



Initial assessment to understand the effect of air temperature on bees as floral visitors in urban orchards

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Abstract

Bees are the most important pollinators and, like many other insects, are facing a global decline that threatens crop pollination services. Both honey bees and some wild bee species are used commercially for pollination, including pollination in blueberry and cherry orchards. In our study, we assessed bee visits to experimental blueberry and cherry orchards immersed in an urban landscape to understand how air-temperature affects the potential contribution of honey bees and wild bees to pollination services. The potential contribution to pollination services was estimated using the Pollination Importance Value index, where the pollen collected by the floral visitor is a determining variable. In our study, bumble bees and honey bees were the most important floral visitors in the orchards, followed by the wild bee *Anthophora plumipes*. We found that honey bees were affected by changes in air-temperature and their decrease in the potential contribution to pollination services was offset by the niche complementarity provided by bumble bees.

Implications for insect conservation Even small changes in air-temperature can alter bee communities by affecting bee species susceptible to low temperatures. Our work is a first assessment of how climate change may affect the complementarity of pollinator communities in orchards. We suggest that strategies to mitigate local air-temperature changes in urban areas, focusing primarily on these species, could potentially have cascading effects that would support the overall pollination services provided by bee communities.

Keywords Blueberry · Sweet cherry · Honey bees · Niche complementarity · Urban landscape · Wild bees

Introduction

Crop pollination is an extremely important ecosystem service in agricultural production (Ziv et al. 2017). Bees are the most important pollinators of both crop and wild plants (Esquivel et al. 2021), and around 12 managed bee species are commonly used for crop pollination (Potts et al. 2016). In Europe, honey bees are used to enhance pollination of many fruit crops, mainly blueberry (*Vaccinium corymbosum* L.) and cherry (*Prunus avium* L.) cultivars (Delaplane and Mayer 2000; Holzschuh et al. 2012; Osterman et al. 2021b), although there is also a demand for some wild bees, such as bumble bees and mason bees species (Garibaldi et al. 2014). In addition, wild bees have been observed to be more efficient pollinators and to maintain constant flower visits compared to honey bees (Garibaldi et al. 2014; Osterman et al. 2021a). This may be due to differences in functional traits that allow for a complementarity or synergy of foraging improving the quantity and quality of pollination (Garibaldi et al. 2014; Brittain et al. 2013).

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Niche complementarity is the capacity of ecosystems to cope with environmental change through differential resource use among species (Tilman et al. 1996; Fargione et al. 2007). In addition, it has been observed that air-temperature affects the foraging behavior of honey bees, which rarely forage when air-temperatures are below 13 °C and above 38 °C (Abou-Shaara 2014; Vicens and Bosch 2000). Temperature has been considered a main driver of bee abundance and community composition in natural and urban areas, with species richness and abundance increasing with temperature increase (Hamblin et al. 2018; Geppert et al. 2022), while extreme climatic events can negatively affect the biology and phenology of species and pollinator communities (Geppert et al. 2022). This suggests that wild bees, such as bumble bees, which can forage at air-temperatures below 13 °C, can provide pollination services in the absence of honey bees, supporting the existence of niche complementarity.

Urbanization is considered a major global driver of biodiversity change, with negative impacts on many pollinator species (Theodorou et al. 2020a), including lower flower visitation rates, reduced species richness, species loss and homogenisation, and changes in pollinator and plant phenology (Hernandez et al. 2009; Harrison and Winfree 2015; Harrison et al. 2019). Furthermore, green heterogeneous spaces within urban areas can maintain taxonomic diversity, greater bee diversity, niche complementarity, higher flower visitation rates, and positively increase pollination services (Theodorou et al. 2016; Baldock et al. 2019; Hamblin et al. 2018; 2020a, b; Fournier and Moretti 2020; Casanelles-Abella et al. 2021). To the best of our knowledge, existing empirical studies on the effect of temperature change on pollinator floral visitation have not yet focused on crops immersed in urban areas. However, some studies have focused on the effect of temperature increases, showing that temperature drives bee diversity regardless of landscape (Geppert et al. 2022). Furthermore, floral and insect phenologies appear to remain synchronized despite increasing temperature; this may be due to the trait diversity of both groups and the positive effect of floral density, which appears to favour bee abundance, especially large bees (Harrison and Winfree 2015; Hamblin et al. 2018; Geppert et al. 2022).

Blueberry is a partially self-incompatible cultivar and depends on pollination by bees (Kendall et al. 2020). Most sweet cherry cultivars are self-incompatible and require cross-pollination (Delaplane and Mayer 2000). In Germany, blueberry is the fourth most produced berry, while the sweet cherry is the third most produced fruit (15,642 tons of blueberry and 27,343 tons of sweet cherry produced in 2021) (DESTATIS 2022). However, the demand for these fruits in Germany is high and a large part of the market is currently covered by imports, mainly from other EU countries (CBI 2022; USDA 2020). In addition to honey bees, wild bees are also frequent visitors to blueberry orchards

(Mallinger et al. 2021) and cherry orchards (Holzschuh et al. 2012), both providing pollination services and increasing fruit production. Bumble bees (*Bombus* spp.) and other wild bees, such as mason bees (*Osmia* spp.) and mining bees (*Andrena* spp.), have been observed foraging in blueberry and cherry orchards and have been shown to be efficient pollinators (Javorek et al. 2002; Isaacs and Kirk 2010; Eeraerts et al. 2020; Miñarro and García 2021). Similarly, *Megachile rotundata* and *Osmia bicornis* are provided to increase pollination services of blueberries and cherries (Scheffield 2008; Ryder et al. 2020). However, a negative effect of increasing *A. mellifera* populations on wild bees has been observed, possibly due to competition for floral resources (Ropars et al. 2019; Herrera 2020; Stevenson et al. 2020; Wignall et al. 2020; Casanelles-Abella and Moretti 2022; MacInnis et al. 2023). Other studies suggest that wild bee species richness is driven by local resource availability rather than beekeeping intensity, observing a partitioning of the foraging niche with increasing wild bee richness (Casanelles-Abella et al. 2023). Therefore, to understand how blueberry and cherry pollination service are provided, it is necessary to identify which pollinator species can contribute significantly to pollination and how the effectiveness of the pollinator is influenced by its environmental conditions in urban areas (Garibaldi et al. 2014).

In the present study, we aimed (a) to identify the pollinator species that may contribute significantly to orchard pollination, (b) to determine the effect of air temperature and the relationship between pollinators on their efficiency measured as pollination importance. We tested the hypothesis that higher air-temperature would favour a greater potential for pollination services by both wild bees and honey bees. To this end, we recorded air-temperature and collected floral visitors in urban blueberry and sweet cherry orchards immersed in an urban landscape, and we estimated the potential contribution to pollination of the most abundant taxonomic bee groups found in each orchard.

Materials and methods

Study area and species

The study was conducted during one spring season (13th March–31 May 2017) in the experimental orchard in Berlin-Dahlem (52.47 °N, 13.30 °E, h = 51 m a.s.l.) (Fig. 1). The blueberry orchard comprises 220 highbush blueberry plants growing in 11 rows of about 20 bushes each. The sweet cherry orchard comprises 80 cherry trees (cultivars Summit, Regina and Karina) planted in 8 rows of 10 trees each. Rapeseed, wheat, maize, peas, potatoes, and aromatic herbs are grown in the surrounding area. The study area is immersed in an urban landscape in the city of Berlin,

Fig. 1 Map of the study area showing the blueberry orchard (letter **A**) and the sweet cherry orchard (letter **B**) in the area marked by the red line. The yellow line marks the boundaries of the experimental station of the Albrecht Daniel Thaer Institut, Dahlem, Berlin Source Google Maps



near remnants of forest and green areas. In the experimental orchard in Berlin-Dahlem, three active *Apis mellifera* hives and four inactive *Osmia bicornis* nest were in our study site. In addition, there are no commercial bumble bee hives in the area.

Bee visits sampling

For each sampling day, three sampling events of blueberry and sweet cherry in bloom (i.e., > 50% of their flowers opened) were made at different observation times, 0900–1100 h, 1200–1400 h, and 1500–1600 h. Records of visits to sweet cherry blossoms were realized in early spring, while records of visits to blueberry blossoms were realized later in the spring when air-temperatures were warmer and favoured more bee activity. The blueberry orchard had an air-temperature from 5.9 to 27.6 °C and precipitation from 0.33 to 15 mm, while for the cherry orchard had an air-temperature was from 3.4 to 13.9 °C and precipitation from 0.033 to 15 mm. In addition, none of the sampled days was rainy or cloudy. Each sampling event consisted of an observation period of 60 min during which a walking transect was conducted throughout the entire orchard and all bees actively foraging on flowers were counted, as described by Westphal et al. (2008) and modified according to Theodorou et al. (2020a). Our sampling sites were not of equal size and our walking transects were of variable length, but standardisation over time is a valid approach for our study. As shown by Theodorou et al. (2020a), variable length transects overcome potential undersampling due to spatiotemporal variation in bee and flora resources and have been shown to be more efficient in terms of sample coverage, bee species

richness and abundance (Westphal et al. 2008). The number and abundance of bees in the field were recorded as morphospecies for *Apis mellifera*, *Anthophora plumipes*, and bumble bees. For these three taxonomic groups (*A. mellifera*, *Bombus* spp., and *A. plumipes*), approximately 10 individuals of each were collected to assess the accuracy of field identification, while for the remaining bees, *Andrena* spp., Halictidae, and Megachilidae and *Xylocopa violacea*, all observed individuals were collected for later identification. All captured individuals were identified to the lowest taxonomic level possible by the principal author, using taxonomic keys, available at the Museum of the Natural History, Berlin. Sampled individuals were compared with specimens from the reference collection of the same museum. As not all bees were retained, multiple counts were possible; therefore, we do not consider abundance, but rather the number of times a species visited a flower (number of visits). A total of 24 sampling events (8 days at three different times) were conducted by a single observer in the blueberry orchard and 15 sampling events (5 days at three different times) in the sweet cherry orchard (Yates et al. 2005; Prendergast et al. 2020). To determine the effect of air-temperature on bees and their preference for pollen collection, the observed bee species were classified into taxonomic groups: “Honey bees”, “*Bombus* spp.”, “*Anthophora plumipes*”, “Andrenidae”, “Halictidae”, “Megachilidae”, and “other Apidae”. In each sampling event, we used sweep nets to capture a maximum of 10 individuals of each of the most abundant species to analyze their pollen collection preferences. Each bee captured on each flower was placed in a separate vial to prevent pollen contamination, and after pollen extraction, specimens were identified to the lowest taxonomic level possible.

Pollen analysis

Pollen was removed from the body of the bee by washing the body twice with absolute ethanol and then the pollen was acetolysed (Erdtman 1969). A drop of the preparation was placed on a microscope slide and covered with a coverslip. Pollen grains were observed with an Olympus CHT CH2 optical microscope at 40X and 100X magnification. For each sample, 200 pollen grains were counted and then analyzed for identification. For pollen identification, we prepared slides of pollen extracted from cherry and blueberry anthers with a dissecting needle, using the same technique as for the collected samples. Pollen grains were photographed in equatorial and polar views, using a Samsung Galaxy J3 (2016) smartphone coupled to the eyepiece of an Olympus CHT CH2 microscope. Since our goal was to identify the proportion of pollen from each specific orchard (blueberry and sweet cherry) present in the collected bees, only the pollen conspecific from which the bee was collected was identified and counted (i.e., for bees collected in blueberry, only blueberry pollen was counted, and the same for sweet cherry).

Effect of air-temperature on bees and pollen preference

Air-temperature measurements were taken from the weather station integrated into the agro-meteorological station at the Berlin-Dahlem experimental orchard. Similarly, the air-temperature data of each sampling event were grouped into three air-temperature ranges: Cherry, Range I (RI): $T < 7$ °C, Range II (RII): $T \geq 7$ to < 10 °C, Range III (RIII): $T \geq 10$ °C. Blueberry, Range I (RI): $T < 10$ °C, Range II (RII): $T \geq 10$ to < 16 °C, Range III (RIII): $T \geq 16$ °C. These classifications were used in the following analysis. Bee composition, diversity, and proportion of pollen carried by bees (preferred pollen) were evaluated for the three most abundant taxonomic groups, *A. mellifera*, *Bombus* spp. and *A. plumipes*. The effect of the air-temperature between taxonomic groups and between orchards was determined using the Wilcoxon test (paired samples). We use the Wilcoxon test due to the lack of normal distribution for these data sets. Mean, standard deviation, and Wilcoxon Test were calculated with the Package Past 4.03 (Hammer et al. 2001).

Estimates of the importance of the floral visitor

To estimate the importance of the floral visitors, we use the Pollination Importance Value index “PIV” used by Escaravage and Wagner (2004), which is an index that includes the amount of pollen carried by the floral visitor to calculate the contribution to pollination. The amount of pollen carried by the bees after and before visiting a flower is considered

by several authors to be a crucial factor in estimating the importance of the pollinator (Escaravage and Wagner 2004; Sihag 2018), which is the reason why this index was chosen in this study. The PIV (Escaravage and Wagner 2004) for the three most frequent taxonomic groups of bees was calculated according to the following formula: $PIV = VR \times PCC \times C \times PE$, where here VR = visit rate of each taxonomic group during the total observation time (%), PCC = pollen carrying capacity, expressed as the proportion of pollen found to be carried by each taxonomic group divided by the maximum value of all floral visitors, C = average proportion (%) of pollen in the body of the bee, PE = number of individuals observed per minute by taxonomic group (based on observation time). In addition, to test which taxonomic groups were significantly affected by air-temperature, we used a linear model with a Gaussian error structure in which each of the taxonomic groups of bees was the dependent variable and air-temperature was the independent variable. Since the time of the day and temperature were correlated ($r^2 = 0.79$, $P = < 0.01$) and presented moderated level of collinearity (Blueberry VIF = 2.08, VIF cherry = 2.73), we tested air-temperature and time of the day in separated models as explanatory variables. Finally, the assumptions of the model (GLMs) (normality, linearity, and homogeneity of variances) were visually verified by examining the QQ Plot, the scale-location plot, and the spread-location plot respectively. The analyses were performed in R studio v.4.1.3 “One Push-Up” (R Development Core Team 20 increasing pollinator services).

Results and discussion

Floral visitor’s species in orchards

We identified 20 different bee species visiting blueberry flowers and 19 bee species visiting sweet cherry flowers in our study site (Table 1). We recorded a total of 5097 visits to blueberry flowers and 340 visits to sweet cherry flowers during the sampling period from mid-March to the end of May. The most frequent visiting bees per hour in blueberry were honey bees (mean visits 156 ± 227.14 SD), followed by *Bombus terrestris* (mean visits 17.7 ± 17.02 SD) and *A. plumipes* (mean visits 8.8 ± 9.39 SD). In sweet cherry, honey bees were also the most frequent visitors (mean visits 6.73 ± 10.19 SD), followed by *B. terrestris* (mean visit 4.87 ± 3.98 SD) and *A. plumipes* (mean visits 2.07 ± 1.62 SD). For both orchards, we observed that flower visitor richness increased with increasing temperature, which is consistent with observations of richer diverse communities at warmer temperatures (Geppert et al. 2022). Contrary to our findings in blueberry, other studies in Poland and Australia showed lower diversity and number of visits for blueberry

Table 1 Bee community observed in blueberry and sweet cherry orchards. Number of bee visits and percentage of bee visits (%) are listed

Bee species	Blueberry		Sweet cherry	
	Number of visits	Number of visits %	Number of visits	Number of visits %
<i>Andrena bicolor</i>	1	0.02	2	0.59
<i>Andrena bimaculata</i>	0	0	1	0.29
<i>Andrena blüthgeni aff.</i>	0	0	1	0.29
<i>Andrena fulva aff.</i>	0	0	30	8.83
<i>Andrena gravida</i>	7	0.14	9	2.65
<i>Andrena hypopolia</i>	0	0	6	1.76
<i>Andrena sp. 1</i>	0	0	1	0.29
<i>Andrena sp. 2</i>	0	0	1	0.29
<i>Andrena sp. 3</i>	0	0	1	0.29
<i>Andrena varians</i>	0	0	2	0.59
<i>Andrenidae sp.</i>	9	0.18	8	2.36
<i>Anthophora plumipes</i>	234	4.6	31	9.12
<i>Apis mellifera</i>	3884	76.43	101	29.71
<i>Bombus hyponorum</i>	71	1.4	0	0
<i>Bombus lapidarius</i>	185	3.64	55	16.18
<i>Bombus pascuorum</i>	48	0.94	12	3.53
<i>Bombus pratorum</i>	85	1.67	0	0
<i>Bombus rupestris</i>	1	0.02	0	0
<i>Bombus terrestris</i>	443	8.72	73	21.47
<i>Bombus vestalis</i>	1	0.02	1	0.29
<i>Halictidae sp.</i>	59	1.16	0	0
<i>Lasioglossum sp. 1</i>	3	0.06	0	0
<i>Lasioglossum sp. 2</i>	2	0.04	0	0
<i>Lasioglossum sp. 3</i>	0	0	1	0.29
<i>Lasioglossum sp.</i>	1	0.02	0	0
<i>Megachilidae sp.</i>	24	0.47	0	0
<i>Osmia bicornis</i>	21	0.41	0	0
<i>Osmia cornuta</i>	2	0.04	4	1.18
<i>Xylocopa violacea</i>	1	0.02	0	0
Total	5082	100	340	100

Total amount of individuals per genus in Blueberry: *Andrena* 7, *Anthophora* 234, *Apis* 3884, *Bombus* 834, *Lasioglossum* 6, *Osmia* 23, *Xylocopa* 1.

Total amount of individuals per genus in Sweet Cherry: *Andrena* 54, *Anthophora* 31, *Apis* 101, *Bombus* 141, *Lasioglossum* 1, *Osmia* 4.

flowers (Kendall et al. 2022; Božek 2021). Other studies analyzing floral visitors in cherry in Germany (Holzschuh et al. 2012) and the United Kingdom (Mateos-Fierro et al. 2022) reported a higher diversity of floral visitors, while similar values of floral visitor diversity as in our study were found in blueberry cultivars in Spain (Miñarro and García 2021). In addition, studies analyzing the diversity of floral visitors in urban areas in the study region have found higher

Table 2 Linear model showing the effect of air-temperature on the number of visits of different bee species, corresponding to the main taxonomic groups (*A. mellifera*, *Bombus* spp., and *A. plumipes*) for blueberry and sweet cherry orchards. Non-significant values ($P > 0.05$) are not shown

Ochard	Estimate	Std. Error	r ²	t value	Pr (> t)
Blueberry					
<i>Apis mellifera</i>	32.46	5.67	0.78	5.73	<0.01***
<i>Bombus</i> spp.	0.45	0.13	0.50	3.46	<0.01**
Sweet cherry					
<i>Apis mellifera</i>	2.53	0.67	0.72	3.76	<0.00**

* $p < 0.05$, ** $p < 0.01$; *** $p < 0.001$

bee diversity (Casanelles-Abella et al. 2021; Hermann et al. 2023; Theodorou et al. 2020b).

Determination of the effect of air temperature and time of day on floral visitors

Time of day was not significant for any taxonomic group or orchard ($P > 0.05$; data not shown). Regarding the effect of air-temperature on bee diversity in the whole sampling area, we observed that the frequency of visits of *A. mellifera*, *Bombus* spp., and *A. plumipes* did not differ between the three air-temperature ranges for both orchards (Kruskal wallis $H_c = 1.09$, $P = 0.58$) and between the two orchards ($H_c = 2.06$, $P = 0.36$). This is in contrast to observations in other studies in northern Spain, where honey bees showed significantly different foraging behaviour in apple orchards at different temperature ranges (Vinces and Bosch 2000). No significant difference was found for the three air-temperature ranges in the number of bee visits to sweet cherry (Kruskal Wallis = 0.29, $P = 0.86$). Conversely, blueberry was found to have a significant difference in the number of bee visits between air-temperature ranges (Wilcoxon test = 19, $P = 0.04$). These differences can be explained by the low number of visits of *A. mellifera* when the air-temperature was between 10 and 16 °C. This suggests that the absence of *A. mellifera* when air-temperature is lower may be compensated by changes in the number of bee visits of other species. Furthermore, *A. mellifera* rarely forages below 13 °C and above 38 °C due to metabolic conditions (Free 1993; Abou-Shaara 2014).

Regarding which taxonomic groups were affected by air-temperature (Table 2), we observed that *A. mellifera* was negatively affected in both blueberry and sweet cherry orchards. *Bombus* spp. were positively and significantly affected, but only in blueberry, while the other bee species did not show a significant effect of air-temperature on their number of visits ($P > 0.05$; data not shown). This suggests that even small changes in early spring temperature could affect the bee community, mainly affecting the number of

visits and abundance of species susceptible to low temperatures, such as honey bees. However, this change in the number of visits and importance of bees does not seem to affect the presence of potential pollinators in our study, as there may be a compensatory mechanism between species mediated by environmental conditions, implying that small changes in temperature do not cause a separation between plant and pollinator phenologies, as observed in other urban habitats (Harrison and Winfree 2015).

Our results are consistent with literature showing that the activity of other species, such as *Bombus* spp., *Anthophora* spp., and *Osmia* spp., early-season flying bees, which can maintain activity at temperatures below 12 °C, can compensate for the absence of *A. mellifera* (Vinces and Bosch 2000; Güler and Dikmen 2013). Correspondingly, Clarke and Robert (2018) observed that 78% of the variation in bee activity was explained by daily and hourly variations in temperature and solar radiation, supporting that the observed differences between air-temperature ranges in our study were mainly due to changes of temperature. In addition, increasing temperature and decreasing humidity favour the proportion of dehiscent anthers (Corbet 1990; Zhang et al. 2019), which increases pollen availability while increasing bee foraging activity (Fig. 2).

Evaluation of the effect of the temperature on floral visitor importance

The importance of bumble bees in the blueberry orchard decreased as air-temperature increased, although they remained the most abundant taxonomic group of bees. In cherries, bumble bees were estimated to far exceed the “pollination importance value” of *A. mellifera* when air-temperature was below 7 °C and to double the PIV when air-temperature was below 10 °C, but with increasing air-temperature, the “pollination importance value” of bumble bees was far surpassed by *A. mellifera* (Table 2). This suggests the existence of temporal niche complementarity, which allows the compensation of pollination service by *Bombus* species when *A. mellifera* is not present at low air-temperatures. In addition, native biodiversity has been shown to be important in mitigating the effects of climate change on pollination, where in the absence of *A. mellifera* due to its sensitivity to extreme temperatures, wild pollinators, which are not significantly affected by air-temperature in our study, can take its place and provide the pollination service (Rader et al. 2013). Furthermore, increasing temperature could disrupt complementarity by affecting the abundance of wild bees (Kammerer et al. 2021) or the presence of temperature-sensitive wild bees, such as *Bombus* spp., which could even disappear (Guiraud et al. 2021). This suggests that climate change poses a significant threat to wild bee communities and the pollination services they provide.

In our study, *A. mellifera* was found to be less efficient at pollen collection (PCC) and pollination service (PIV; Table 3) in the blueberry orchard, even when present in large numbers, compared to wild bees. Blueberry flowers are small and have urceolate corollas that make access difficult for larger bees; they also have dehiscent poricidal anthers that require buzz pollination, which *A. mellifera* cannot provide (revised in Javorek et al. 2002). The low number of pollen grains found on the bodies of *A. mellifera* in our study is consistent with the findings of low honey bee foraging and pollen storage in highbush blueberries by Dogterom and Winston (1999) and Hoffman et al. (2018), suggesting that pollination services by honey bees are limited in this crop. The PIV is strongly influenced by species abundance, but also by the amount of pollen found on bees (Escaravage and Wagner 2004). However, due this index takes into account the amount of pollen collected, it has the strength to provide more accurate estimates of pollinator efficiency and importance (Sihag 2018).

A caveat of our study is that we analysed orchards immersed in an urban area, which have been observed to be beneficial to pollinators by providing a diversity of floral resources and more stable temperatures compared to forested or agricultural areas (Theodorou et al. 2020a). However, due to sampling from only one site, any variability in temperature gradient and urban intensity and other possible interacting factors may not have been observed. It is expected that in agricultural and natural areas the effect of air-temperature may be even stronger than what we have observed in urban orchards. In agricultural areas, as suggested by Geppert et al. (2022), a possible homogenization of bee communities may occur through selection for adaptive traits in the face of extreme climatic and environmental conditions, but this was beyond the scope of our study and we recommend that future studies integrate both agricultural and natural areas to better assess the effect of temperature change on bee diversity. This first approach to understanding the effect of air-temperature on bees as flower visitors in urban orchards showed that changes in spring air-temperature affect the bee community, primarily social and common bees, and that changes in community composition are compensated by the temporal niche complementarity. However, the extent to which temperature changes can be buffered by complementarity remains to be determined and further studies are needed. In addition, the study highlights the importance of environmental conditions, such as temperature, for pollinator communities, their phenological response and pollination services, and how future climate change may affect the composition of bee communities, their interaction network and their potential as pollinators.

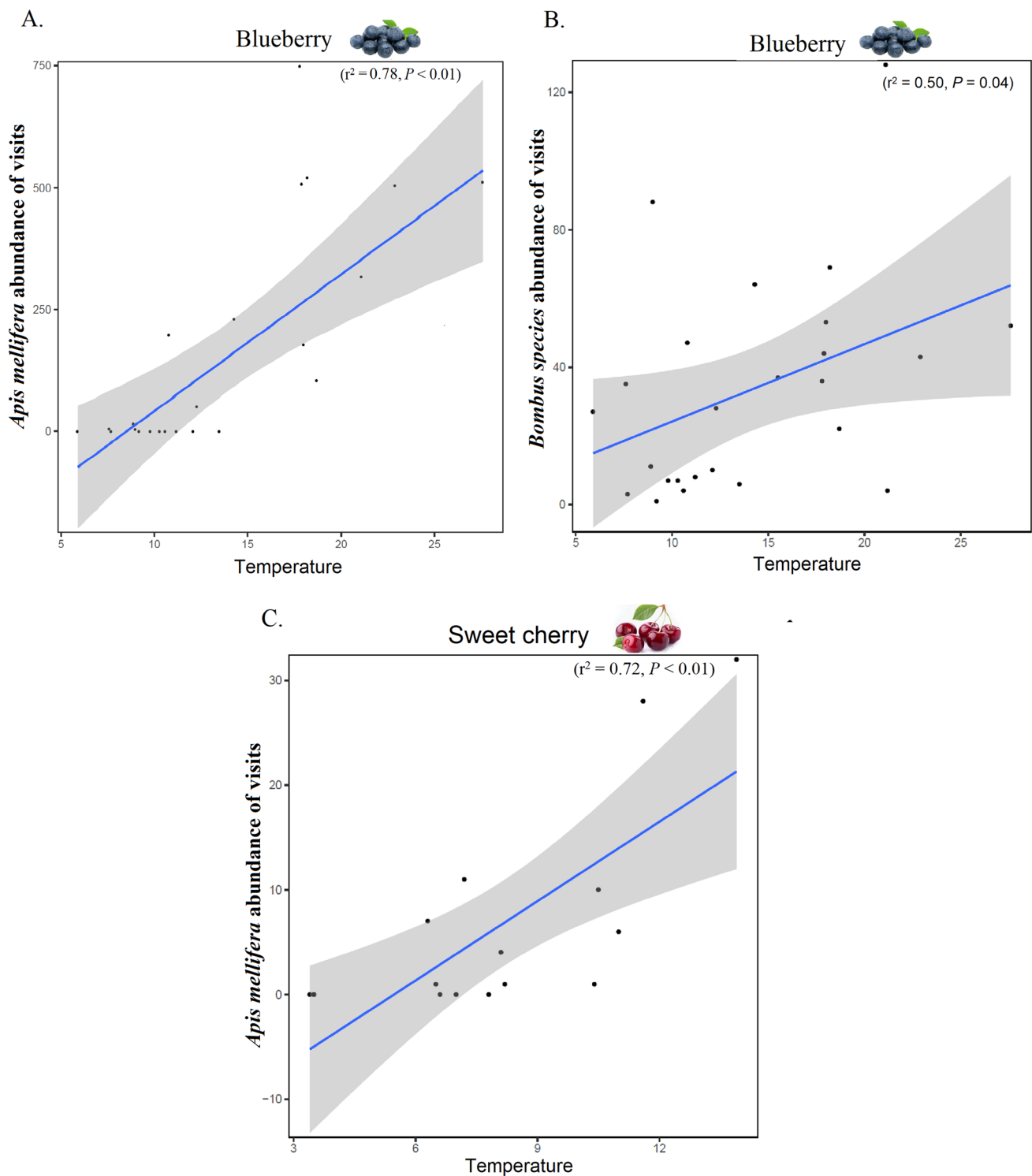


Fig. 2 Relationships between the number of visits of the taxonomic groups of bees and the temperature were calculated with general linear models (GLMs). **A** *A. mellifera* number of visits in blueberry in relation to temperature. **B** *Bombus* species number of visits in blue-

berry in relation to temperature. **C** *A. mellifera* number of visits in sweet cherry in relation to temperature. Plotted lines indicate predicted relationships and the shaded areas indicate 95% confidence intervals

Table 3 Importance of honey bees, *Bombus* spp., and *A. plumipes*, main taxonomic groups of bees for blueberry and sweet cherry orchards, in air-temperature ranges

Taxonomic group		Range I					Range II					Range III				
		VR	PCC	C	PE	PIV	VR	PCC	C	PE	PIV	VR	PCC	C	PE	PIV
Blueberry	Honey bees	0.1	0	0	0.06	0.000	0.54	0	0	0.89	0.000	0.85	0	0	6.29	0.000
	<i>Bombus</i> spp.	0.74	0.53	53.2	0.41	8.547	0.24	0.46	46.1	0.39	1.985	0.11	0.43	43.3	0.84	1.720
	<i>A. plumipes</i>	0.12	0.5	0.5	0.07	0.002	0.17	0.3	30	0.28	0.428	0.11	0.38	37.5	0.07	0.110
Sweet cherry	Honey bees	0.1	0.91	53	0.03	0.145	0.21	0.91	87	0.05	0.811	0.42	0.82	78	0.26	6.984
	<i>Bombus</i> spp.	0.78	0.62	36	0.2	3.482	0.45	0.2	19	0.12	0.205	0.24	0.31	29.5	0.15	0.329
	<i>A. plumipes</i>	0.08	0.11	6.5	0.02	0.001	0.14	0.11	10.5	0.04	0.001	0.08	0	0	0.05	0.000

VR visitation rate of each taxonomic group (%); PCC Pollen carrying capacity expressed as proportion of pollen carried by each taxonomic group of the maximum value found by all floral visitors; C average proportion of pollen in the body of the bee (%); PE number of individuals observed per minute by taxonomic group; PIV Pollination Importance Value

Range Temperatures:

Sweet Cherry, Range I: T <7 °C, Range II: T ≥7 to <10 °C, Range III: T ≥ 10 °C

Blueberry, Range I: T <10 °C, Range II: T ≥10 to <16 °C, Range III: T ≥16 °C

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Data availability The authors confirm that the data supporting the results of this study are available in the article and its supplementary materials.

Declarations

Conflict of interest There exist no potential conflicts of interest.

Ethical approval The sampling of bees was carried out according to the “Code of Honor for Entomological Fieldwork” of the Federal Expert Committee (BFA) Entomology of NABU- Naturschutzbund Deutschland e.V..

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