Resumen

Las abejas silvestres son las mayores contribuyentes a la polinización de cultivos de importancia económica. Sin embargo, la conversión generalizada del hábitat a la agricultura y la exposición a plaguicidas están asociadas con la disminución de la abundancia y la biodiversidad de las abejas silvestres. Un número creciente de estudios ha investigado la incorporación de una variedad de especies de flores en los agroecosistemas para aumentar la disponibilidad de recursos y hábitats para las abejas silvestres y la polinización de cultivos cercanos. Aquí investigamos si las tiras de flores silvestres que contienen *Gaillardia pulchella* Foug. (Asteraceae) en el 2018 y *G. pulchella*, *Rudbeckia hirta* L. (Asteraceae) y *Monarda citriodora* Cerv. ex Lag. (Lamiaceae) en el 2019 podría promover la abundancia de polinizadores y la polinización del maní y el algodón cercanos. Usamos cuencos para capturer las abejas en el campo de cultivo e identificar el polen en las abejas. Capturamos un total de 291 abejas en maní y 89 abejas en algodón de 2 familias (Apidae y Halictidae) con 10 especies representadas en dichas familias. Las especies del maní estaban compuestas principalmente por *Melissodes communis* Cresson y *Melissodes bimaculatus* Lepeletier (Apidae). Las especies de abeja en el algodón estaba compuesta principalmente por *Lasioglossum reticulatum* Robertson (Halictidae), *M. communis* y *M. bimaculatus*. En el pico de abundancia de maní, el 48% de las abejas tenían polen de *G. pulchella* y maní. En el pico de abundancia del algodón, el 37% de las abejas tenían 1 o más tiras de polen de flores silvestres y polen de algodón. A lo largo de la temporada, el 62% de las abejas capturadas en algodón tenían polen no identificado de fuentes circundantes. Estos resultados indican que el buffer de flores silvestres había proporcionado polinizadores y recolectores de abejas a estos cultivos a principios de la temporada. Al estudiar la búsqueda de alimento de las abejas entre los campos de cultivo y las franjas de flores silvestres con base en la identificación del grano de polen en las abejas, demostramos el potencial para aumentar la polinización en los campos de cultivo mediante la provisión de recursos florales durante la temporada de crecimiento.

Palabras Clave: *Arachis hypogaea*; *Gossypium hirsutum*; Asteraceae; recursos florals; abejas nativas

Wild bees are major contributors to pollination of economically important crops (Garibaldi et al. 2013). Because of the loss of natural and semi-natural habitat in agricultural settings (Cameron et al. 2011; Carvalheiro et al. 2013) and exposure of individuals to pesticides in agricultural crops (EPA 2017; IPBES 2017), wild bee declines now are widespread. In response, a growing number of studies have investigated the incorporation of native wildflower strips in agroecosystem programs to augment and enhance habitats for insect pollinators (e.g., Haaland et al. 2011 and references therein; Blaauw & Isaacs 2014; Williams et al. 2015; van Rijn & Wäckers 2016; Xavier et al. 2017; Buhk et al. 2018; Herbertsson et al. 2018; Campbell et al. 2019). Planting a diversity of flowering plants is thought to be important in provisioning resources throughout the season, ensuring resources are available to a wider range of bee species with different floral preferences (e.g., color, odor, shape, pollen quality, and nutritional composition) and ability to

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access nectar and pollen (e.g., Campbell et al. 2017; van Rijn & Wäckers 2016; Vaudo et al. 2016; Shinnosuke et al. 2018).

While peanut and cotton do not require pollinators, 2 studies in peanut found that bees can 'trip' ejection of pollen and cause cross pollination, resulting in increased yield in peanut (Hammons & Leuck 1966; Leuck & Hammons 1967), and pollinators increase yield, fiber weight, and seed number in cotton (Pires et al. 2014; but see Vaissière & Vinson 1994 for *Apis mellifera*). Peanut flowers bloom from May to harvest in late Aug, and cotton flowers bloom from late Jun to mid-Aug with some re-growth and flowering occurring after boll set. However, resource availability to pollinators, commonly quantified as percentage area of flowers in the landscape (Coutinho et al. 2018), is highly variable over the season. Therefore, providing ecological buffers containing native floral resources may support continuous pollination. For example, Xavier et al. (2017) found that although buffers delivered season-long bloom, bees were most abundant early in the season and declined in mid-season. This suggests that although blooms were present, insufficient floral resources such as nectar or pollen may limit bee use of habitat enhancements or crop benefits.

Tracking pollen use by pollinators is 1 method that can resolve habitat preferences and potential resource limitations over space and time (Bänsch et al. 2019). Pollen tracking allows for documenting the movement between ecological buffers and crops to predict the outcomes and weaknesses of habitat provisioning designs for building pollinator populations. In the current study, our objectives were to (1) investigate pollinators occurring in cotton and peanut in relation to adjacent sown wildflower strips and determine composition of pollen loads; (2) assay the nectar and pollen in the wildflowers to estimate resource availability in the floral strips over time; and (3) estimate the effects of open-pollinated and pollinator exclusion on cotton seed, lint yield, and lint quality. We hypothesized that although native wildflower buffers bloom season-long, signaling quality habitat, resource limitation occurs over time and bee pollinators forage elsewhere in nearby later-flowering crop fields. Complementary floral provisioning may, therefore, enhance both pollination services by native bees and bee conservation.

Materials and Methods

STUDY SITE

The 3 fields sampled were located on a University of Georgia Experimental Farm in southern Georgia, USA (31.5116667°N, 83.6419444°W) and were spaced > 500 m apart. The fields contained peanut in 2018 and cotton in 2019. One peanut field was an irrigated, organically farmed field, 0.12 ha in size, and planted on 15 May 2018 with variety GA-06G. The second peanut field was irrigated, 0.35 ha in size, and planted 7 Jun 2018 with variety GA-06G. The third peanut field was irrigated, 0.61 ha in size, and planted on 13 May 2018 with varieties GA-06G, GA-12Y, and FloRun 331. One cotton field was planted on 23 Apr 2019, the second planted on 7 May 2019, and the third planted on 1 May 2019 with varieties PHY 444 WRF, DP 1646, and DP 1840 B3XF, respectively. Wildflower strips were established in 2016 by Xavier et al. (2017) and were non-irrigated and located ≤ 30 m from the edge of the peanut and cotton fields sampled. The wildflower strips were 88.4 m^2 (34 m × 2.6 m) in size and the seeds were sown by hand broadcasting in 2016 with a mixture of 26 species of native flowers (Xavier et al. 2017). However, in 2018 *Gaillardia pulchella* Foug. (Asteraceae) was the only wildflower species present. *Gaillardia pulchella* blooms from mid-Apr through Sep in the region (Xavier et al. 2017). In 2019, *Monarda citriodora* Cerv. ex Lag. (Lamiaceae) and *Rudbeckia hirta* L. (Asteraceae), part of the seed mixtures originally sown in the buffer, also were found in patches throughout all 3 wildflower strips, and their pollen was added to the library. *Monarda citriodora* blooms from early Jun to early –Jul, and *R. hirta* blooms from early Jun through Sep in the region (Xavier et al. 2017). Bees in peanut were sampled weekly from 19 Jun to 20 Jul and bi-weekly from 1 Aug to 16 Sep when the peanut was harvested. Season-long sampling was conducted to estimate bee visitation over an entire season. Bees in cotton were sampled when cotton flowers were present on 2 Jul, 10 Jul, 17 Jul, and then sampling ceased to minimize bee mortality. Peanut and cotton were grown using University of Georgia Extension guidelines with no foliar insecticides applied throughout the sampling period.

POLLINATOR AND POLLEN SAMPLING

A total of 12 bee bowls were established in the 30 m area of peanut and cotton nearest to the wildflower strip. At each sampling point randomly placed and spaced at least 5 m apart, a single blue bee bowl was secured on a red-colored PVC pole and filled with 50 mL of a soapy water solution as described by Gill and O'Neal (2015). Blue plastic bowls (8 oz), hereafter referred to as blue bee bowls (Walmart, Tifton, Georgia, USA), were used because they capture a greater abundance of bees than do white or yellow bowls (Gill & O'Neal 2015; Wheelock & O'Neal 2016; see Toler et al. 2005). The height of the bowl was maintained just above the canopy of the crop. Insects captured in the bowls were collected after 24 h. The bee bowls with captured insects were stored at 4 °C for 1 to 18 h; bees were isolated, pollen removed, and the pollen present on the bees was identified. No pollen was observed in the soap and water solution indicating that the pollen remained on the bees. Bee species were pinned and then identified by JG based on taxon concepts of Mitchell (1962), Packer (1999), and Gibbs (2011). In 2018 peanut, the Halictidae were not identified to genera and species because only representative specimens were identified as *Halictus ligatus* or *Halictus poeyi* (Halictidae) based on a University of Georgia reference collection. Halictid species look very similar (JG personal observation), therefore, it is unlikely that all these specimens were *H. ligatus* or *H. poeyi*. A pollen library was created for all floral species in the strips and nearby crop species (maize, peanut, and cotton) using the method of Bernhardt (2005). The bees collected were 'bathed' in several drops of HPLC grade ethyl acetate to aid in pollen removal, and the pollen present on the entire bee was gently removed with forceps, mounted on slides, stained with Calberla's fluid (Ogden et al. 1974), and identified from the library samples with a compound microscope (Leica Microsystems Inc., Buffalo Grove, Illinois, USA). Pollen was recorded as present if 1 grain was found. Pollen present on the bees that was not in the library was recorded similarly and analyzed as 'other.'

NECTAR AND POLLEN RESOURCES IN WILDFLOWER STRIPS

Estimates of nectar and pollen availability in the wildflower strips over time were assayed on 6 occasions every 1 to 2 wk beginning 21 May in 2019 and ending 25 Jul 2019. At 9:30 A. M., a total of 10 blooming flowers of each species were randomly selected in the buffer. The presence of nectar on the flowers was determined by removing the ray flowers on the composites or the petals of *M. citriodora* and examining the base of the corolla. The radius of the non-blooming to blooming area of disc flowers of *G. pulchella* and *R. hirta* were measured over time to estimate the rate of bloom in these flowers. For *G. pulchella* we measured the diam of the blooming and non-blooming area of the circle of the disc flowers (the multitude of small darker-colored flowers at the center of composite flowers that contain their own pollen and nectar), and for *R. hirta* we used the surface area of a dome formula:

$2\pi(\text{radius}^2)$. The presence or absence of nectar and pollen of blooming *G. pulchella* and *R. hirta* disc flowers was determined by examining the flowers under a dissecting microscope (Leica Microsystems Inc., Buffalo Grove, Illinois, USA).

BEE EXCLUSION IN COTTON

On 26 Jul 2019, 25 flowers close to blooming were selected and covered with a fine mesh bag to exclude pollinators (self-pollinated). On 29 Jul 2019, 10 of the flowers had aborted on the plant and 10 new plants with flowers close to bloom were selected and bagged as replacements. The bags were removed when the boll had set. Twenty-five bolls at the same height on the plants as those that were covered were randomly chosen as the open-pollinated treatment. The lint and seeds from all 50 open bolls were collected, separated by treatment (*n* = 25 bolls per treatment) and weighed so the results only estimate weight differences between treatments. Because of minimal weight requirements for quality analysis, the treatments also were grouped and sent for ginning and lint quality analysis (Fiber & Biopolymer Research Institute, Texas Tech University, Lubbock, Texas, USA).

STATISTICS

Analyses of variance (ANOVA) were used to test the effects of date on the abundance of bees and pollen species on the bees with Tukey's HSD used to separate the means (SAS 1998). ANOVA was used to test the effects of date on the ratio of the blooming to non-blooming disc flowers of *G. pulchella* and *R. hirta*. All ANOVA assumptions were met (Levine's test $P > 0.05$) so that no data transformations were needed. Chi-Square analysis was used to test a date effect on the presence of nectar and pollen on *M. citriodora* (SAS 1998).

Results

We captured a total of 291 bees in peanut (Table 1) and 89 bees in cotton (Table 2) that were comprised of 2 families (Apidae and Halictidae) in each crop with 10 species in cotton. The numerically dominant species in peanut were *Melissodes communis* Cresson (50%) and *M. bimaculatus* Lepeletier (23%) (Hymenoptera: Apidae) (Table 1). The numerically dominant species in cotton were *M. communis* (30%), *M. bimaculatus* (13%), and *Lasioglossum reticulatulatum* Robertson (39%) (Hymenoptera: Halictidae) (Table 2). *Melissodes communis* and *M. bimaculatus* were most observed with *G. pulchella* and *R. hirta* pollen, whereas *L. reticulatulatum* was most observed with *M. citriodora* pollen. A total of 95 bees captured in peanut (31%) also had cotton pollen, possibly obtained from the nearest cotton field 322 m away. Additionally, 55 bees captured in cotton (62%) had unidentified pollen.

Table 1. Bee species and their numbers captured in peanut in 2018 and carrying *Gaillardia pulchella* pollen, peanut pollen, *G. pulchella* plus peanut pollen (= both), and cotton pollen.

		No. of bees found with pollen			
Bee species	*N*	*G. pulchella*	Peanut	Both	Cotton
Apidae					
Melissodes communis	145	127	118	14	33
Melissodes bimaculatus	67	0	44	0	29
Apis melifera	8	1	5	1	4
Bombus bimaculatus	6	2	5	0	2
Halictidae					
Unknown	65	8	40	26	27
Total	291	138	212	41	95

POLLINATOR AND POLLEN LOADS

There was a significant date effect on bee abundance in peanut ($F_{8/368} = 8.54$; $P < 0.001$). The number of bees in peanut was highest on the first date and declined on subsequent dates with the lowest number of bees observed in late season peanut fields (Fig. 1a). There was a significant date effect on the abundance of bees with *G. pulchella* pollen ($F_{8/266} = 6.13$; $P < 0.001$) and both *G. pulchella* and peanut pollen ($F_{8/266} = 6.41$; $P < 0.001$). The abundance of bees with *G. pulchella* pollen or *G. pulchella* and peanut pollen was highest on 6 Jul and no bees with *G. pulchella* pollen were captured after 20 Jul (Fig. 1b). Of the 27 bees captured on 6 Jul, 14 (52%) had *G. pulchella* pollen and 13 (48%) had both *G. pulchella* and peanut pollen.

There was no significant date effect on the abundance of bees with cotton pollen ($F_{2/43} = 0.30$; $\mathrm{P} = 0.742$) (Fig. 2a), *G. pulchella* pollen ($F_{2/43} = 1.25$; $P = 0.297$), *R. hirta* pollen ($F_{2/43} = 0.62$; $P = 0.877$), and 1 or more of the wildflower strip pollen species and cotton pollen ($F_{2/43} = 0.87$; $P = 0.425$) (Fig. 2b). Date had a significant effect on the abundance of bees with *M. citriodora* pollen ($F_{2/43} = 7.58$; $P = 0.001$). The highest number of bees in cotton with *M. citriodora* pollen was on 2 Jul; no bees with *M. citriodora* pollen were captured after 10 Jul (Fig. 2b). Of the 43 bees captured on 2 Jul, 23 (53%) had *M. citriodora*. Over the sampling dates, 89 bees were captured in cotton; 27% had *M. citriodora*, 15% had *G. pulchella*, 13% had *R. hirta* pollen, and 11 (26%) had cotton and 1 or more wildflower species pollen. There were no significant date effects ($F_{2/43} = 0.11$; $P = 0.896$) on the abundance of bees in cotton with unidentified pollen (Fig. 2a), and 55 of the 89 bees captured in cotton (62%) had 1 or more unidentified pollen species. Based on pollen morphology, a total of 15 species of unidentified floral pollen was found on bees captured in cotton.

NECTAR AND POLLEN IN WILDFLOWER STRIPS

Overall *G. pulchella* and *R. hirta* had nectar in the ray flowers over all 6 dates of floral sampling. Seventy percent (mean ± SE: 70 ± 0.01%, *n* = 60) of the area of the disc flowers of *G. pulchella* was comprised of non-opened flowers; there was no significant date effect on this percentage over the floral sampling period ($F_{5/54} = 1.68$; $P = 0.154$). For *R. hirta*, 69% of the area of the disc flowers (mean ± SE: 69% ± 0.01%, *n* = 60) had unopened flowers; there was no significant date effect of this percentage over the floral sampling period ($F_{5/54} = 9.05$; $P = 0.998$). Date, however, had a significant effect on the nectar and pollen in *M. citriodora* flowers ($\chi^2 = 7.84$; df = 3; $P = 0.044$). From 21 May through 18 Jun, 100% of the inflorescences in *M. citriodora* had nectar and pollen present, but this was reduced to 0% and 10%, respectively, on 2 Jul. *Monarda citriodora* had totally senesced by 10 Jul.

BEE EXCLUSION IN COTTON

The weight of the lint plus seeds was 127.30 g in the open pollinated treatment and 92.10 g in the self-pollinated treatment. The quality of the lint differed in micronaire and color (Table 3). The ideal range of micronaire, a measure of lint fineness, is between 3.7 and 4.2. The open pollinated lint had a micronaire value of 5.2 which would get a discount at the gin for being too dense. The closed pollination treatment micronaire value of 4.6 would not be discounted but would not get any quality points at the gin. The color of the open pollinated cotton lint was classified as white-good middling and the self-pollinated cotton was a grade lower in the white-strict middling range according to the HVI® (Cotton Incorporated, Cary, North Carolina, USA)

Table 2. Bee species and their numbers captured in cotton in 2019 with *Gaillardia pulchella*, *Monarda citriodora*, *Rudbeckia hirta*, cotton, and cotton and 1 or more wildflower buffer pollen (= both).

		No. of bees found with pollen					
Bee species	*N*	*G. pulchella*	*M. citriodora*	*R. hirta*	Cotton	Both	Other
Apidae							
Melissodes communis	27	5	2	6	15	5	14
Melissodes bimaculatus	12	3	0	3	10	6	8
Apis melifera	3	0	3	0	3	3	3
Halictidae							
Halictus ligatus/poeyi	4	2	3	2	2	1	1
Agapostemon splendens	1	0	1	0	0	0	1
Agapostemon virescens	1	0	1	0	1	1	0
Lasioglossum trigeminum	4	0	2	0	1	1	4
Lasioglossum reticulatum	35	3	11	1	16	5	23
Lasioglossum pilosum	1	0	1	0	0	0	0
Lasioglossum callidum	1	0	0	0	0	0	1
Total	89	13	24	12	48	22	55

color chart: https://www.cottoninc.com/cotton-production/quality/us-cotton-fiber-chart/hvi-color-chart/ (Table 3). The size and number of Neps, a knot of entangled fibers that usually comprises dead or immature fibers, was higher in the closed pollination than in the open-pollinated treatment (Table 3).

Discussion

We found that early in the season in 2018 and 2019, at peak bee abundance, nearly 50% of the bees captured had pollen from the flowers present in the wildflower strips, and nearly 40% of the bees captured had pollen from the crop flowers and pollen from the wildflowers in the strips. This indicates that the buffers were recruiting wild bees in early season and the bees also foraged in both crops. The pollen of *M. citriodora* was the most abundant of the wildflower strip species pollen found on captured bees in cotton indicating that, although short-lived, this wildflower is of relatively high resource value to the bees. In addition, the unidentified pollen on the bees in cotton was high over the sampling period (62% of the bees captured). This suggests that other non-crop flowers on the experimental farm contributed a substantial number of wild bee pollinators to the crops over the entire season. Identifying and augmenting these floral species may be needed to increase overall resource availability to the bees. Additionally, the weight of the lint and seed was higher in the open pollinated treatment which is comparable to that found by Pires et al. (2014). The lint color quality also was higher, and the size and number of Neps were lower in the open pollenated cotton suggesting overall higher quality fibers in the open versus the closed pollination treatments.

The nectar droplets found on the ray flowers of *M. citriodora*, could be seen easily initially but no nectar was found after 2 Jul and the plants were totally senesced by 10 Jul. The disc flowers of both composites that had opened represented 30% of the total area of disc flowers and this percentage did not change over time; the unopened disc flowers were very slow in opening with 0 to 2 flowers open on each floral sampling date. Therefore, this suggests that nectar and pollen may not have been enough for, or may not have been accessible to, the bees after 2 Jul, and supports our hypothesis that resource limitation results in bees foraging elsewhere. For *G. pulchella* and *R. hirta*, resource availability did not coincide with the percentage area of flowers present (Coutinho et al. 2018). However, the disc flowers of *G. pulchella* and *R. hirta* continued to open well into Sep and many smaller-sized bees were observed on the flowers with pollen of these species. The dominance of small-sized species on *G. pulchella* is consistent with unpublished data from the 2016 and 2017 study of Xavier et al. (2017) where 97% of bees captured in *G. pulchella* were from the family Halictidae. The lack of bees with *G. pulchella* pollen captured in peanut later in the season, and the smaller-sized bees observed on *G. pulchella* in the flower strip, suggests that these bees may have preferred *G. pulchella* over later season peanut flowers.

A growing number of studies show that it is the diversity of pollinators that increase pollination services, and not the number of bees (Dainese et al. 2019 and references therein; see Kleijn et al. 2015 & Winfree et al. 2015). Although we are well aware that the use of bee bowls has many limitations that preclude monitoring changes in bee populations (Portman et al. 2020), our study's goal was to understand the foraging of bees relative to sown wildflowers to improve the composition of these floral buffers. *Gaillardia pulchella* and *R. hirta* had many unopened disc flowers resulting in less pollen and nectar available over time, and *M. citriodora* was an early season, but short-lived flower species. This suggests that increasing bee resource availability over time may be necessary. However, we recommend that *G. pulchella* remain in the buffer mainly for later-season, smaller-sized bees that may prefer this species, or bees that need refuge. Also, *G. pulchella* may provide needed resources to natural enemy species because nectar feeding has been shown to increase the longevity and egg load of the stink bug parasitoid, *Aridelus rufotestaceus* Tobias (Hymenoptera: Braconidae) (Aduba et al. 2013). The high attraction that bees had for flowers of *M. citriodora* strongly suggests that this wildflower be included in the wildflower strips as a monoculture to minimize competition from aggressive species such as *G. pulchella*. The other composite species, *R. hirta*, should be replaced with a species having a higher resource availability over time. Also, the wildflower strips of Xavier et al. (2017) and our wildflower strips were dominated by orange and yellow-colored floral species. Because bees may have differential preferences for floral color and temporal needs for resources (e.g., Campbell et al. 2017; van Rijn & Wäckers 2016; Vaudo et al. 2016; Shinnosuke et al. 2018), the addition of later-season flowers of more variable colors and later bloom periods (e.g., blue-colored sweet alyssum) that may be more attractive to a wider range of bee species may be needed to increase bee abundance and diversity in the landscape.

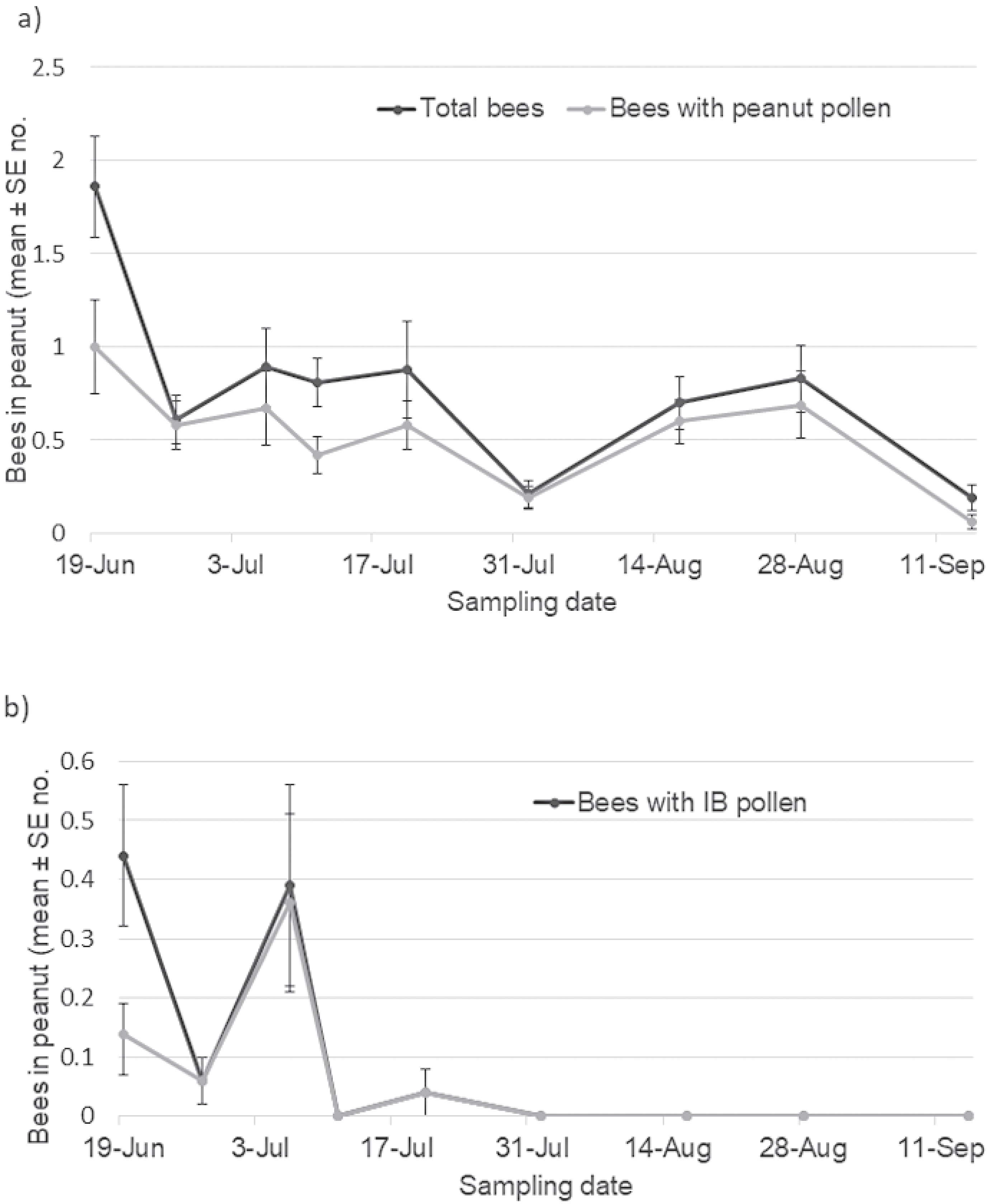

Fig. 1. The 2018 mean (± SE) of bees per bee bowl captured in peanut and those with peanut pollen (a), and the mean (± SE) of bees per bee bowl captured in peanut with *Gaillardia pulchella* (IB), and both *G. pulchella* and peanut pollen (b).

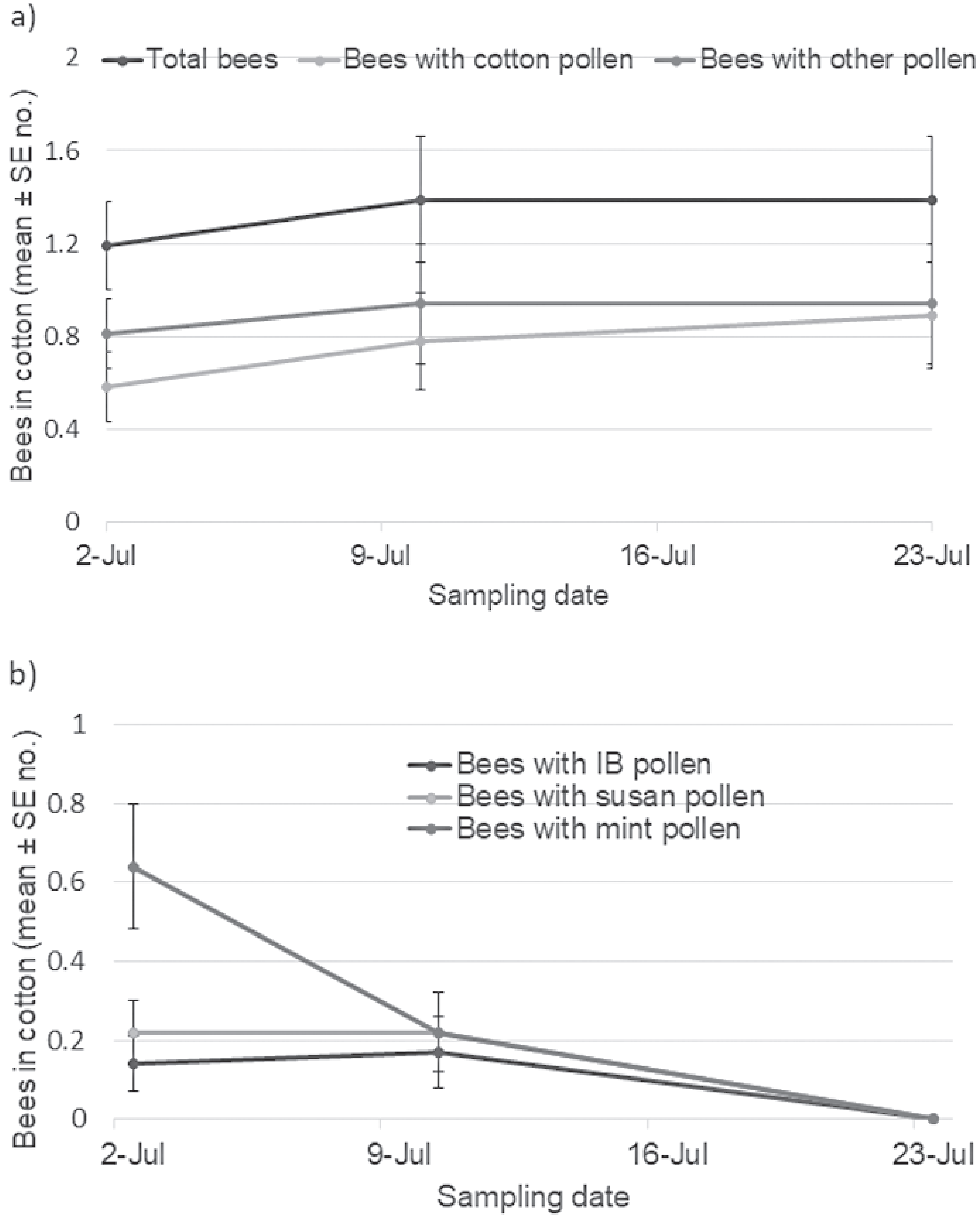

Fig. 2. The 2019 mean (± SE) of bees per bee bowl captured in cotton and those with cotton pollen and unidentified pollen (= other) (a), and the mean (± SE) of bees per bee bowl captured in cotton with *G. pulchella* (IB), *Monarda citriodora* (mint), and *Rudbeckia hirta* (susan) (b).

Table 3. High volume instrument (HVI) results of cotton fiber properties in open (bee accessible) and closed (bee exclusion) treatments. *N* = 25 bolls per treatment.

Sample	Micronaire	Nep size (µg)	Neps per g	Color grade
Open	5.20	609	98	11.20
Closed	4.60	665	164	21.40

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References Cited

Aduba OL, Olson, DO, Ruberson JR, Hartel PG, Potter TL. 2013. Flowering plant effects on adults of the stink bug parasitoid *Aridelus rufotestaceus* (Hymenoptera: Braconidae). Biological Control 67: 344–349.

Bänsch S, Tscharntke T, Ratnieks FLW, Härtel S, Westphal C. 2019. Foraging of honeybees in agricultural landscapes with changing patterns of flower resources. Agriculture, Ecosystem and Environment 291: 106792. doi.org/10.1016/j.agee.2019.106792

Bernhardt P. 2005. Pollen transport and transfer by animal pollinators, pp. 371–378 In Dafni A, Kevan PG, Husband BC [eds.], Practical Pollination Biology. Enviroquest Ltd., Cambridge, Ontario, Canada.

Blaauw BR, Isaacs R. 2014. Larger patches of diverse floral resources increase insect pollinator density, diversity, and their pollination of native wildflowers. Basic and Applied Ecology 15: 701–711.

Buhk C, Oppermann R, Schanowski A, Bleil R, Ludermann J, Maus C. 2018. Flower strip networks offer promising long-term effects on pollinator species richness in intensively cultivated agricultural areas. BMC Ecology 18: 55. doi.org/10.1186/s12898-018-0210-z

Cameron SA, Lozier JD, Strange JP, Koch JB, Cordes N, Solter LF, Griswold TF. 2011. Patterns of widespread decline in North American bumble bees. Proceedings of the National Academy of Science of the United States of America 108: 662–667.

Campbell AJ, Wilby A, Sutton P, Wäckers F. 2017. Getting more power from your flowers: multi-functional flower strips enhance pollinators and pest control agents in apple orchards. Insects 8: 101. doi.org/10.3390/insects8030101

Campbell JW, Kimmel CB, Grodsky SM, Smithers C, Daniels JC, Ellis JD. 2019. Native wildflower plantings increase overall arthropod richness and abundance within intensively managed agricultural areas. Ecosphere 10: e02890. https://doi.org/10.1002/ecs2.2890

Carvalheiro LG, Kunin WE, Keil P, Aguirre-Gutierrez J, Ellis WN, Fox R, Groom Q, Hennekens S, Van Landuyt W, Maes D, Van de Meutter F, Michez D, Rasmont P, Ode B, Potts SG, Reemer M, Roberts SPM, Schaminée J, DeVries MFW, Biesmeijer JC. 2013. Species richness declines and biotic homogenization have slowed down for NW-European pollinators and plants. Ecology Letters 16: 870–878.

Coutinho JGE, Garibaldo LA, Viana BF. 2018. The influence of local and landscape scale on single response traits in bees: a meta-analysis. Agriculture, Ecosystems and Environment 256: 61–73.

Dainese M, Martin EA, Aizen MA, Albrecht M, Bartomeus I, Bommarco R, Carvalheiro LG, Chaplin-Kramer R, Gagic V, Garibaldi LA, Ghazoul J, Grab H, Jonsson M, Karp DS, Kennedy CM, Kleijn D, Kremen C, Landis DA, Letourneau DK, Marini L, Poveda K, Rader R, Smith HG, Tscharntke T, Andersson GKS, Badenhausser I, Baensch S, Bezerra ADM, Bianchi FJJA, Boreux V, Bretagnolle V, Caballero-Lopez B, Cavigliasso P, Ćetković A, Chacoff NP, Classen A, Cusser S, Silva e Silva FD, de Groot GA, Dudenhöffer JH, Ekroos J, Fijen T, Franck P, Freitas BM, Garratt MPD, Gratton C, Hipólito J, Holzschuh A, Hunt L, Iverson AL, Jha S, Keasar T, Kim TN, Kishinevsky M, Klatt BK, Klein AM, Krewenka KM, Krishnan S, Larsen AE, Lavigne C, Liere H, Maas B, Mallinger RE, Martinez Pachon E, Martínez-Salinas A, Meehan TD, Mitchell MGE, Molina GAR, Nesper M, Nilsson L, O'Rourke ME, Peters MK, Plećaš M, Potts SG, Ramos DDL, Rosenheim JA, Rundlöf M, Rusch A, Sáez A, Scheper J, Schleuning M, Schmack JM, Sciligo AR, Seymour C, Stanley DA, Stewart R, Stout JC, Sutter L, Takada MB, Taki H, Tamburini G, Tschumi M, Viana BF, Westphal C, Willcox BK, Wratten SD, Yoshioka A, Zaragoza-Trello C, Zhang W, Zou Y, Steffan-Dewenter I. 2019. A global synthesis reveals biodiversity-mediated benefits for crop production. Science Advances 5: eaax0121. doi:10.1126/sciadv.aax0121

EPA – United States Environmental Protection Agency. 2017. EPA Actions to Protect Pollinators. Washington, DC,, USA. https://www.epa.gov/pollinator-protection/epa-actions-protect-pollinators (last accessed 31 May 2021).

Garibaldi LA, Steffan-Dewenter I, Winfree R, Aizen MA, Bommarco R, Cunningham SA, Kremen C, Carvalheiro LG, Harder LD, Afik O, Bartomeus I, Benjamin F, Boreux V, Cariveau D, Chacoff NP, Dudenhöffer JH, Freitas BM, Ghazoul J, Greenleaf S, Hipólito J, Holzschuh A, Howlett B, Isaacs R, Javorek SK, Kennedy CM, Krewenka KM, Krishnan S, Mandelik Y, Mayfield MM, Motzke I, Munyuli T, Nault BA, Otieno M, Petersen J, Pisanty G, Potts SG, Rader R, Ricketts TH, Rundlöf M, Seymour CL, Schüepp C, Szentgyörgyi H, Taki H, Tscharntke T, Vergara CH, Viana BF, Wanger TC, Westphal C, Williams N, Klein AM. 2013. Wild pollinators enhance fruit set of crops regardless of honeybee abundance. Science 339: 1608–1611.

Gibbs J. 2011. Revision of the metallic *Lasioglossum* (*Dialictus*) of eastern North America (Hymenoptera: Halictidae: Halictini). Zootaxa: 1–216.

Gill KA, O'Neal ME. 2015. Survey of soybean insect pollinators: community identification and sampling method analysis. Environmental Entomology 44: 488–498.

Haaland C, Naisbit RE, Bersier L. 2011. Sown wildflower strips for insect conservation: a review. Insect Conservation and Diversity 4: 60–80.

Hammons RO, Leuck DB. 1966. Natural cross-pollination of the peanut, *Arachis hypogaea* L., in the presence of bees and thrips. Agronomy Journal 58: 396. doi.org/10.2134/agronj1966.00021962005800040009x

Herbertsson L, Jonsson AM, Andersson GKS, Seibel K, Rundlof M, Ekroos J, Stjernman M, Olsson O, Smith HG. 2018. The impact of flower strips on plant reproductive success in Southern Sweden varies with landscape context. Agriculture, Ecosystems and Environment 259: 127–134.

IPBES – International Science-Policy Platform on Biodiversity and Ecosystem Services. 2017. The Assessment Report on Pollinators, Pollination and Food Production. IPBES, Bonn, Germany.

Kleijn D, Winfree R, Bartomeus I, Carvalheiro, Henry M, Isaacs R, Klein AM, Kremen C, M'GonigleLK, Rader R, Ricketts T, Williams NM, Adamson NL, Ascher JS, Báldi A, Batáry P, Benjamin F, Biesmeijer JC, Blitzer EJ, Bommarco R, Brand MR, Bretagnolle V, Button L, Cariveau DP, Chifflet R, Colville JF, Danforth BN, Elle E, Garratt MPD, Herzog F, Holzschuh A, Howlett BG, Jauker F, Jha S, Knop E, Krewenka KM, Féon VL, Mandelik Y, May EA, Park MG, Pisanty G, Reemer M, Riedinger V, Rollin O, Rundlöf M, Sardiñas HS, JScheper J, Sciligo AR, Smith HG, Steffan-Dewenter I, Thorp R, Tscharntke T, Verhulst J, Viana BF, Vaissière BE, Veldtman R, Ward KL, Westphal C, Potts SG. 2015. Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. Nature Communication 6: 7414. doi.org/10.1038/ncomms8414

Leuck DB, Hammons RO. 1967. Pollen collecting activities of bees among peanut flowers. Journal of Economic Entomology 58: 1028–1030.

Mitchell TB. 1962. Bees of the Eastern United States, Vol. II. Technical Bulletin #152. North Carolina Agricultural Experimental Station, Raleigh, North Carolina, USA.

Packer L. 1999. The distribution of *Halictus ligatus* Say and *H. poeyi* Lep. (Hymenoptera: Halictidae) in North America. University of Kansas Natural History Museum Special Publication 24: 81–84.

Pires VC, Silveira FA, Sujii ER, Torezani KRS, Rodrigues WA, Albuquerque FA, Rodrigues SMM, Salomão AN, Pires CSS. 2014. Importance of bee pollination for cotton production in conventional and organic farms in Brazil. Journal of Pollination Ecology 13: 151–160.

Portman ZM, Burninga-Socolar B, Cariveau DP. 2020. The state of bee monitoring in the United States: a call to refocus away from bee bowl traps and towards more effective methods. Annals of the Entomological Society of America 113: 337–342.

Ogden EC, Raynor GS, Hayes JV, Lewis DM, Haines JH. 1974. Manual for Sampling Airborne Pollen. Hafner Press, New York, USA.

SAS. 1998. SAS version 6. SAS/STAT User Guide Release. SAS Institute, Cary, North Carolina, USA.

Shinnosuke M, Fukui H, Oishi M, Sakuma M, Kawakami M, Tsukioka J, Goto K, Hirai N. 2018. Biocommunication between plants and pollinating insects through fluorescence of pollen and anthers. Journal of Chemical Ecology 44: 591–600.

Toler TR, Evans EW, Tepedino VJ. 2005. Pan-trapping for bees (Hymenoptera: Apiformes) in Utah's west desert: the importance of color diversity. Pan-Pacific Entomologist 81: 103–113.

van Rijn PCJ, Wäckers FL. 2016. Nectar accessibility determines fitness, flower choice and abundance of hoverflies that provide natural pest control. Journal of Applied Ecology 53: 925–933.

Vaudo AD, Patch HM, Mortensen DA, Tooker JF, Grozinger CM. 2016. Macronutrient ratios in pollen shape bumble bee (Bombus impatiens) foraging strategies and floral preferences. Proceedings of the National Academy of Sciences of the United States of America 113: E4035–E4042.

Vaissière BE, Vinson SB. 1994. Pollen morphology and its effect on pollen collection by honey bees, *Apis mellifera* L. (Hymenoptera: Apidae), with special reference to upland cotton, *Gossypium hirsutum* L. (Malvaceae). Grana 33:128–138.

Williams NM, Ward KL, Pope N, Isaacs R, Wilson J, May EA, Ellis J, Daniels J, Pence A, Ullmann K, Peters J. 2015. Native wildflower plantings support wild bee abundance and diversity in agricultural landscapes across the United States. Ecological Applications 25: 2119–2131.

Wheelock MJ, O'Neal ME. 2016. Insect pollinators in Iowa cornfields: community identification and trapping method analysis. PLOS ONE 11: e0143479. doi.org/10.1371/journal.pone.0143479

Winfree R, Fox JW, Williams NM, Reilly JR, Cariveau DP. 2015. Abundance of common species, not species richness, drives a real-world ecosystem service. Ecology Letters 18: 626–635.

Xavier SS, Olson DM, Coffin AW, Strickland TC, Schmidt JM. 2017. Perennial grass and native wildflowers: a synergistic approach to habitat management. Insects 8: 104–117.