Vane Traps Collected More Bee Genera and Less Bycatch of Other Insects Compared to Pan Traps

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Abstract: Many declining insect species are essential pollinators, and more information is needed to choose the best method to sample and monitor these animals. We investigated how trap type, shape, and color affected the insects and bee genera caught. We deployed one vane trap and two types of pan traps at seven locations and four habitat types. The insect assemblage captured differed among vane traps, bee bowls, and bee cups. Vane traps caught the most bees, the highest richness of bee genera, and the least insect bycatch. Bee bowls caught the most Diptera and the fewest bees. Bee cups caught the fewest insects. More bee genera were attracted to blue and white pan traps compared to yellow pan traps. Our results can help managers and researchers choose the best methods to collect their target insects or design a monitoring program.

Introduction

Bees perform essential ecosystem services by pollinating billions of dollars of crops annually (Gallai et al. 2009, Losey and Vaughan 2006), but these insects are declining globally (Potts et al. 2010) in both abundance and species richness (LeBuhn and Luna 2021, Zattara and Aizen 2021). One study found half of eastern bumblebee species (*Bombus*) are declining in North America (Colla et al. 2012). Some of the largest drivers of these declines are habitat loss and fragmentation due to changes in land use by humans (LeBuhn and Luna 2021, Potts et al. 2010). Other causes of bee declines include increased air temperatures from anthropogenic climate change (Soroye et al. 2020), pathogens (Meeus et al. 2011), and increased pesticide use (Sánchez-Bayo et al. 2016). Declines in pollinator populations and the loss of species have negatively affected both wild plant health and agricultural crop yield (Kremen et al. 2002). As such, we must develop effective sampling methods to monitor the abundance and richness of bees with less bias and less bycatch of other insects that are not being targeted.

Many monitoring methods use passive traps, usually bee bowls, to collect bees. These traps are often used to assess bee assemblages and monitor population changes; however, the proportion of the population these traps collect is unknown, making changes in abundance or richness of bees collected from passive traps difficult to estimate (Tronstad et al. 2022). Pan traps do not accurately reflect bumblebee populations on farmland (Wood et al. 2015). Passive sampling methods can collect a biased assemblage resulting in samples with only a portion of the insect community. For example, pan traps collect a large number of genera in the family Halictidae (Droege et al. 2010). Pan traps vary widely in size and shape, making comparisons between studies difficult, and pan trap diameter can affect bycatch (Gonzalez et al. 2020). Pan traps often collect taxa outside those of interest, such as spiders and beetles, referred to as bycatch (McCravy 2018). Vane traps are a relatively new type of passive trap, and much less is known about their efficacy. Vane traps can be effective at

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collecting bumble bees, seeing as they collect a wider range of bee genera than pan traps in some ecosystems (Bell et al. 2023). Some studies have employed a combination of passive trap types to reduce catch biases, but this can result in a substantial number of specimens that require time and resources to process (Portman et al. 2020).

Despite many studies that investigated methods to collect insects, more research is needed to assess methods to collect and monitor pollinators. The success of surveying methods depends on time and resource constraints as well as study goals. Much of the current research on bee monitoring has been done in Europe (e.g., Biesmeijer et al. 2006, Westphal et al. 2008) and the eastern United States (e.g., Campbell et al. 2023, Joshi et al. 2015), but there is less information on bee monitoring in the western United States. The objective of our study was to evaluate how insect catch differed among passive trap types to discern the best method for collecting and monitoring in the western United States. We measured how insect abundance, richness, and assemblage differed among two passive trapping methods: vane traps and pan traps. We used two shapes of pan traps and three colors of each shape to explore how shape and color affected catch at locations in and near Laramie, Wyoming. Our questions were: 1) How do bee assemblages differ between trap type and color? 2) Are some insect orders and bee genera caught exclusively in one trap type or trap color? and 3) Which trap type had the lowest bycatch (non-bee catch)? This study will provide information to managers and scientists to help them select the best passive trap to use for their sampling or monitoring program.

Study Area

We collected insects in the Laramie Valley of southeastern Wyoming. One site was located in an urban yard, two sites were collected insects in well-maintained parks, and three sites were located in a natural area of a third park that received little maintenance. A final site was a natural area near Medicine Bow, Wyoming in the sagebrush steppe. The elevation of our sites varied between 2000 and 2200 m. Southeastern Wyoming is semi-arid and dominated by sagebrush steppe and short-grass prairie in the Southern Rocky Mountain ecoregion. Summer temperatures range from 10–25.8°C on average in July and August. The valley receives an average of 29 cm of precipitation annually, with most precipitation occurring in the spring and summer (U.S. Climate Data 2022).

Methods and Methods

We sampled seven sites weekly for six weeks to measure insect catch in three types of passive traps (vane traps and two types of pan traps). We began sampling on 5 July 2019 and ended on 8 August 2019. At each site, we collected insects using one blue vane trap (vane traps hereafter) and two sets of pan traps. Each set of pan traps consisted of three colors (yellow, blue, and white). One type of pan trap was shorter and broader and we refer to those as bee bowls (4 cm height x 15.5 cm inside diameter; Fig. 1a). The other type of pan trap was narrower and upright; we called these bee cups (10 cm height x 6 cm diameter; Fig. 1b). Bee bowls were placed on the ground and bee cups were placed ~30 cm above the ground. Bee cups were secured by a 20-cm length of rebar with a zip tie wrapped around them and we placed a small rock in bee bowls so they would not take flight in windy weather. Bee bowls and bee cups were filled with soapy water to break the surface tension to increase insect retention in these passive traps (Packer and Darla-West 2020). Vane traps consisted of a blue vane mounted on a yellow collection basin and hung on L-shaped rebar ≤ 0.5 m above the ground (37 cm height x 14 cm diameter; Fig. 1c). Vane traps were left dry to make processing samples more efficient. Insects were transferred to a Whirl-Pak® bag using a funnel and transported to the lab in a cooler and frozen immediately. Insects from pan traps were sieved using a coffee filter, placed in a Whirl-Pak® bag, transported to the lab in a cooler and frozen immediately. Trap types were placed at least 20 m apart. All three trap types and colors were deployed for 48 hours during each visit.

We compared insect abundance and bee richness caught among three sampling methods (vane traps, bee cups, and bee bowls) and trap color (yellow, white and blue; pan traps only). We compared the abundance of all insects, individual orders (Coleoptera, Diptera, and Hymenoptera) and bee genera using generalized linear models (GLMs). We report the range of t-values and p-values because GLMs report a value for each trap type and color. We also compared the richness of bee genera among the three trap types and colors using GLMs and the R package *Matrix* (Bates and Maechler 2019). We used estimated marginal means (R package *emmeans*, Lenth 2022) to estimate differences among trap types and colors ($\alpha \leq 0.05$). We analyzed the data using a Gamma distribution because the data most closely fit that curve as determined by examining histograms and using the *fitdistrplus* package in R (Delignette-Muller and Dutang 2015). Additionally, we compared the assemblages of insect orders and bee genera captured in each trap type using non-metric multidimensional scaling (NMDS) with R packages *vegan* (Oksanen et al. 2020), *MASS* (Venables and Ripley 2002), *gclus* (Hurley 2019), and *ade4* (Dray and Dufour 2007). To analyze the NMDS, rare insect orders (abundance < 0.1%), orders only found at one location, and samples with zero individuals were removed. We used an analysis of similarities test (ANOSIM) using the R package *vegan* (Oksanen et al. 2020) to statistically describe differences among our trap types. We did not run an NMDS for bee genera because the model did not converge. Finally, we created ternary plots to compare bee genera caught in each trap type and color using R packages *ggplot2* (Wickham 2016) and *ggtern* (Hamilton and Ferry 2018). We used R (R Core Team 2020) and the packages *plyr* (Wickham 2011) to summarize the data for statistical analysis.

Results

We collected 8 orders of insects among traps types and colors. Diptera (37% of all insects) were the most abundant order of insects followed by Coleoptera (33%), Hymenoptera (25%), Hemiptera (4%), Lepidoptera (<1%), Orthoptera (<1%), Odonata (<1%), and Ephemeroptera (<1%). The most common Coleoptera family was Meloidae, and the most common Diptera families were Scathophagidae, Syrphidae, and Tachinidae, all of which are flower-visiting

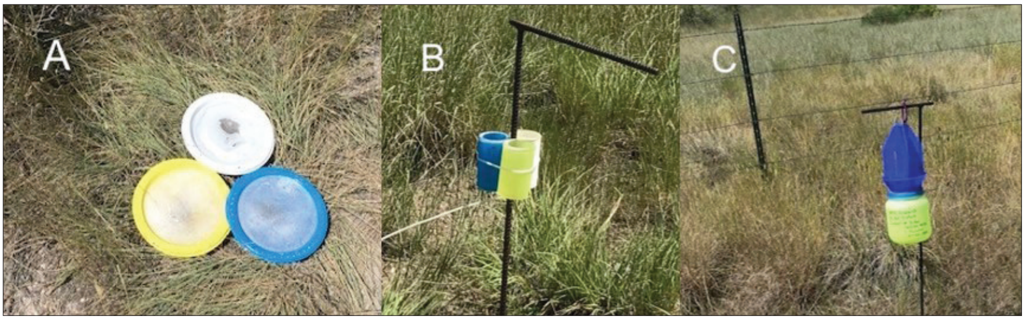

Figure 1. Bee bowls (A), bee cups (B), and a vane trap (C) were deployed to collect insects. Bee bowls and bee cups were filled with soapy water to break the surface tension to increase insect retention in these passive traps. Vane traps were left dry to decrease processing time in the laboratory.

insects. Bee bowls captured 7 insect orders, vane traps collected 7 orders, and bee cups caught 6 insect orders. Bee cups caught fewer insects compared to vane traps and bee bowls (GLM, t = 4.43 to 0.12, p = <0.0001 to 0.85; emmeans, p < 0.003; Fig. 2a). Yellow pan traps caught more insects than blue pan traps (GLM, t = 0.84 to 2.39, p = 0.018 to 0.40; emmeans, p = 0.047; Fig. 2b). Samples from bee bowls were 4.5% bees (% of individuals), bee cup samples captured 12% bees, and samples from vane traps were 23% bees (Fig. 2c). Vane traps had 77% bycatch, bee cups had 88% bycatch, and bee bowls had 95.5% bycatch (Fig. 2d). The

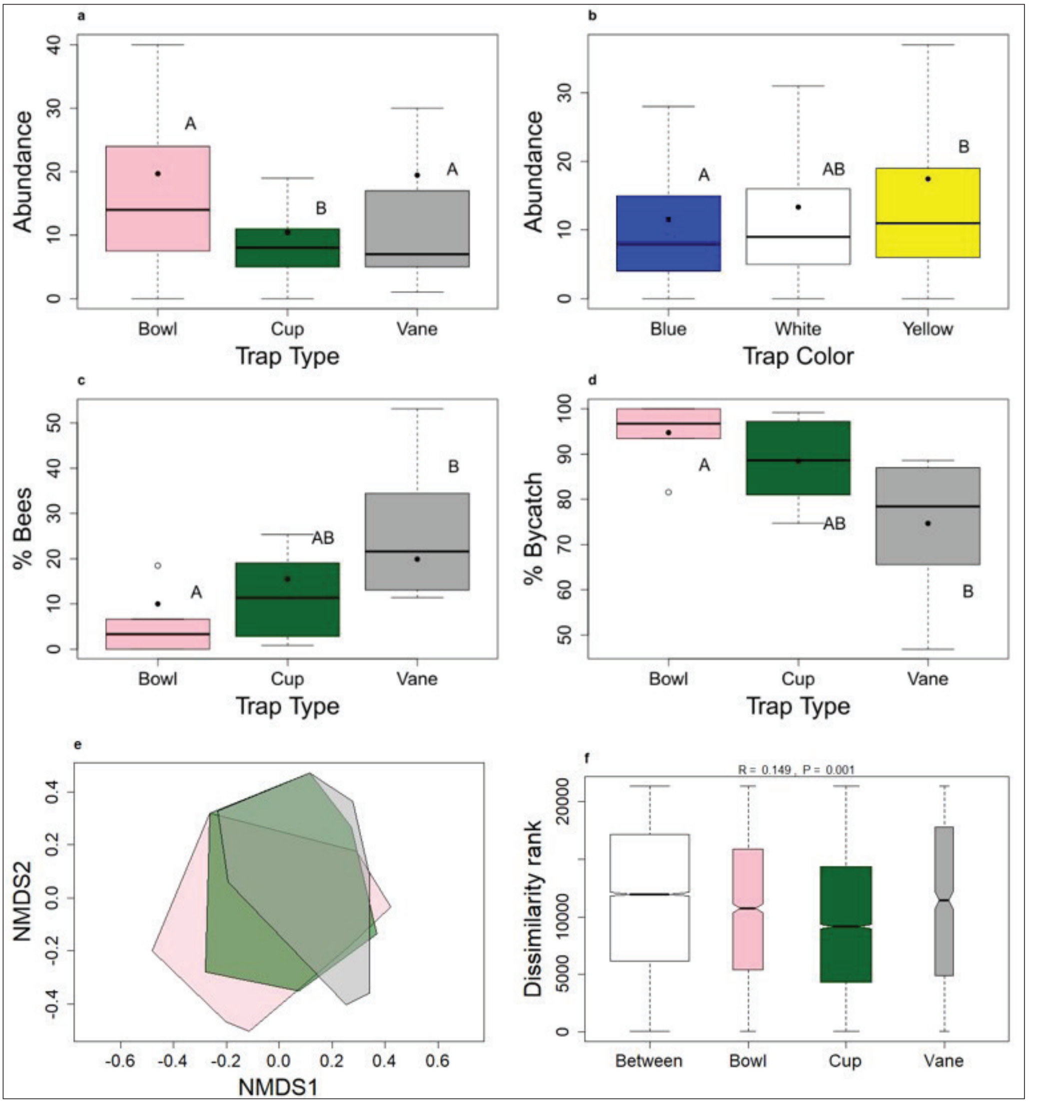

Figure 2. The abundance of insects varied among a) trap types and b) pan trap colors. Bee cups captured fewer insects compared to bee bowls and vane traps. Yellow pan traps caught more insects than blue and white pan traps. c) The percent of individuals that were bees was highest in vane traps, d) resulting in the least bycatch (non-bee insects). e) The assemblage of insects differed among traps types according to non-metric multidimensional scaling and f) dissimilarity ranks from Analysis of Similarity were lowest for bee cups (R = 0.149, p = 0.001). The bold line on boxplots is the median, the black circle is the mean, the lower and upper edges of the box are the 25th and 75th percentiles of the data, and the whiskers are the minimum and maximum values excluding outliers. Differing letters indicate significant differences (α ≤ 0.05).

insect assemblages captured in bee bowls, bee cups, and vane traps differed (Stress = 0.21, 2D solution, 96.3% of variance explained), with assemblages captured in bee bowls and bee cups occupying more space suggesting that they caught a more diverse assemblage (Fig. 2e). Dissimilarity ranks among trap types indicated that bee cups had the lowest dissimilarity rank compared to the estimate between all trap types ($R = 0.14$, $p = 0.001$; Fig. 2f).

Individual orders of insects were attracted to different trap types and colors. Bee bowls caught the most Diptera, and vane traps caught the least (GLM, $t = 6.0$ to 4.07, $p < 0.0001$; emmeans, $p < 0.002$; Fig. 3a). Yellow pan traps caught more Diptera than blue pan traps

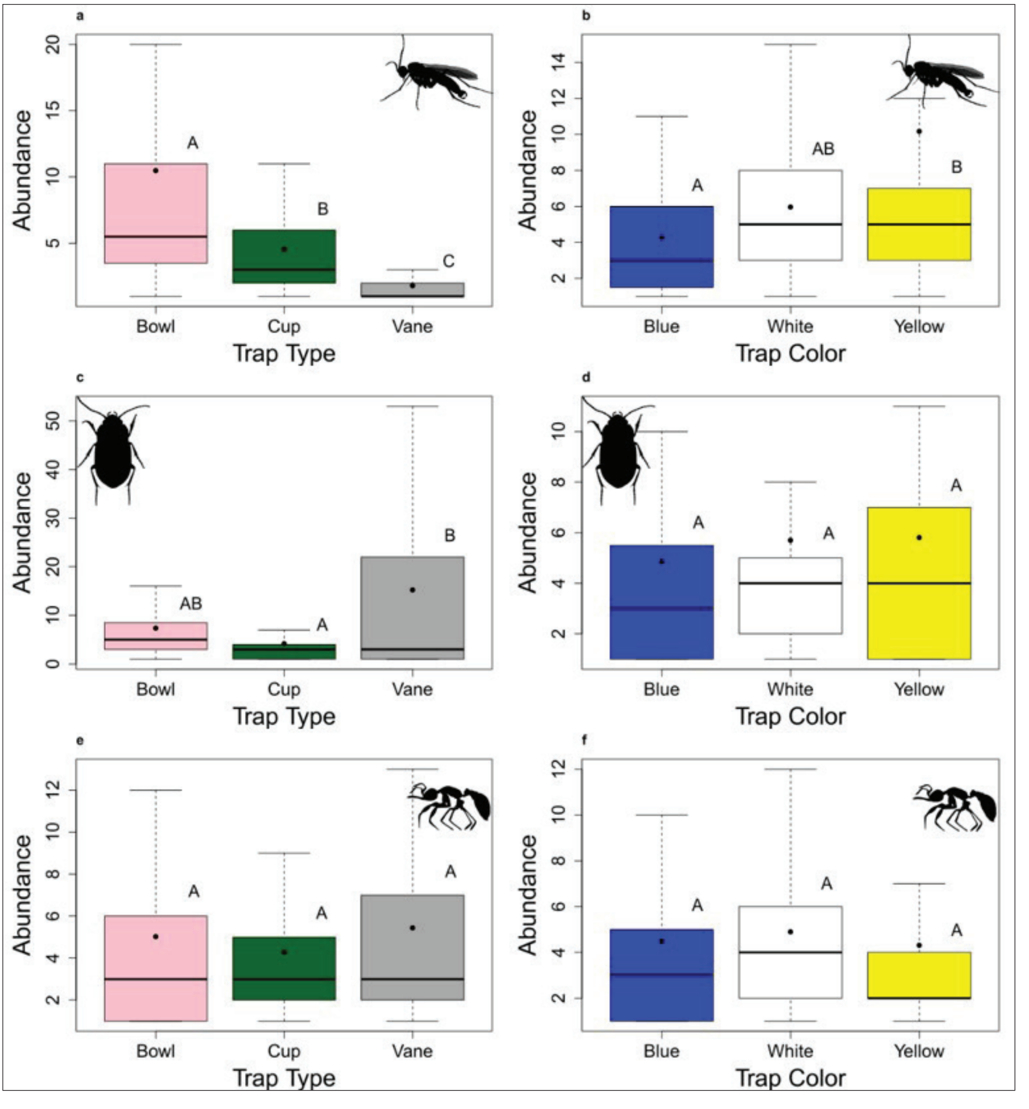

Figure 3. The abundance of Diptera, Coleoptera, and Hymenoptera varied among trap types and pan trap colors. a) Bee bowls, and b) yellow and white pan traps caught the most Diptera. c) Vane traps caught the most Coleoptera but d) the abundance of Coleoptera did not differ among pan trap colors. e) Hymenoptera abundance did not differ among trap types or f) pan trap colors. The bold line on boxplots is the median, the black circle is the mean, the lower and upper edges of the box are the 25th and 75th percentiles of the data, and the whiskers are the minimum and maximum values excluding outliers. Differing letters indicate significant differences ($\alpha \leq 0.05$).

(GLM, t = 1.23 to 3.22, p = 0.0016 to 0.22; emmeans p = 0.0045; Fig. 3b). Vane traps caught more Coleoptera than bee cups (GLM, t = 2.16 to 2.30, p = 0.02 to 0.03, emmeans, p = 0.0001; Fig. 3c). The abundance of Coleoptera did not differ among pan trap colors (GLM, t = 0.52 to 0.63, p = 0.53 to 0.59, emmeans, p = 0.80 to 0.99 Fig. 3d). The abundance of Hymenoptera did not differ among trap types (GLM, t = 0.72 to 0.30, p = 0.47 to 0.77, emmeans, p = 0.59 to 0.95; Fig. 3e) or pan trap color (GLM, t = 0.18 to 0.38, p = 0.71 to 0.86, emmeans, p = 0.85 to 0.98; Fig. 3f). Bee bowls collected the most wasps (5.4%), compared to bee cup (1.7%) and vane traps (2.0%).

Vane traps caught twice as many bees and twice as many bee genera compared to pan traps. We collected bees from 5 families and 20 genera among trap types and colors. Vane traps caught more bees than bee bowls (GLM, t = 1.05 to 2.49, p = 0.014 to 0.30, emmeans, p = 0.038; Fig. 4a). The abundance of bees did not vary among pan trap color (GLM, t = 1.25 to 0.024, p = 0.22 to 0.98, emmeans, p = 0.43 to 0.999; Fig. 4b). Vane traps caught the most bee genera (GLM, t = 0.17 to 3.56, p < 0.001, emmeans, p ≤ 0.001; Fig. 4c; Supplemental Table 1, available online at https://eaglehill.us/prnaonline/suppl-files/prna-026-short-s1.pdf). The number of bee genera captured in blue, yellow,

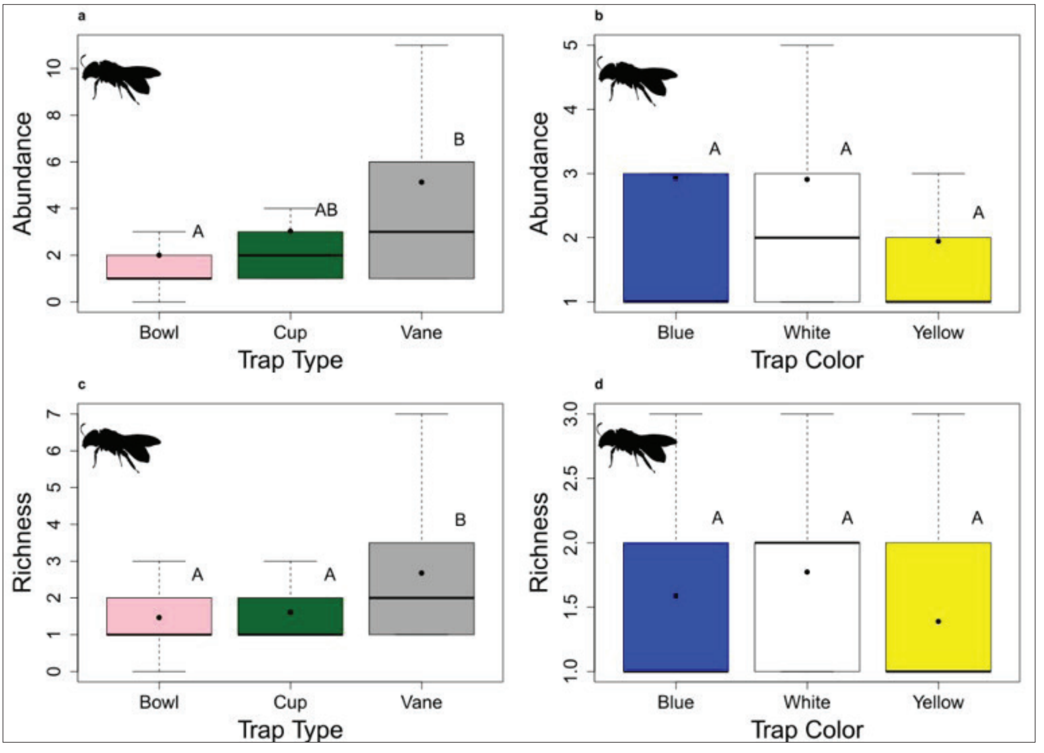

Figure 4. The abundance and richness of bees varied among trap type and pan trap color. a) Vane traps caught the most bees and b) the abundance of bees captured in pan trap colors did not differ. c) Vane traps caught the most bee genera and d) the richness of bee genera did not differ among pan trap colors. The bold line on boxplots is the median, the black circle is the mean, the lower and upper edges of the box are the 25th and 75th percentiles of the data, and the whiskers are the minimum and maximum values excluding outliers. Differing letters indicate significant differences (α ≤ 0.05).

and white pan traps did not differ (GLM, t = 0.84 to 0.74, p = 0.41 to 0.46, emmeans, p = 0.32 to 0.74; Fig. 4d; Fig. 5). *Anthidium*, *Anthophora*, *Colletes*, *Diadasia*, *Eucera*, *Megachile*, and *Melecta* were only collected in vane traps (Fig. 5a). *Agapostemon*, *Halictus*, *Lasioglossum*, *Osmia*, and *Perdita* were caught in vane traps, bee bowls, and bee cups. Only three genera were not caught in vane traps, and these genera were rare overall (2 *Apis*, 8 *Calliopsis*, and 2 *Sphecodes* caught in the entire study; Supplemental Table 1). A higher proportion of most bee genera were captured in white and blue traps (Fig. 5b).

Discussion

Vane traps collected the highest number of bees and beetles as well as the most bee genera in our study. Vane traps have been successful in collecting a large abundance of wood-boring beetles in Michigan cities and forests (Graham et al. 2012), and more beetles and bee genera were captured in vane traps compared to bowls and sweep netting around Alabama electric transmission areas (Campbell et al. 2023). Similarly, vane traps captured 4x more bees and 2x more bee genera compared to bee cups across most ecosystems in Wyoming (Bell et al 2023). Vane traps also caught more bees and bee species in apple orchards in Pennsylvania compared to pan traps (Joshi et al. 2015). These traps may catch a higher abundance and diversity of bees compared to pan traps because of differences in deployment height, size, color and reflectance. In the present study, vane traps were elevated off the ground, whereas pan traps were placed on or near the ground and were smaller, making them less visible. The elevation of passive traps above the ground has been shown to increase the number of bee species captured (Chamorro et al. 2022) but may also attract insects outside of the immediate study site. While vane traps may collect a biased assemblage like any passive trap, they are generally selective for bees and make specimen processing easier because they can be deployed dry (Kimoto et al. 2012), and therefore we recommend vane traps for most bee studies in the western United States.

Our results agree with previous studies, showing that bee assemblages did not differ between bee bowls and bee cups (Gonzalez et al. 2020); however, our total insect abundance differed between pan trap types. Both pan traps have physical resemblances and are used with similar methods (Packer & Darla-West 2020). Bee catch did not differ among two sizes of bowls and five sizes of cups in the U.S. (Droege 2006). Bee abundance and richness did not differ among pan traps with 4, 7, 10, and 12 cm diameters, but larger pan traps collected more bycatch (Gonzalez et al. 2020). Our results agree with Gonzalez et al. (2020); our bee bowls (15.5 cm diameter) collected more bycatch than our bee cups (6 cm diameter). Our bee bowls also collected the most Diptera, and appear to be an excellent method to collect some groups of flies. We are not aware of any other studies that compared Diptera caught in pan traps to vane traps. Pan trap color preferences varied within Diptera, reinforcing the idea that color preferences differ within insect families and across orders (Bradbury and Bennett 1974, Greany et al. 1977). For example, *Eristalis tenax* Linnaeus (Hoverflies) preferred yellow traps in Germany (Neimann et al. 2018), while *Musca domestica* Linnaeus (House Flies) preferred blue traps in Taiwan (Kafle et al. 2019). The best pan trap color may depend on the Diptera family of interest in the study region. If minimizing bycatch, such as Diptera, is the goal, we recommend using vane traps or smaller pan traps for sampling. Pan traps have been suggested as useful monitoring tools in many different habitats, and they can collect more bee species and individuals than methods such as observation plots and transect walks in Europe (Westphal et al. 2008).

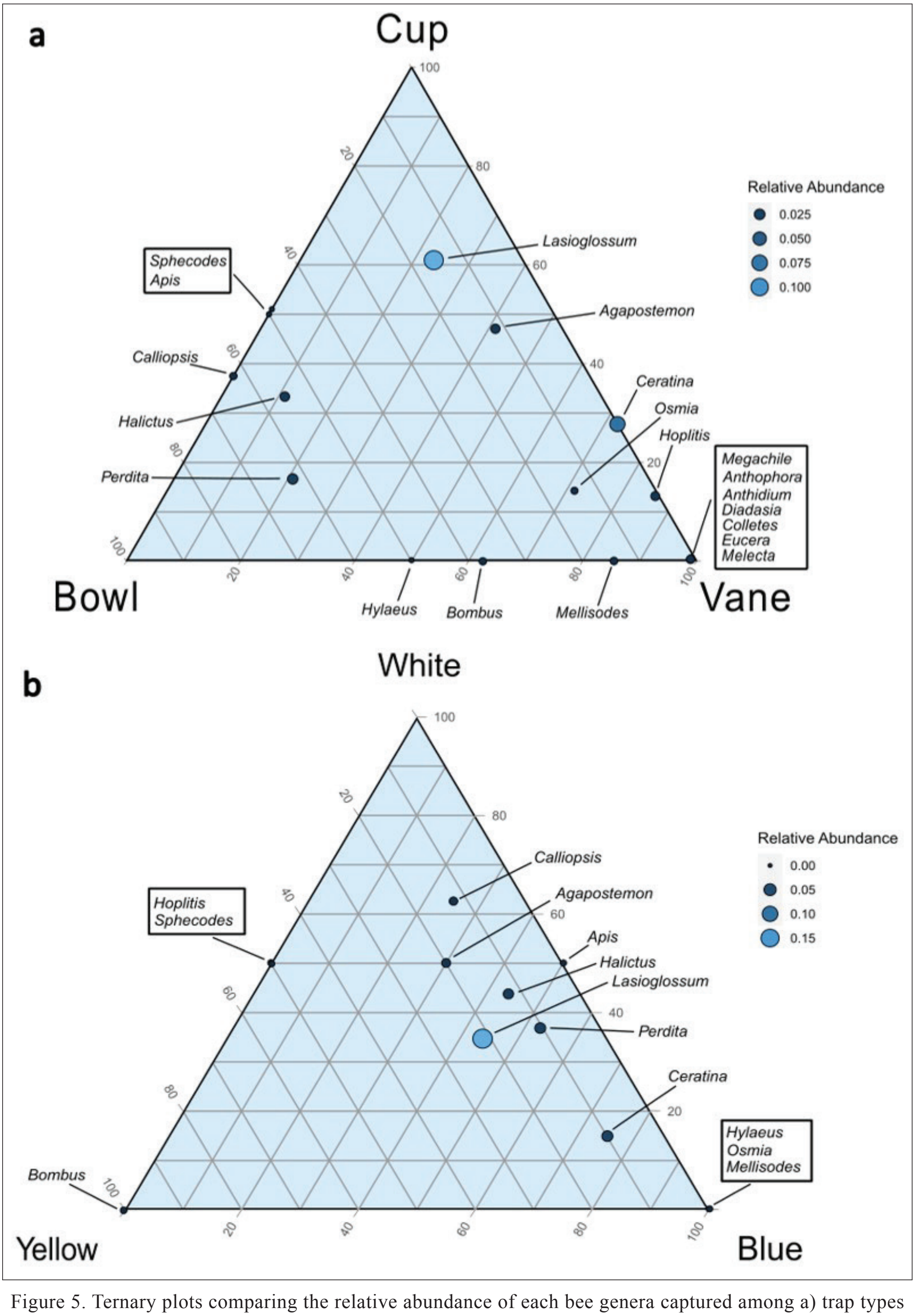

Figure 5. Ternary plots comparing the relative abundance of each bee genera captured among a) trap types and b) pan trap colors. Larger circles indicate a higher abundance of genera. A circle in the middle of the plot indicates that the genus was equally sampled among trap types or pan trap colors. A circle in the corner indicates that the genus was sampled in only one trap type or pan trap color.

White and blue pan traps caught a higher proportion of bee genera compared to yellow traps in our study; however, more bees were caught in yellow and blue pan traps compared to white pan traps in northern Florida (Hall 2016), which appears to be a common pattern in the literature (Buffington et al. 2020, Leong and Thorp 1999, Stephen and Rao 2007, Toler et al. 2005). White traps next to a white vertical pole were preferred by bees on a ridge in Wyoming (Crawford et al. in press). Different results may be due to color preferences within bee genera. Several studies have shown that different bee genera have different color preferences (Wilson et al. 2008), such as bumble bees preferring white and blue pan traps over yellow pan traps (Sircom et al. 2018). Alternatively, disparities in these results may be due to differences in trap color. Pan traps are not standardized in their size, shape, or color, and light reflectance often varies among brands of plastic bowls and cups commonly used for these traps, affecting results. One study found that the ultraviolet (UV) counterparts of colored pan traps caught a higher abundance of bees than the non-UV versions (Droege 2006). Because of the wide variety in color preference among bee genera and insect orders (Campbell and Hanula 2007), as well as differences in color and reflectivity of pan traps, we recommend the use of multiple colors of pan traps for sampling in the western United States.

There are a few drawbacks of our study to consider, including the limited number of sites and trap types investigated, as well as the level of taxonomic identification. Because our study was restricted to the Laramie Valley, our results were collected in urban and sagebrush steppe ecosystems. Pan trap catch can vary among habitats (Saunders and Luck 2012) suggesting that insect catch among trap types and colors may differ in other ecosystems. Furthermore, because we only tested differences between vane and pan traps, we cannot make any conclusions about the effectiveness of these trapping methods in comparison to other passive methods or active methods, such as observational surveys and netting. The use of lethal traps in areas with threatened pollinator species should be considered as well, as these methods may negatively impact already imperiled populations (U.S. Fish and Wildlife Service 2019). The height of vane traps may influence bee catch, as these traps are large, high visibility, and may attract insects from a larger area. Finally, due to the limited taxonomic information on bees in the Intermountain West, we were only able to identify bee specimens to genus. Species-level identification would provide results on a finer scale of differences among trap type and colors.

Our results reinforce the idea that an array of trap types and colors can collect a larger proportion of the insect assemblage at a site (Buffington et al. 2020, Packer and Darla-West 2020), and a combination of active and passive sampling methods may provide more accurate results as well (Tronstad et al. 2022), such as the deployment of pan traps and the use of netting (Wilson et al. 2008). Target netting is an excellent method to collect large bees visiting flowers, but this method is not as productive for smaller bees or in areas with few flowers (Kuhlman et al. 2021, Pei et al. 2021). Passive traps are useful tools to collect bees in areas with few flowers, and they catch a variety of bee sizes, but they are not as effective in areas with abundant floral resources (Bell et al. 2023, Kuhlman et al. 2021). Tailoring methods to collect a species or group of interest can be done with studies such as ours. We recommend using vane traps to sample bee and beetle communities in the western United States and we urge others to limit their deployment to 48 hours due to their high visibility when elevated. These traps had the least bycatch of other insect orders and caught the most bee genera and beetles. Some researchers have called into question the use of vane traps because of the significant quantity of insects they collect, which may negatively impact local insect populations and result in an unmanageable number of insects to be processed in the lab (Portman et al. 2020). We encourage other researchers to employ strict protocols when using vane traps to reduce the risk of overcollection. For example, we left vane traps out for ≤48 hrs and we did not deploy them until queen bumble bees were in their nests. Bee bowls caught the most Diptera, particularly yellow bee bowls, and may be useful for true fly studies in the western United States. Pan traps have been shown to be effective in sampling chalcid wasps (Noyes 1982); however, we captured few wasps, and other sampling techniques (e.g., Malaise traps and colony collection) may be more productive (Prezoto et al. 2021). Basic investigations that compare capture methods are vital to help us select the best methods to collect different types of insects, capture less bycatch, and evaluate biases. There is an ongoing effort to establish a national bee monitoring program in the United States (Woodard et al. 2020) and the results of this study may be used to further inform the best sampling methods. Further studies are needed to compare capture methods and their efficiency, accuracy, and effect on the insect community in different ecosystem types.

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