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The potential of arboreal pitfall traps for sampling nontargeted bee and wasp pollinators

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Abstract

Insect pollinators, including bees and wasps, are facing a marked decline in their native populations, caused mainly by human activities, such as forest fragmentation, urbanization, and the use of agrochemicals. To help mitigate the rapid decline of pollinators, new efforts towards understanding basic and applied aspects of these organisms are necessary. Among these efforts, there is a focus on increasing the sampling efficiency, including a broader range of targeted groups and collection methods. Although each method has its advantages and disadvantages, the pollinators' crisis calls for alternative methods to analyze bee and wasp diversity and population dynamics. Here, we assess the potential role of incidental captures of bees and wasps by a method widely used to collect ants but not targeted for bees: arboreal pitfall traps. We compared the sampling efficiency of human urine-baited arboreal pitfall traps and two traditional methods for bee sampling: pan traps and scent traps. Arboreal pitfalls collected a high diversity of bees and sphecoid wasps, and when compared with pan traps and scent traps, they had the highest species richness and the second-highest abundance. Although the three trapping methods shared most species, each method collected particular groups of species, and there were indicator species for each trapping method. When used in pairs with pan traps, arboreal pitfalls collected a higher species diversity than pan traps paired with scent traps. In addition, each trapping method responded differently to seasonal variation, and although arboreal pitfalls had lower diversity during the rainy season, scent traps detected differences only in species abundance, and pan traps detected no differences at all. Our study reinforces the importance of complementary methods in sampling bees and wasps and the use of non-traditional methods to increase the sampling coverage of these insects.

KEYWORDS
Apoidea, bee survey, Brazilian savannas, Cerrado, decline of pollinators, incidental captures, insect pollinators, pan traps, pitfall traps, sampling efficiency, sampling methods, scent traps

INTRODUCTION

Plant-pollinator relationships emerged more than 20 million years ago (Engel, 1999), and the loss of such ancient and important relationships might have serious consequences, ultimately impacting food production (Garibaldi et al., 2011). Among the several taxa responsible for pollination, bees comprise perhaps the most important group, and a strong decline in their species and populations has been observed in the last decades (Burkle et al., 2013). The decline of bee populations can be associated with various factors, such as climatic changes (Giannini et al., 2012; Jacobson et al., 2018), habitat change due to agricultural expansion (Nemésio et al., 2016; Gómez-Martínez et al., 2020; Perillo et al., 2020), the use of agrochemicals (Woodcock et al., 2014, 2017; Tschoeke et al., 2019), and urbanization (Zanette et al., 2005; Cardoso & Gonçalves, 2018). In the face of population decline, many efforts have been employed to understand basic and applied aspects of the ecology of bees. However, there are still gaps in need of further exploration.

In some areas of high diversity of insects and plants, such as South America, native bees are relatively undersampled (Freitas et al., 2009; Da Costa & Gonçalves, 2017). Additionally, there is a taxonomic bias in the collection and identification of native bees. The bees belong to the superfamily Apoidea, but other members of this superfamily, such as sphecoid wasps, are largely ignored, even though this group is responsible for the pollination of a large diversity of plants (Larson et al., 2017; Rader et al., 2020). Therefore, to better understand the pollination process, we must expand our focus to these less-studied pollinators, which may also have great importance in maintaining interactions with plant species (Rader et al., 2016).

To monitor the demographic changes of pollinator populations and to understand the ecology of species, the most effective collection methods are needed. Many methods have been developed for sampling bees, each with its advantages and disadvantages, such as cost-effectiveness, sampling effort, and replicability (Almeida et al., 2019). The direct active collection methods are problematic due to the need for massive sampling effort and their dependence on trained collectors, being highly costly (O'Connor et al., 2019). Passive collection methods (using traps) are more commonly used as the results are less influenced by the collector's experience, easier to replicate, often easier to deploy, and implying less workforce. Among the most efficient and consolidated indirect methods for sampling and monitoring bees are pan traps and scent traps (Leong & Thorp, 1999; Droege et al., 2010; Moreira et al., 2016; O'Connor et al., 2019; Prendergast et al., 2020). However, pan traps are usually biased towards smaller pollinators that forage near the ground (Prendergast et al., 2020), and scent traps are biased towards larger bees (Nemésio & Vasconcelos, 2014). There is no universally good method for collecting bees as its success is dependent on many factors, including targeted taxa and sampled habitats. Moreover, whereas mixing methods is usually required for increased reliability, as they may complement each other, the choice of methods to mix can depend on the study system, the research aim, and the targeted pollinators.

In face of the rapid pollinator decline, alternative strategies are needed to gather more information regarding their diversity and population dynamics. In many cases, trapping methods that do not have pollinators as their primary target may also collect significant numbers of bee species (Hung et al., 2015). For example, arboreal pitfall traps are primarily used for sampling ants (Powell et al., 2011; Camarota et al., 2015; Koch et al., 2016; Vasconcelos et al., 2018; Arruda et al., 2021), and this method collects many other arthropods as well, such as beetles, spiders, bees, and wasps. Therefore, much information may be acquired when assessing non-target taxa on broadly used trapping methods, such as arboreal pitfalls. In addition, many arboreal pitfall traps are baited, mostly with protein-based baits (Powell et al., 2011; Vasconcelos et al., 2018), which can add to their attractiveness for several kinds of insects. Presumably, our knowledge of the pollinators' ecology and population dynamics would improve dramatically by gathering data on the bees and wasps collected by this method. However, only a few studies have considered the potential role of trapping methods used to sample other target organisms, such as pitfall traps, in collecting species of insect pollinators, including bees and wasps (Almeida et al., 2019). Although trapping methods not targeted for bees and wasps are unlikely to substitute the more traditional methods, such as scent traps and pan traps, they may provide an opportunity for collecting these insects (Hung et al., 2015).

When assessing adequate methods for sampling bees, we need to consider the potential role of seasonality (Wojcik et al., 2008; de Assis et al., 2020). Shifts in many abiotic factors, such as luminosity, temperature, and humidity, influence the activity and abundance of bee populations (Pollato et al., 2014; Escobedo-Kenefic et al., 2020). The seasonal changes in bee activity patterns are regulated by their physiology, such as water stress and the thermal regulation of their bodies (Sarospataki et al., 2009; Abou-Shaara et al., 2017). Additionally, differences in abiotic conditions might reflect the availability of the plant resources used by the bees. For example, in seasonal habitats, the rainy season increases the number of flowering plants, which would imply an increase in food collection by the bees (Aleixo et al., 2016; Mattos et al., 2018). Adequate methods for sampling bees and wasps thus must consider the potential role of seasonal fluctuations in abiotic conditions and resource availability. New methods for collecting nontargeted insects should be consistently efficient across seasons.

Here, we assessed the role of incidental captures from trapping methods nontargeted for bees and wasps in sampling the communities of native bees and sphecoid wasps in a Brazilian savanna (Cerrado). For this, we tested two traditional trapping methods, i.e., scent traps and pan traps, and compared their sampling effectiveness with arboreal pitfall traps, a method largely ignored for collecting bees. We evaluated the difference between these trapping methods in species richness, abundance, composition, and prevalence of collected species. We also compared the trapping methods to assess whether they could be used together, evaluating which methods would be more effective when used as pairs. Additionally, we tested whether there was a role of seasonality in the efficacy of the various trapping methods.

MATERIAL AND METHODS

Study area

The study was performed in the State of Goiás, Mid-West Brazil (Figure 1A), where three sampling areas were selected, two in the municipality of Catalão (area 1: 18°10′68″S, 47°52′27″W; area 2: 18°1′49″S, 47°51′56″W), and one in the municipality of Bonfinópolis (area 3: 16°34′23″S, 49°2′51″W) (Figure 1B). All sampled areas are within the Cerrado biome, consisting of similar savanna-like vegetation and habitat structure. The climate is tropical (Aw Köppen), with two well-defined seasons, viz. a rainy season where 70% of the annual precipitation occurs (from October to March/April) and a dry season (from April/May to September) (Peel et al., 2007).

Data collection and sampling design

The bee sampling happened during the dry and wet seasons. In areas 1 and 2, the sampling occurred in the dry period, between August/September 2018, and in the rainy season, in December of the same year. In area 3, the samplings were also performed in August/September 2018 in the dry season, but the collections in the wet season occurred in March 2019.

In each of the three sampling areas, we marked seven sites in different patches of native vegetation, totaling 21 sampling sites, at 350 m or more from each other. In each sampling site, a transect of 80 m was established, and each transect was divided into five sampling points separated 20 m from each other (Figure 1C). At each point, a group of traps was installed, consisting of scent traps, pan traps, and arboreal pitfalls. The pan traps were placed at the same sampling point as the scent traps, 5 m apart from the arboreal pitfalls.

Arboreal pitfalls

We used four pitfalls (Figure 1D), consisting of 50-ml cups (5 cm diameter, 5 cm high) installed on each tree. The pitfalls were wired at a height between 1.5 and 3.5 m above breast height. Each cup was then filled with water (70%), human urine (30%), and drops of soap. Soap was used to break the surface tension of the water and avoid the escape of captured insects, a method similar to that used by Almeida et al. (2019). Human urine is used as an attractant, as it contains lipid, protein, and minerals, and recently, this method is already widely used to collect ants (e.g., Powell et al. 2011; Vasconcelos et al., 2018; Arruda et al., 2021). The urine was always collected less than 24 h before the pitfall exposure. To avoid any nutritional and hormonal bias, we mixed the urine of at least four researchers, two men and two women. Pitfalls were exposed for 48 h and were later collected.

Scent traps

We used scent traps (Figure 1E) made of plastic bottles with two openings (adapted from Campos et al., 1989; Sofia &

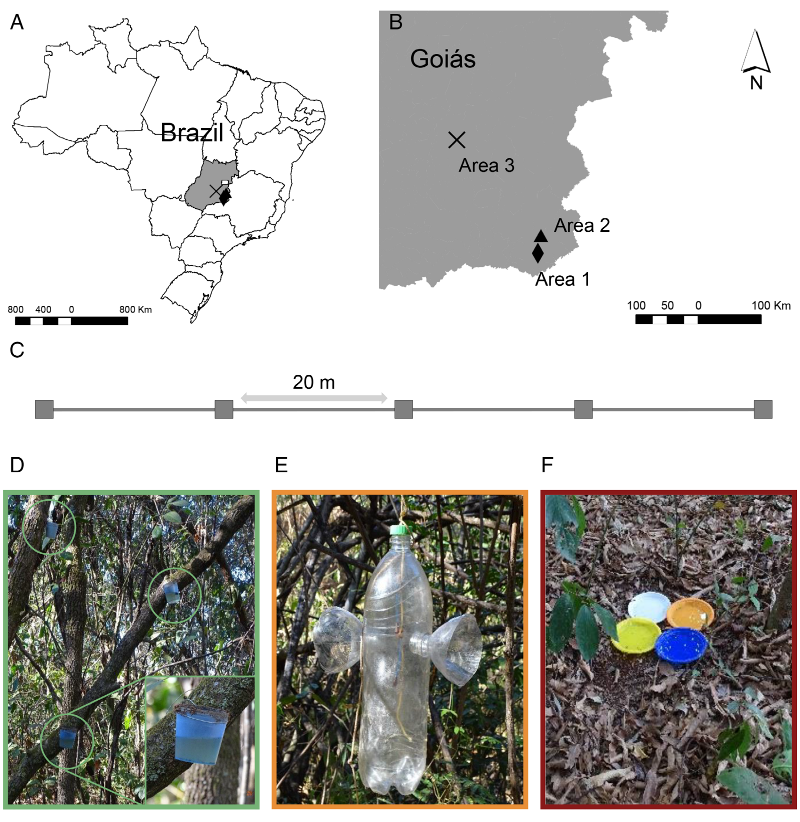

FIGURE 1 (A,B) Sampling areas in the State of Goiás, Mid-West Brazil, (C) spacing between samples, and collection methods: (D) arboreal pitfalls with human urine attractant, (E) scent traps, and (F) pan traps.

Suzuki, 2004). The traps were placed 1.8 m from the ground and fixed to tree branches with a cotton rope. We used five scents, one per sampling location in each one of the six areas. The scents used (benzyl acetate, methyl cinnamate, cineol, eugenol, and vanillin) were selected because they are commonly used to sample Euglossini bees in field surveys due to their similarity to plant chemicals or as attractants of male specimens (Silva & De Marco, 2014). Scent traps were left out for 7 days, revisited every 48 h to remove specimens from traps and to replenish scents.

Pan traps

We used colored dishes (Figure 1F; yellow, blue, orange, and green) filled with water and drops of soap to improve the killing efficiency by breaking the water's surface tension and preventing the insects from escaping. Four dishes were used at each point, each one of a different color. Combining different colors increases the diversity of collected insects, contributing to a wide and diverse sampling of pollinators (Vrdoljak & Samways, 2012; Franceschinelli et al., 2019). The pan traps were exposed in the field and collected after 48 h.

The hymenopterans of the Apoidea superfamily (hereafter referred to as 'bees and wasps') were identified with the highest possible taxonomic precision. Specimens of the registered species were deposited in the Brazilian Institute of Geography and Statistics (IBGE) Ecological Reserve entomological collection, located in Brasília, Distrito Federal.

Statistical analysis

Sampling efficiency

We compared the diversity of bees and wasps between trapping methods using accumulation curves, using the traps as units, and rarefaction curves using the collected individuals. For that, we use the 'iNEXT' function of the package with the same name (Hsieh et al., 2020). In addition, we analyzed pairwise combinations of traps (i.e., arboreal pitfalls + scent trap, arboreal pitfalls + pan trap, and scent trap + pan trap) to assess the joint efficiency of the traps.

Species richness and abundance of bees and wasps among methods

To assess the richness and abundance of bees and wasps collected by different trapping methods and seasons, we used generalized linear mixed models (GLMM). Species richness and abundance were tested as response variables in different models, and we used collections as sampling units (n = 21) with trapping methods (pitfall, scent, or pan traps) and season (dry and rainy) as explanatory variables, and the three locations as a random effect. As we detect overdispersion on the initial model, we used the 'glmer.nb' function of the lme4 package (Zuur et al., 2010; Bates et al., 2015). Statistical differences between methods were assessed with post-hoc pairwise tests, and model validation was performed graphically following the protocol of Zuur et al. (2010).

Composition of bees and wasps among methods

To assess whether there is a difference in the composition of wasp and bee communities between the various trapping methods and seasons, we used a multivariate analysis of permutation (PERMANOVA; Clarke, 1993). The species composition was the response variable in two models, considering (1) abundance [after log(x + 1) transformation to decrease the effect of very abundant species] and (2) presence and absence. The collections were the sampling units, with trapping method and season as explanatory variables. We used the 'adonis' function of the vegan package (Oksanen et al., 2018) with 9999 randomizations and stratified randomizations ('strata' argument), considering the paired sampling design at the localities. After the significance was detected, we evaluated the difference of the levels with simplified post-hoc pairwise tests. We performed two principal coordinates analyses (PCoA), one for each model, to visualize the data distribution, using the 'cmdscale' function also from the vegan package. We used the Bray-Curtis index to measure similarity, and for presence/absence data we used the Jaccard index (Gotelli et al., 2011).

To assess the specificity of bee and wasp species in the various trapping methods, we used the Indicator Value (IndVal) index to measure the association between a species and each trapping method (Dufrêne & Legendre, 1997), applying the 'multipatt' function of the indicspecies package (De Caceres & Legendre, 2009). Selected species were represented in ternary diagrams using the frequency of occurrence in the methodologies using the 'ggtern' function of a package with the same name (Hamilton & Ferry, 2018).

All statistical analyzes were performed using R software (R Core Team, 2020). In addition, figures and tables were made using the ggplot2 (Wickham, 2016) and gridExtra (Auguie, 2017) packages.

RESULTS

We collected 1698 bees and wasps, distributed in 82 species in 42 genera, eight subfamilies, and five families (Table S1). Five genera stood out as the most diverse, with five species each: *Paratetrapedia*, *Ceratina*, *Liris*, *Augochloropsis*, and *Augochlora*, and were responsible for 20.5% of the species collected. The most abundant species were *Trigona spinipes* (Fabricius) (n = 760) and *Eulaema nigrita* Lepeletier (n = 205), followed by *Tetragona clavipes* (Fabricius) (n = 17). These three species represent 66.8% of all bees and wasps collected, with *T. spinipes* representing 44.7% of the sampled individuals.

Sampling efficiency

By assessing the accumulation curves, the trapping methods differed in relation to bee and wasp species richness: arboreal pitfalls presented more species (45), followed by pan traps (37) and scent traps (24 species) (Figure 2A, Table S1). The trapping methods also differed in relation to the number of collected individuals, with scent traps collecting more individuals (1274), followed by arboreal pitfalls (284) and pan traps (140) (Figure 2B, Table S1). There was a slight increase in the number of collected individuals in the rainy season (937) compared to the dry season (761). Furthermore, evaluating two methods together (arboreal pitfalls + scent traps, arboreal pitfalls + pan traps, and scent traps + pan traps), pitfall and pan traps together sampled the largest portion of bee and wasp species (Figure 3A), while also collecting a smaller number of individuals than scent traps (Figure 3B).

Bee and wasp species richness and composition

Abundance varied between the methods; the scent traps presented the highest abundance, whereas the arboreal pitfalls and pan traps did not differ in abundance (scent traps: 212.3 ± 70.7; arboreal pitfalls: 47.3 ± 21; pan traps: 23.3 ± 7.4 individuals; Table 1, Figure 4A). Also the species richness differed between the methods: arboreal pitfalls had the highest richness per sampling point (13.3 ± 3.4 spp., vs. scent traps: 9.8 ± 1.3 and pan traps: 9.5 ± 2.5 spp.; Table 1, Figure 4B).

When taking into account the seasonal variation in the number of individuals collected by the various methods (interaction term in Table 1), each method presented a different pattern: arboreal pitfalls showed greater abundance in the dry period, scent traps presented greater abundance in the rainy period, and pan traps did not differ in relation to seasonality (Table 1, Figure 4A). Only arboreal pitfalls showed a difference in species richness in relation to seasonality: it was greater in the dry period (Figure 4B).

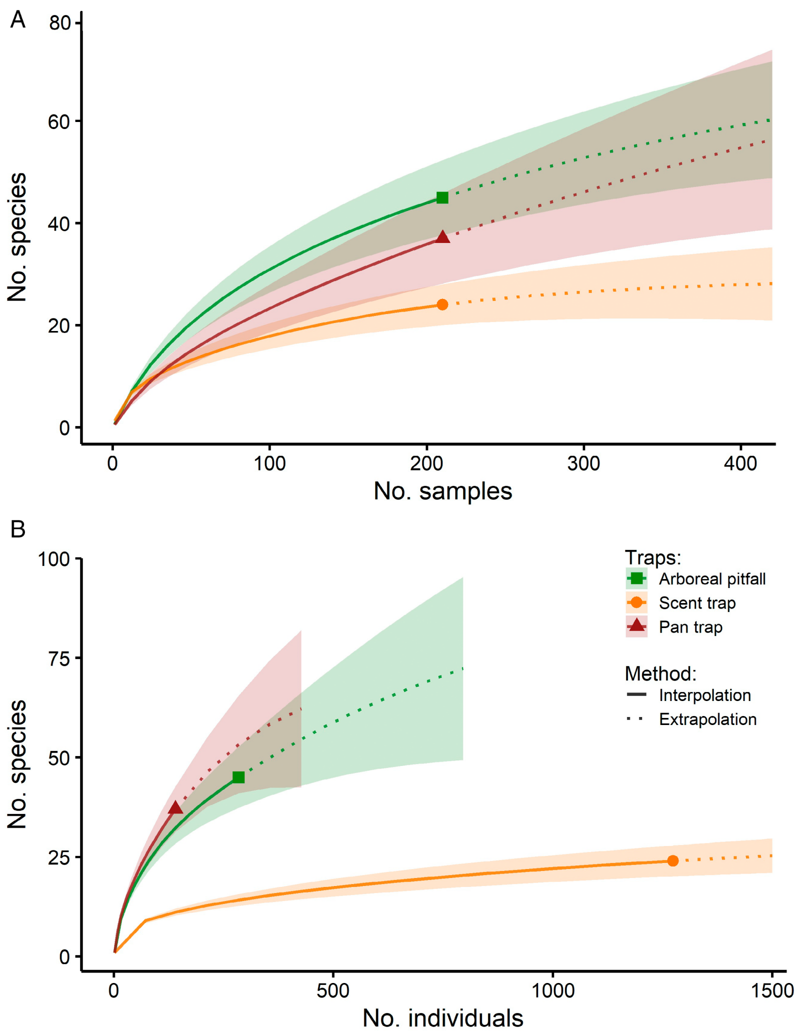

FIGURE 2 Interpolation and extrapolation curves of (A) sample-based and (B) individual-based bees and sphecoid wasps collected with three trap types (arboreal pitfall traps, scent traps, and pan traps) in the State of Goiás, Brazil. The continuous lines represent the observed species richness, the dotted lines represent the extrapolated species richness of each sampling method. The symbols (i.e., ■, ●, and ▲) represent the total number of (A) samples and (B) collected individuals. The shaded areas near the lines represent 95% confidence intervals of the samples.

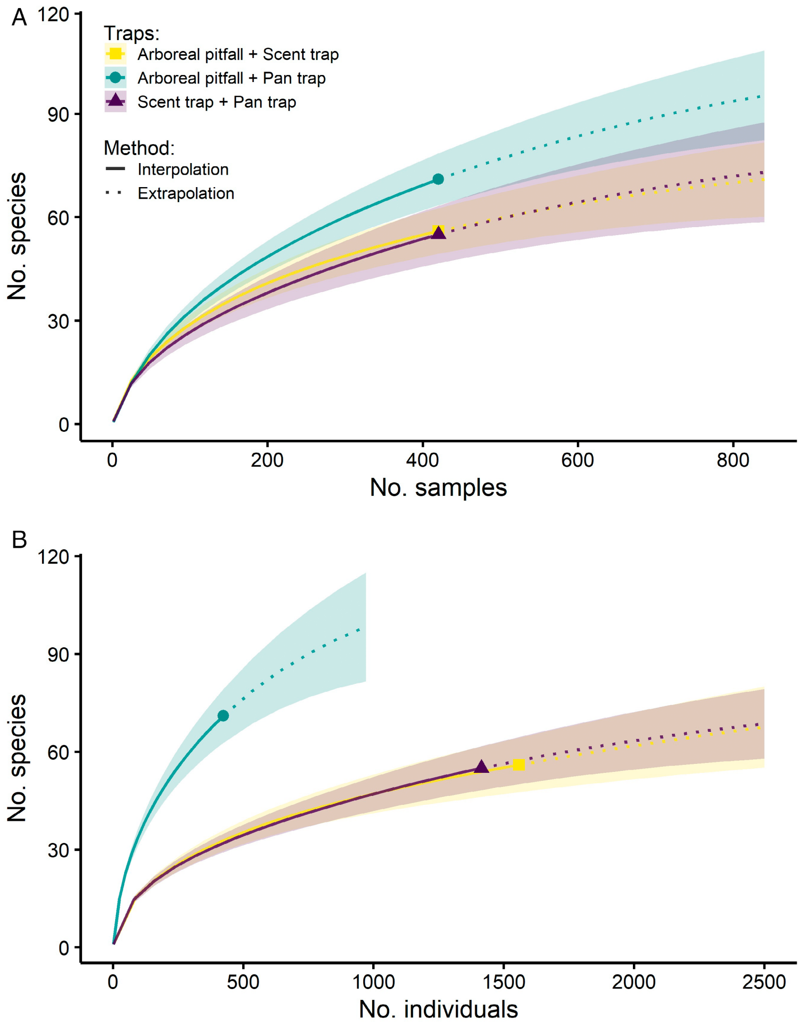

FIGURE 3 Interpolation and extrapolation curves of (A) sample-based and (B) individual-based bees and sphecoid wasps considering paired sampling methods (arboreal pitfalls + scent traps, arboreal pitfalls + pan traps, scent traps + pan traps) in the State of Goiás, Brazil. The continuous lines represent the observed species richness, the dotted lines represent the extrapolated species richness of each sampling method. The symbols (i.e., ■, ●, and ▲) represent the total number of (A) samples and (B) collected individuals. The shaded areas near the lines represent the 95% confidence intervals of the samples.

TABLE 1 Estimated parameters by the generalized linear mixed model with a binomial distribution. The random effect has three levels (areas 1–3)

Response variable	Fixed effect	χ^2	d.f.	P	Random effect	Variance
Abundance	Methodology	164.713	2	<0.001	Locality	0.745
	Season	1.567	1	0.21		
	Interaction	30.568	2	<0.001		
Richness	Methodology	4.670	2	0.097	Locality	0.141
	Season	6.630	1	0.010		
	Interaction	11.256	2	0.003		

Composition of bees and wasps in different methods

The species composition of bees and wasps, both their presence/absence and their abundance, differed among the trapping methods (Table 2). No differences were found in the species composition between the dry and wet seasons. The principal coordinates analysis indicated that the first two axes for the ordination using abundance explained 40.8% of the total variation of the data (Figure 5A), and for the ordination using presence/absence they explained 34.4% (Figure 5B).

Of the 82 species of bees and wasps collected, 10 were detected as specialists, eight of which associated with a single method – one species with pitfall traps, three with pan traps, and four with scent traps. Two bee species were associated with two trapping methods, i.e., arboreal pitfalls and scent traps (Figure 6, Table S2).

DISCUSSION

Whereas arboreal pitfalls collected the highest number of bee and wasp species, they were less successful in

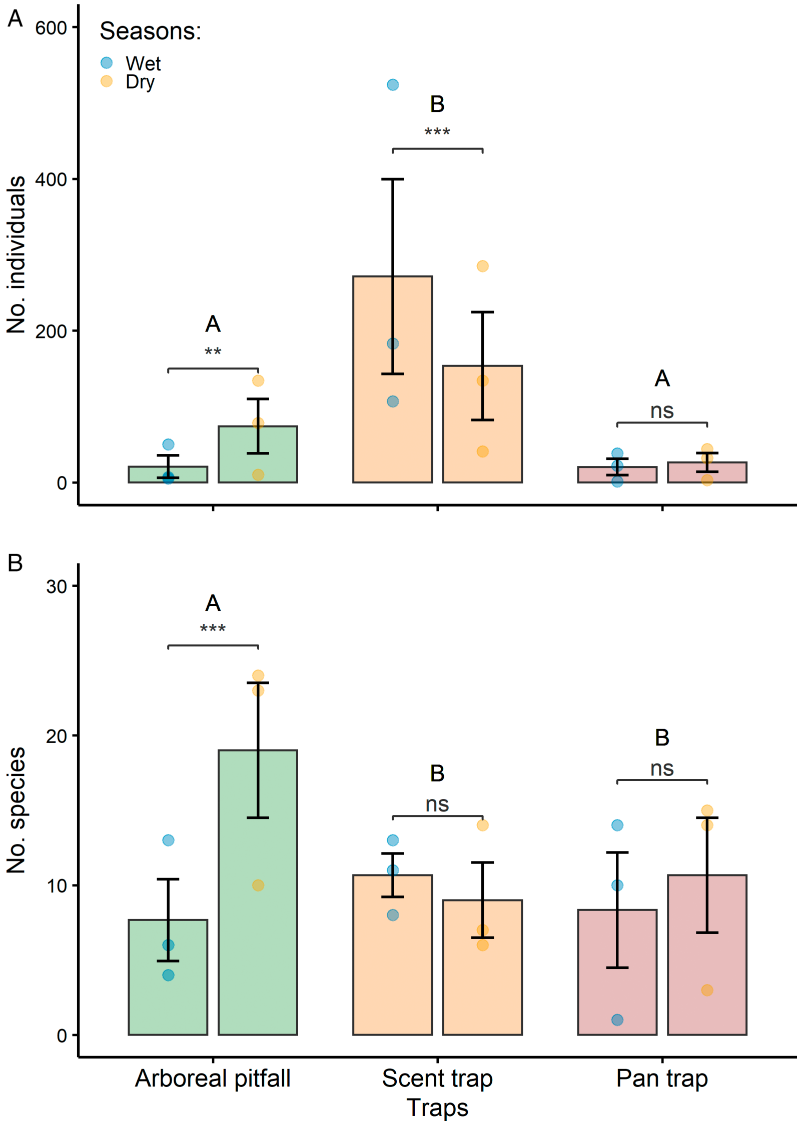

FIGURE 4 Mean (± SE) number of (A) individuals and (B) species of bees and sphecoid wasps collected with three trap types (arboreal pitfall traps, scent traps, and pan traps) in the dry and wet season in the State of Goiás, Brazil. Asterisks above bars indicate significant differences between seasons within collection method (GLMM: ***$P<0.001$; **$0.001<P<0.01$; ns, $P>0.05$), whereas different capital letters above trap types indicate significant differences between collection methods (GLMM: $P<0.05$).

collecting target groups. Our species indicator analysis indicated that arboreal pitfalls had only one species primarily found in this method – *Augochlora* (*A.*) sp.1 – compared with four species for scent traps and three species for pan traps. Therefore, as expected, traditional collecting methods were much more successful in collecting targeted groups, including the orchid bees (Euglossini) for scent traps (Silva & De Marco, 2014; Storck-Tonon & Peres, 2017) and small wasps, such as Crabronidae, which we found only in pan traps. The main explanation for arboreal pitfalls' higher diversity (and lower specificity) is probably related to the broader spectrum of offered resources and the lack of bias for bees and wasps of specific sizes. First, we baited pitfall traps with human urine, which has many chemical elements that can be attractive to various insects, including bees, such as carbohydrates (Brodschneider & Cralsheim, 2010), amino acids (Inouye & Waller, 1984; Cook et al., 2003), and sodium (Brodschneider & Cralsheim, 2010; Clay et al., 2014; Petit et al., 2020). Additionally, arboreal pitfalls are relatively wide and deep (5 cm wide and high), allowing the collection of bees of different sizes, including large *Xylocopa* and small *Augochlora*.

There is often a vertical stratification of bee and wasp communities, both in temperate forests (Ulyshen et al., 2010) and tropical forests (Roubik, 1993). Usually, there are more bees and wasp species and individuals in the canopy stratum than in the ground and understory strata (Ramalho, 2004; Sobek et al., 2009). Therefore, the success of arboreal pitfall traps might also be related to the baits' spatial configuration and bait placement height: four pitfalls spread up stems on the trees, up to 5 m from the ground. Thus, arboreal pitfalls were significantly higher than the scent traps (located <2 m from the ground) and the pan traps placed in the ground. Although the arboreal stratum of most tropical habitats is significantly taller than 5 m, this is not the case for the Cerrado (our focal biome), where the trees rarely grow larger than 8 m tall (Oliveira & Marquis, 2002).

The proximity of baits can be a problem as the different methods can compete for bees and wasps. Therefore,

TABLE 2 PERMANOVA results, showing the composition of bees and sphecoid wasps compared between three collection methods (AP, arboreal pitfalls; ST, scent traps; PT, pan traps) and two seasons (dry, wet)

Model	Explaining variable	d.f.	SS	Pseudo F	R^2	P
Abundance	Methodology	2	2.249	4.348	0.367	<0.001
	Season	1	0.256	0.988	0.042	0.45
	Residuals	14	3.620		0.591	
	Total	17	6.124		1	
Paired methods	AP vs. ST	1	1.081	5.397	0.351	0.003
	AP vs. PT	1	0.820	2.521	0.201	0.024
	ST vs. PT	1	1.472	5.900	0.371	0.009
Presence/absence	Methodology	2	1.930	3.134	0.295	<0.001
	Season	1	0.312	1.013	0.048	0.41
	Residuals	14	4.311		0.658	
	Total	17	6.554		1	
Paired methods	AP vs. ST	1	0.961	5.689	0.363	0.006
	AP vs. PT	1	0.777	2.579	0.205	0.027
	ST vs. PT	1	1.223	5.161	0.340	0.003

[a]P values determined by permutation.

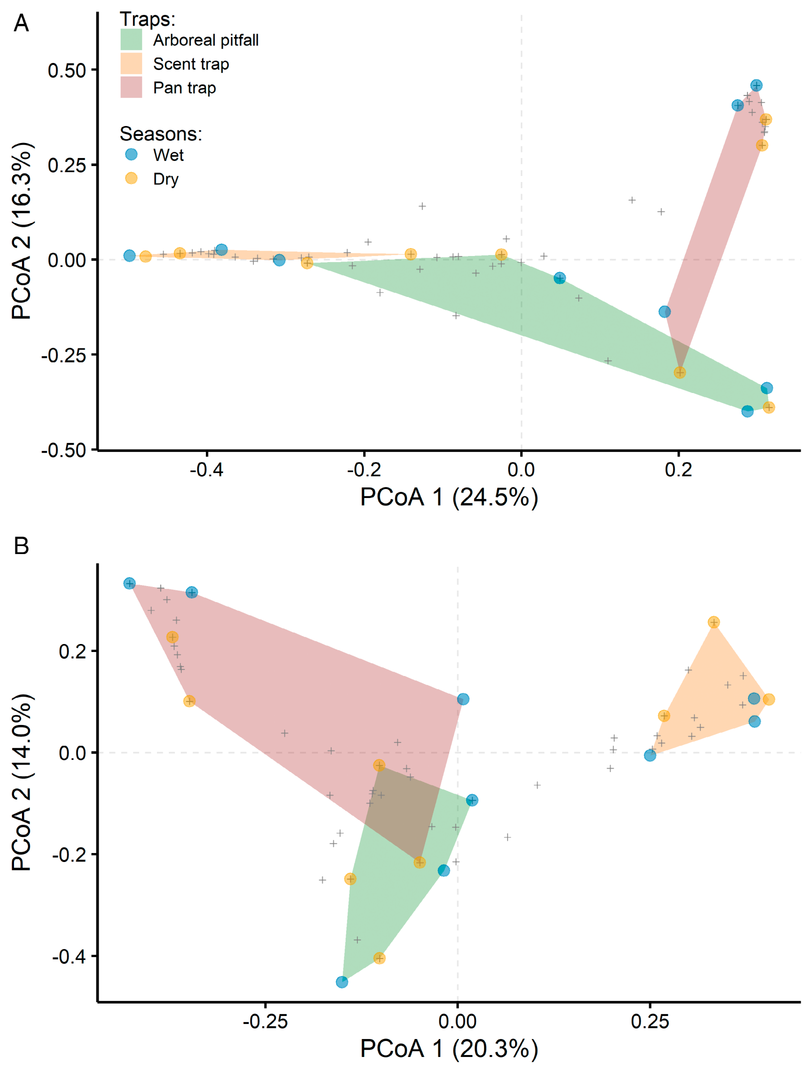

FIGURE 5 Ordination showing the composition of bees and sphecoid wasps based on (A) abundance and (B) presence and absence, collected with three trap types (arboreal pitfalls, scent traps, and pan traps) in the dry and wet seasons in the State of Goiás, Brazil. Grey symbols represent collected species.

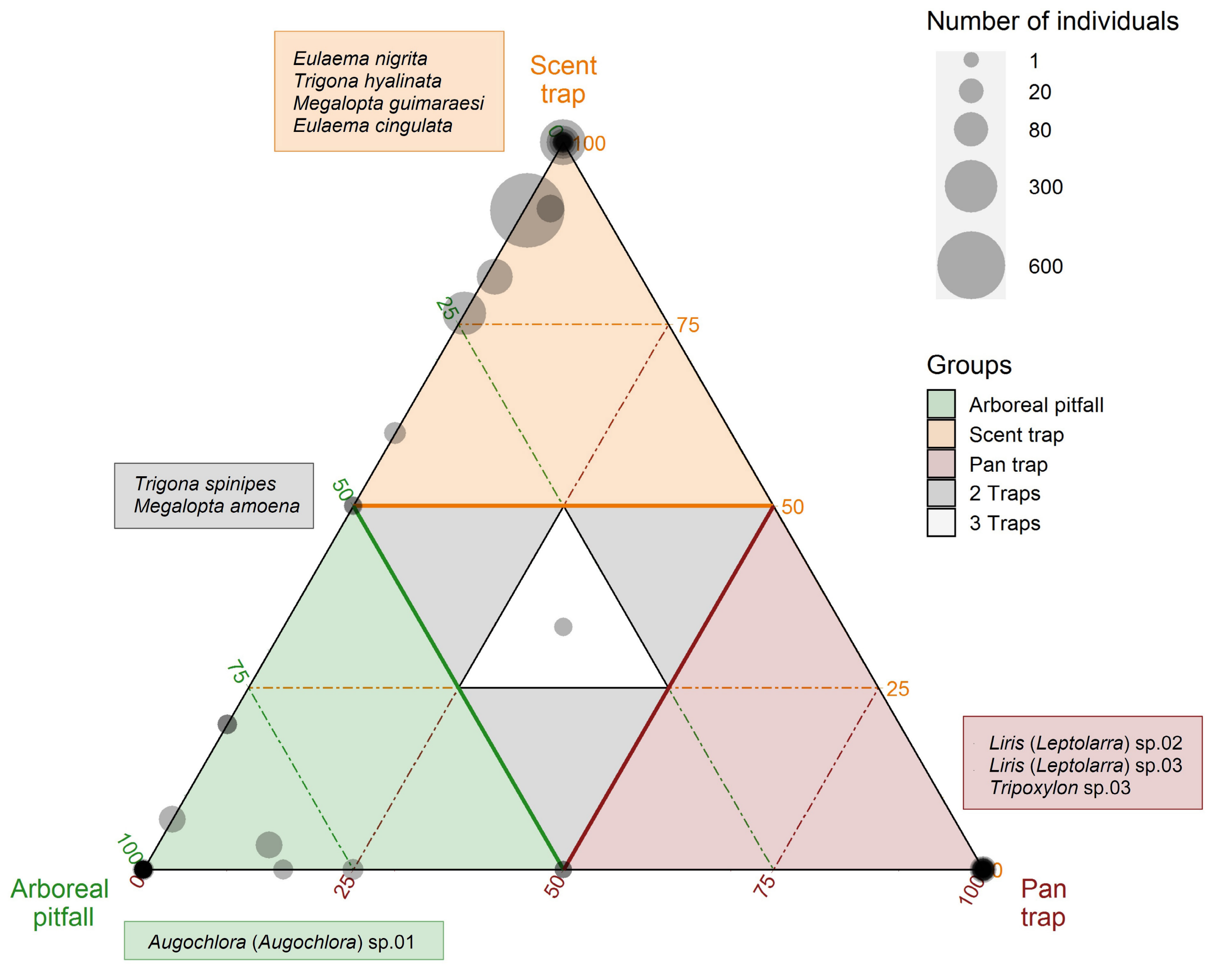

FIGURE 6 Collection frequency of species of bee and sphecoid wasp collected with each of three trap types (arboreal pitfalls, scent traps, and pan traps). The dots represent species, and the size of the dots indicates the total number of sampled individuals. Names represent the selected species based on IndVal values for each different group (see Table S2).

adequate spacing is essential to guarantee the best results of each method (Prado et al., 2017). Accordingly, we placed both baited traps (i.e., arboreal pitfalls and scent traps) at least 5 m apart, which is within the recommended distance (3–5 m) by Droege et al. (2010). Therefore, there is little possibility of bait odor influencing capture rates of other trapping methods. Scent traps and pan traps were closer to each other (ca. 2 m), but as each method covers different vegetation strata, there was probably little influence, if any, of one trap on the other. Indeed, arboreal, and shrub-feeding species are less likely to be caught in ground-level traps (Gonçalves & Brandão, 2008; Gonçalves et al., 2012). Furthermore, our finding that each method had marked differences in their species composition confirms that they were complementing rather than competing with each other for specific groups of bees and wasps.

When comparing the various trapping methods used as pairs, we found that arboreal pitfalls and pan traps were the most efficient method for paired sampling of the diversity of focal pollinator species. Indeed, as discussed above, pitfall traps collected more species, whereas pan traps collected targeted species, including two *Liris* species (Crabronidae), which are more often collected in trap nests (e.g., Matos et al., 2013). In addition, scent traps collected a larger number of individuals, and it is perhaps more adequate than the other methods for surveying the abundance of pollinators. However, scent traps were left in the field for 7 days, in contrast to the 48 h of arboreal pitfalls and pan traps. Nevertheless, our species accumulation curves showed that scent traps were rapidly dominated by a few species of bees, suggesting that they could be left in the field for <7 days. Nevertheless, even with some sampling design limitations, our results showed that scent traps successfully collected specific groups of bees. Although this kind of trapping method was developed and is mainly used to sample orchid bees (Euglossini) (Dressler, 1982), our results corroborate some literature records of other non-target bee groups being attracted to the scents (Alves et al., 2011; Nemésio & Siqueira, 2011; Knoll & Santos, 2012). This observation points to the possibility of extending the usage of this kind of trap to studies focused on additional target groups, including hard-to-sample nocturnal bees such as *Megalopta* (Carvalho et al., 2012). Furthermore, the importance of scent traps should not be ignored for detecting seasonal patterns of species activity.

Seasonality is often considered an important factor in regulating the activity of bee communities (e.g., Abou-Shaara et al., 2017; Medeiros et al., 2017; de Assis et al., 2020), and, therefore, it is crucial to use trapping methods that would adequately show the seasonal shifts of these insects. Among the three trapping methods used here, arboreal pitfalls were the most sensitive to the sampling season, with higher species richness and more individuals in the dry season. One reason for increased efficacy during the dry season might be related to the potential water deficit during extreme droughts, like those observed in the sampled areas. Moreover, as discussed above, we used pitfall traps baited with human urine, which has attractive elements for many insects (Cook et al., 2003; Brodschneider & Cralsheim, 2010; Clay et al., 2015). During the dry season, the traps often dry faster, which might increase the urine odor. Therefore, a decrease in water availability and an increase in scent might help explain the increase in the pitfall trap collection efficiency in the dry season. Although scent traps were also affected by seasonality, there was only a difference in the number of collected individuals, which increased in the wet season. Therefore, scent traps are presumably more adequate for collecting at different seasons than pitfall traps, which showed a difference in species composition, and pan traps, which did not detect any difference.

CONCLUSIONS

We provided evidence that methods traditionally used to collect distinct taxa can also be important in gathering information on bee and wasp species diversity patterns. Particularly, we showed that arboreal pitfalls, usually employed for ant collection, collect a significant number of bees and wasps, comparable to more traditional methods, such as scent traps and pan traps. Although we do not claim that alternative methods should replace targeted methods to collect insect pollinators, we advocate using the available specimens collected in such methods as complementary information. The need to consider the data gathered by alternative trapping methods is especially urgent in the face of the fast worldwide decline of bees and the lack of sufficient funds in many highly biodiverse areas. Future studies should aim to assess the potential of other methods with different target groups, but that could also collect insect pollinators. Additionally, it would be important to adapt those trapping methods to collect a broader number of taxa, thus decreasing the cost and increasing the effectiveness of collecting methods.

AUTHOR CONTRIBUTIONS

Filipe Arruda: Conceptualization (lead); data curation (equal); formal analysis (equal); methodology (equal); project administration (lead); writing – original draft (lead); writing – review and editing (equal). **Flávio Camarota**: Conceptualization (equal); methodology (equal); supervision (equal); writing – review and editing (lead). **Rogério Silva**: Conceptualization (equal); funding acquisition (equal); methodology (equal); writing – review and editing (equal). **Thiago Izzo**: Methodology (equal); resources (equal); supervision (equal); writing – review and editing (equal). **Leonardo Bergamini**: Data curation (equal); formal analysis (equal); methodology (equal); writing – review and editing (equal). **Rony Almeida**: Conceptualization (equal); data curation (lead); formal analysis (lead); methodology (equal); writing – review and editing (equal).

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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