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Pollinators communities differ across years and crops

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Abstract: Insect pollination is one of the most important ecosystem services. Pollinator communities are rarely studied across years and crops in the same location. The aim of this study was to investigate the pollinator community structure on five different fruit crops, as well as the activity of different pollinator groups during the day and their temperature preferences. Pollinator activity was observed across two years on apple trees and blueberry, strawberry, blackcurrant and raspberry bushes. Pollinator community structure varied by plant and year. Honeybees were the most numerous pollinators on all plants except blueberry bushes (39–95% of visits). Bumblebee numbers were high on blackcurrant (up to 28%) and blueberry bushes (up to 61%). Solitary bees visited all plants except blueberries. Honeybees, solitary bees, and hoverflies were most active in the middle of the day, while bumblebees became active earlier in the morning and remained active later in the evening. Pollinators also differed greatly in their temperature preferences. This knowledge gained is necessary for less harmful pesticide application management and the development of more sustainable agriculture to maintain pollinator diversity and thus reliable pollination in extreme weather conditions.

Keywords: fruit pollination; agroecology; biodiversity; wild bees; conservation

Insect pollination is one of the most important ecosystem services, essential for both ecosystem functioning and agricultural production (Klein et al. 2007, Ollerton et al. 2011). The net value of insect pollination is estimated at around 10% of the total value of agricultural production. This corresponds to EUR 153 billion per year at the global level (Gallai et al. 2009). In Europe, it is about EUR 22 billion per year (Potts et al. 2015). Pollination services can be provided by honeybees and/or a variety of oftenly overlooked wild pollinators. Wild bees, as well as flies, butterflies, some beetles, and wasps, are among the most important wild pollinators (Garibaldi et al. 2013, Potts et al. 2016, Rader et al. 2016).

Due to human-induced environmental changes, wild pollinator populations are in decline (Biesmeijer et al. 2006). Globally, about 25% fewer bee species were found between 2006 and 2015 than before 1990 (Zattara and Aizen 2021). Both honeybee and wild pollinators are threatened by land-use change, pesticides, disease, invasive alien species (Nieto et al. 2014, Potts et al. 2016) and climate change (Rasmont et al. 2015).

Wild pollinators are, in many cases, even more efficient than honeybees (Garibaldi et al. 2013). Bumblebees, for example, are active even in cold, windy, and rainy conditions, visit more flowers per unit of time, and are able to shake flower anthers to obtain pollen (known as buzz pollination) that honeybees cannot perform (Goulson 2010). Reliable pollination is therefore closely intertwined with pollinator diversity (Hoehn et al. 2008, Winfree et al. 2008, Garibaldi et al. 2011, 2013, Martins et al. 2015, Mallinger and Gratton 2015). More diverse pollinator communities are more stable across years (Senapathi et al. 2021).

Wild pollinators also have different daily activities compared to honeybees, which is not adequately considered in pesticide risk assessments. Some wild pollinators are active at different times of the day

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(Corbet et al. 1993, Willmer et al. 1994, Vicens and Bosch 2000, Fründ et al. 2013).

The first objective of this research was to study the pollinator community structure on five different fruit crops at the same site in two consecutive years. The second objective was to study the activity of different pollinator groups during the day and their temperature preferences. Most previous research focuses on a limited number of pollinator species or one crop. Our research includes all flower visitors and five crops, bringing a more complex view. The knowledge gained is necessary for better crop protection management and the development of more sustainable agriculture to maintain pollinator diversity. These measures will ensure reliable pollination in increasingly extreme weather conditions.

MATERIAL AND METHODS

In 2016–2018, the activity of honeybees, bumblebees, other wild bees (solitary bees) and hoverflies in the orchard was monitored.

Description of location. The study was conducted in the experimental orchard of the Agricultural Institute of Slovenia in Brdo pri Lukovici (central Slovenia, 46°10'2.46''N, 14°40'48.61''E). It covers 16.8 ha, of which 14.9 ha are apple plantations. The rest are pear (0.5 ha), cherry, plum (both 0.3 ha), raspberry, blueberry, strawberry and blackcurrant (all 0.2 ha). In the orchard, itself is an apiary with 10 honeybee colonies. However, within a 1 km radius, there were 115 additional colonies, and within a 3 km radius, there were 481 colonies at the time of observations. A weather station in the orchard allowed us to monitor air temperature and other weather parameters (precipitation, relative humidity, solar radiation, wind). Most of the orchard is integrated, while the smaller portion of the apple tree planting is organic. All observations except on the apple tree were made in the integrated part. The orchard was managed according to orchard practices, including the use of pesticides.

Monitoring of pollinator visitation. Pollinator activity was observed across two consecutive years on apple trees and blueberry, strawberry, blackcurrant (2017 and 2018) and raspberry (2016 and 2017) bushes. The number of pollinators was determined by counting them either 7 or 10 h from morning to evening (Table 1). Each year, for each crop, pollinator activity was observed in intervals of three to ten days regardless of weather conditions (Figure 1).

Pollinators were counted at four sampling sites for each target plant. The size of the sampling site was adjusted to the number of flowers and pollinators so that it was possible to count all pollinators in about one minute. In the apple orchard, one sampling site consisted of five trees, for blueberry and blackcurrants; it was three bushes, five meters of row for raspberries and 20 m of row for strawberries. Ten counts per hour were made at each sampling site (i.e., 280 and 400 counts per plant species per day, respectively).

We counted honeybees, bumblebees, other wild bees (solitary bees), and hoverflies. Only bumblebees were identified to species. *Bombus terrestris* L. and *B. lucorum* L. were counted together. For practical

Table 1. Schedule of monitoring of activity of pollinators on sampling sites

	Apple trees (10 + 9 days), blueberries (5 + 5 days), strawberries (5 + 3 days), blackcurrants (5 + 5 days)	Raspberries (8 + 7 days)
5:00–6:00	–	+
6:00–7:00	–	+
7:00–8:00	+	+
9:00–10:00	+	+
11:00–12:00	+	+
13:00–14:00	+	+
15:00–16:00	+	+
17:00–18:00	+	+
18:00–19:00	–	+
19:00–20:00	+	+
Number of counts per day	280	400

In parentheses is the number of observation days for years 1 and 2

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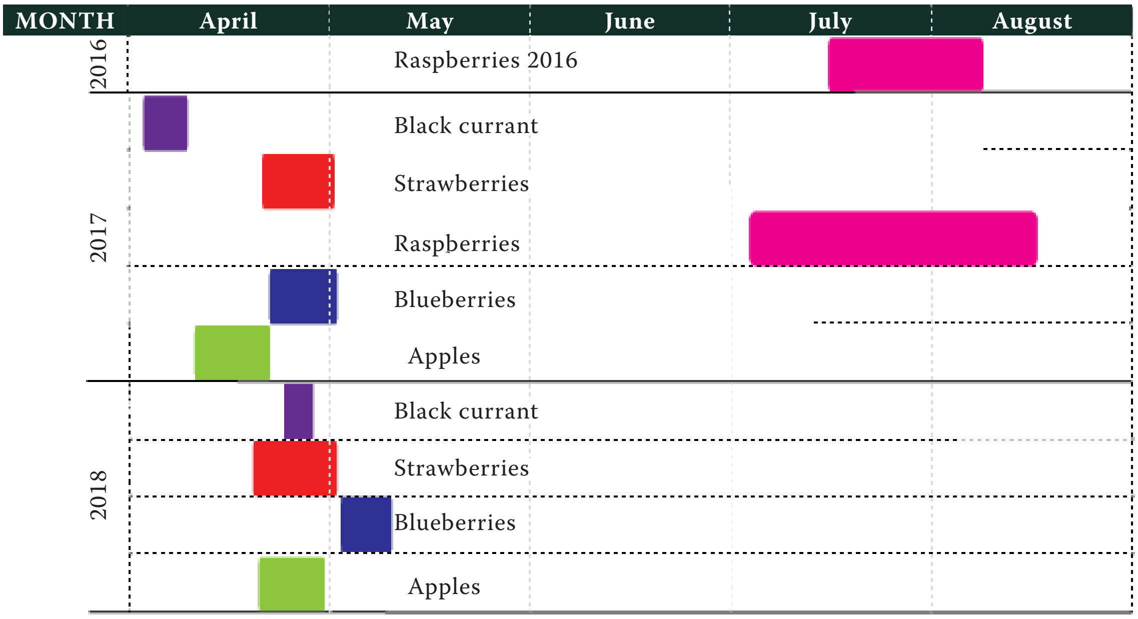

Figure 1. Observation intervals for each plant/crop in years 2016, 2017 and 2018. Bloom of raspberry did not overlap with any other crop, blueberries and strawberries overlapped in 2017; in 2018, the bloom of black currant overlapped with strawberries and apples

reasons, we call other wild bees solitary bees, but some of them can be eusocial or facultative eusocial.

Analysis. For each observation day, pollinator counts were summed, and the ratio between pollinator groups was calculated and displayed. Basic descriptive statistics were acquired for the duration of observation. Pollinator counts acquired at designated hour intervals were averaged between days, and the percentage of visitation per pollinator per interval was plotted for each year. For pollinators activity temperature's dependence, the temperature was binarised (bin width 1 °C), and pollinator counts were averaged for that bin for each pollinator group and crop and year separately. Basic descriptive statistic was computed, and data displayed graphically.

RESULTS AND DISCUSSION

In 62 observation days together, 77 920 pollinators were counted. The most numerous pollinators were honeybees (65 665), solitary bees (4 804), bumblebees (4 179) and hoverflies (3 272). Within the orchard, 10 species of bumblebee were found (listed by frequency from the most to the least frequent: *Bombus terrestris* and *B. lucorum*, *B. lapidarius*, *B. pratorum*, *B. pascuorum*, *B. sylvarum*, *B. haematurus*, *B. hypnorum*, *B. argillaceus* and *B. humilis*).

Pollinator community structure. Pollinator community structure varied among plants and years (Figure 2, Table 2). By far, the most numerous pollinators on all plants were honeybees. Except for

Table 2. Table of percentages of visits (%) for every pollinator group and every fruit in the study

Year	Pollinator	Apple	Blueberry	Strawberry	Blackcurrant	Raspberry
1	honeybees	80	39	94	65	91
	bumblebees	2	61	0	28	3
	solitary bees	4	0	1	0	6
	hoverflies	14	0	5	7	0
2	honeybees	95	84	83	92	80
	bumblebees	1	16	0	7	2
	solitary bees	2	0	15	1	18
	hoverflies	2	0	2	0	0

Year 1 – 2017; Year 2 – 2018, with the exception of raspberry where year 1 is 2016 and year 2 is 2017

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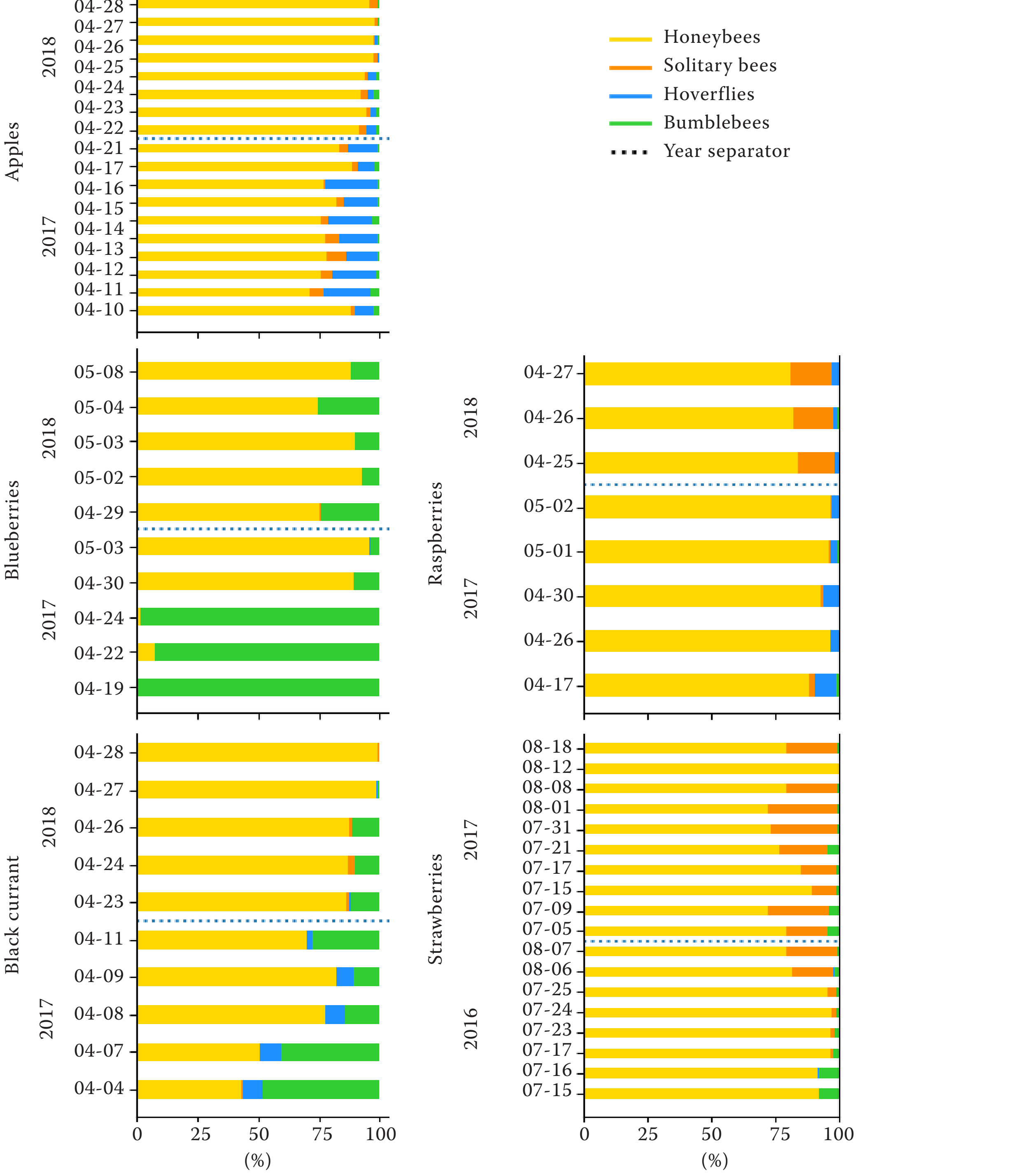

Figure 2. Daily pollinator ratios for each crop

blueberry bushes in 2017 (containing only 39 ± 17% honeybees), they accounted for at least two-thirds of all visits (Table 2). Honeybees made up the largest proportion on strawberries in 2017 (94 ± 4%) and apples in 2018 (95 ± 2%).

Bumblebees were observed on all plants except strawberries. Their numbers were high on blackcurrant and blueberry bushes, accounting for up to 61% and 24% of visits in 2017. On some days, they were the far the most numerous pollinators present on these plants. Solitary bees visited all plants except blueberries. They were numerous on raspberries and strawberries, but only in the second year (18 ± 8% and 15 ± 1%). Hoverflies visited apples, strawberries, and blackcurrants. They were never relatively numerous except on apples, but only in the first year when they reached 14 ± 5% of visits.

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Because of many hives in the vicinity, a large number of honeybees were expected. Nevertheless, the proportion of wild pollinators was high. These results only represent the ratio between different groups of pollinators, which unlikely corresponds to the exact ratio of pollination carried out by these groups. Considering that bumblebees are faster and, along with solitary bees, often deposit more pollen on flower stigmas (Thorp 2000, Thomson and Goodell 2001, Park et al. 2016), the importance of wild pollinators is much greater than could be concluded based only on their relative abundance.

Across all plants, pollinator communities differed between the two successive years. We assume that these differences are due to factors such as population fluctuations and weather differences, as well as the availability of alternative food sources (Bänsch et al. 2020, Osterman et al. 2021). In the second observation year (2018), plants began to flower around two weeks later. At the time of flowering, it was much warmer, with daily maximum temperatures in spring around 25 °C, while in the first year, they were mostly around 15 °C (Figure 3). Due to the higher temperatures, the flowering period was shorter. Similarly, the second summer was also warmer. All this demonstrates the highly dynamic nature of pollinator communities and the importance of pollinator diversity in agricultural systems to reduce the risk of pollinator-crop mismatches due to climatic variation.

The activity of different pollinator groups during the day. Pollinators had different patterns of day activity, which likely depends on the pollinator as well as on crop properties, time of the year and weather conditions (Figure 3). In apple orchards and black currant plantations, we have recorded bumblebee activity already at the first observation interval, that is in the 7:00–8:00 interval, while in both crops, other pollinators were recorded on average only in the second interval, 9:00–10:00. Not so in other crops: in raspberries, bumblebee activity seems to match the honeybee, recorded in the 6:00–7:00 interval; similarly, in blueberries, the 2017 observation returned 0 for both honeybees and bumblebees at 7:00–8:00 and around 5% of daily counted bumblebees in the same interval in 2018.

Bumblebees became active earlier in the morning and remained active until later in the evening. Unlike other pollinators, there were different patterns of activity. The first pattern was a peak in activity in the morning and/or evening (apple and raspberry 2017, blueberry and blackcurrant 2018), the second was a relatively steady activity throughout the whole day (raspberry 2016, blackcurrant 2017, apple tree 2018), and the third was a peak in activity in the middle of the day (blueberry 2017). These results are not entirely consistent with the prevailing view that bumblebees are predominately active in the morning and evening. This suggests greater complexity in bumblebee activity. We assume that their activity depends on the weather. Unlike other pollinators, they avoid high temperatures. Peak activity in the morning and/or evening was associated with warmer temperatures and peak activity in the middle of the day with cooler temperatures.

Given the curves in apples, blackcurrant, and blueberry 2018, we potentially missed the first bumblebees in the morning and the last in the evening. To get a better insight into bumblebee activity, we should start observations earlier and finish later within further research.

The activity of bumblebees should be taken more thoroughly into account when applying pesticides. Because bumblebees become active earlier in the morning, they are potentially more exposed to pesticides or their residues if sprayed too late in the morning. Spraying in the early evening imposes a similar risk. Since queens forage in early spring, bumblebees are particularly at risk during this time, as poisoning, the queen means the demise of the entire colony (Thompson 2001). In our investigations in spring, almost exclusively, the queens were recorded foraging.

Temperature and pollinator activity. The blooming periods in which observations were made differed in temperatures (Figure 3).

Pollinators' dependence on temperature varies widely (Figure 4), yet the common denominator seems to be the shape of the activity, having in most cases single spike but generally retained similar shape between observation years with some exceptions, like bumblebees and raspberries. Depending on crops, pollinators were active through the wide span of temperatures: for example, honeybees were active from 9 (apple 2017) to 35 °C (the highest recorded temperature in the research, raspberry 2017), with the highest recorded number at 28 °C on raspberry in 2017 (137.0 ± 45.2). Solitary bees preferred even higher temperatures and were active from 9 °C to 35 °C, with a peak at 33 °C, again on raspberry 2017 with 58.8 ± 6.1 recorded individuals. Bumblebees had the widest range. They were active from 3 (apple 2017, the lowest recorded temperature in the research) to 35 °C and in blueberries, for example, had a peak at 8 (14.1 ± 5.7; 2017) and

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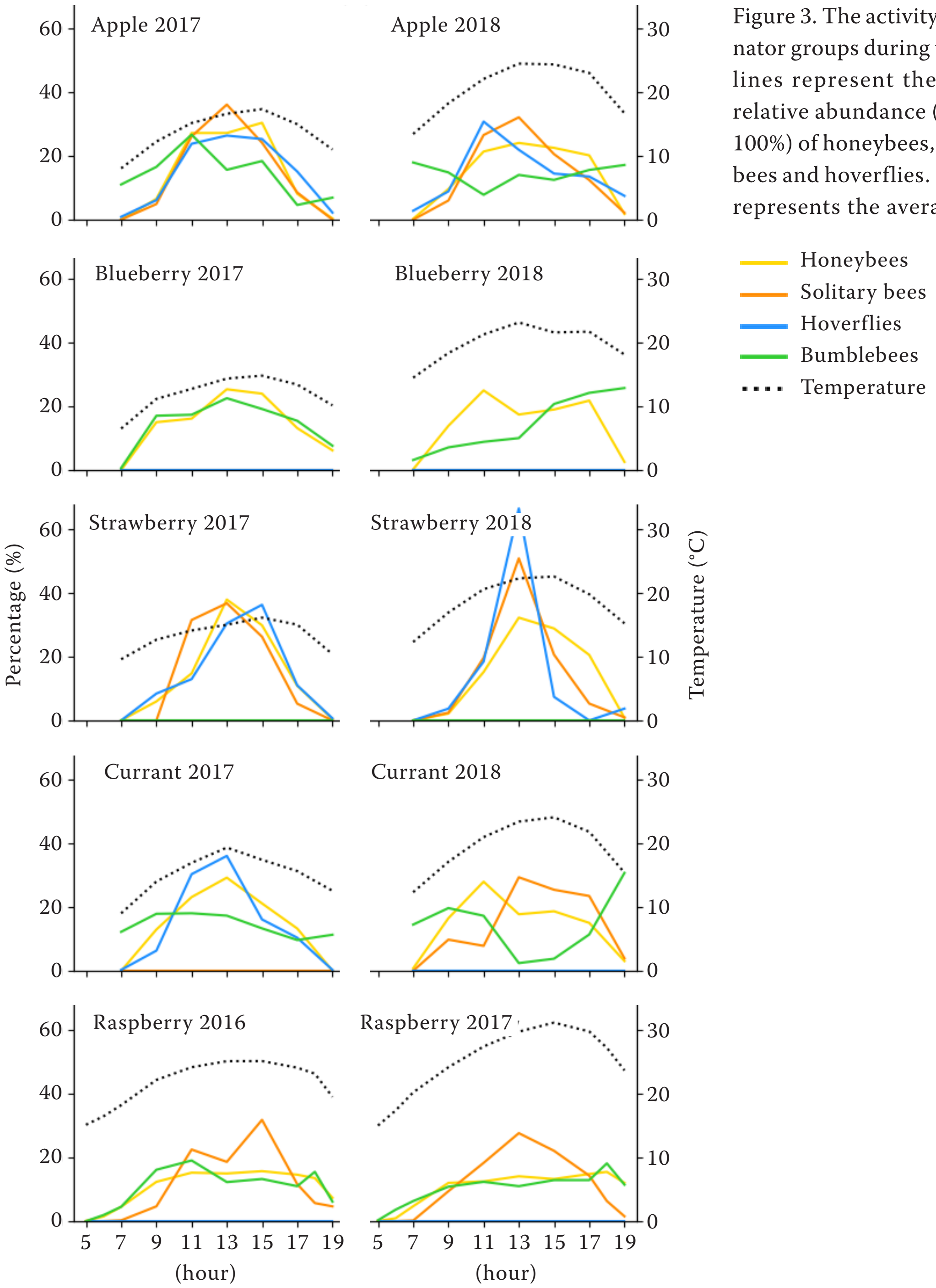

Figure 3. The activity of the different pollinator groups during the day. The coloured lines represent the distribution of the relative abundance (whole day activity is 100%) of honeybees, bumblebees, solitary bees and hoverflies. The black dotted line represents the average temperature

20 °C (10.2 ± 7.2; 2018). Hoverflies were active from 5 °C to 30 °C with a peak at 15 °C on apples in 2017.

Differences in temperature preferences are probably one of the main factors behind the different patterns in diurnal activity. Among other differences between pollinator types, such as pollination efficiency and ability of buzz pollination, they play an important role in providing reliable pollination under extreme weather conditions. As the weather becomes more unpredictable in times of climate change, pollinator diversity will become even more important in the future. Ensuring sufficiently large populations of both honeybees and wild pollinators will therefore be crucial.

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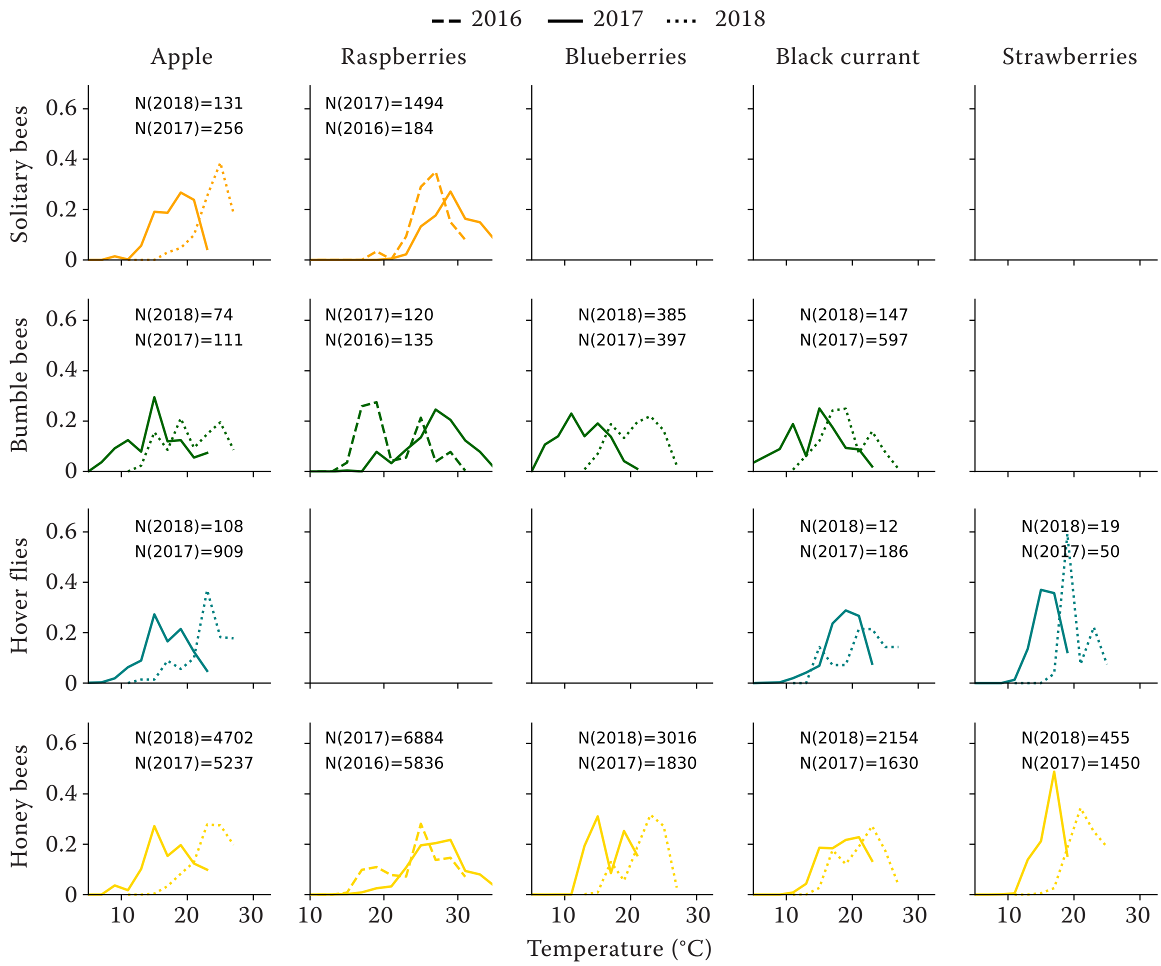

Figure 4. Average temperature preferences of pollinators for each year of observation. Counts are averaged and normalised to allow direct comparison between pollinators' daily activity for each plant/crop

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