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Original article

Why do queen bumblebees emerge from hibernation during weekends?

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Abstract – Climate-driven shifts in bumblebee emergence and flowering time can disrupt plant reproduction and affect pollinator health. To study such mismatches, accurate phenological data is crucial but challenging to collect, especially for pollinator hibernation emergence. Citizen science is increasingly being used to expand the spatial and temporal scope of data collection in research. Nevertheless, these data can be biased due to different reasons. We found that 33.14% of records in Europe and 32.47% in North America were gathered on weekends – exceeding what would be expected by random chance and showing opposite patterns to bumblebee museum specimen records. Bias also affected queen emergence date and varied by species, suggesting that species-specific traits may mediate the bias extent. We also present a case study showing how adjusting for day-of-the-week effects can change the statistical significance of temporal trends in bumblebee emergence dates. We thus recommend including the day of the week in statistical models to account for temporal biases. Our findings highlight the importance of correcting temporal biases in citizen science data to ensure accurate evaluations of ecological responses to climate change.

citizen science / climate change / global warming / phenology / temporal bias

1. INTRODUCTION

In response to the increase in global temperatures caused by climate change, winter emergence of certain bumblebees in North America has advanced by approximately 10 days in the past 130 years (Bartomeus et al. 2011), and by 5 days over the last 20 years in European regions like Sweden (Blasi et al. 2023). Additionally, warmer springs have caused flowering times to advance by an average of 2.4 days per degree Celsius of warming in north-central North America (Calinger et al. 2013) and by 3.6 days per degree Celsius in Europe (Willems et al. 2022). Despite both pollinators and plants adjusting their emergence and flowering times to warmer temperatures, phenological mismatch can take place when these responses occur at different intensities or are not sufficiently synchronized. For instance, if a plant species blooms earlier than usual due to warmer temperatures but its pollinators do not adjust their timing accordingly, the plant may experience reduced pollination (Kudo and Cooper 2019). This phenological mismatch can interfere with the coexistence of interacting species, compromising their biotic relationships and survival, ultimately affecting the fitness of both plants and pollinators. For

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example, near the Rocky Mountain Biological Laboratory in Colorado, USA, the reduced synchrony between flowers and bumblebees has apparently resulted in a reduction of bumblebee abundance (Pyke et al. 2016).

Bumblebee emergence date is crucial for phenology studies, particularly in the context of climate change (Blasi et al. 2023; Kudo and Cooper 2019; Miller-Struttmann et al. 2022). When temperatures start to rise in early spring, queen bumblebees emerge from hibernation and search for a suitable nesting site, often finding refuge in old rodent burrows or grassy areas (Kells and Goulson 2003). This is the only moment in which queens will be foraging, as they need to collect pollen and nectar to create a food supply and lay their first batch of eggs. The quantity and quality of resources gathered during this stage determines the size of the colony, or even whether the colony will establish at all (Becher et al. 2024). Therefore, it is important that floral resources be available and that flowering time is synchronized with queen bumblebee emergence. Once workers develop from the first batch of eggs, they will be the ones in charge of collecting pollen and nectar, taking over the foraging and nest maintenance duties, and allowing the queen to focus solely on egg-laying. The colony then expands rapidly throughout mid to late summer, as more workers are produced to bring back nectar and pollen to sustain the growing nest. As late summer approaches, the queen begins to lay eggs that will develop into new queens and males. These new queens leave the nest to mate, with males dying shortly after. The fertilized new queens then seek hibernation sites for the winter, while the old queen and the remaining colony members perish as the weather gets colder. The new queens will emerge from hibernation the following spring, beginning the cycle again. However, not all bumblebee populations across climatic zones experience winter diapause. In warmer climates, colonies can develop year-round, and bivoltinism can take place in some populations (Hart et al. 2021; Stelzer et al. 2010). Additionally, in very hot and arid climates, bumblebees may undergo summer aestivation instead of winter diapause (Gurel et al. 2008).

Gathering comprehensive data on the timing of queen bumblebee winter emergence can present a challenge. Traditional methods are often labor-intensive, time-consuming, and logistically demanding, limiting the scope and scale of studies. Recognizing these challenges, research has increasingly turned to citizen science as a valuable tool for data collection (*e.g.*, Blasi et al. 2023). Citizen science offers the opportunity to mobilize the collective efforts of volunteers, thereby significantly expanding the spatial and temporal coverage of data collection efforts. By engaging citizens in observing and recording bumblebee emergence events, researchers can harness a vast network of observers to gather valuable data across diverse habitats and geographical regions. Nevertheless, these data can be biased based on different factors such as regional accessibility, variability in reporting consistency, temporal coverage, observer taxonomic preference or observer experience and skill level (Díaz-Calafat et al. 2024; Rosário et al. 2024). In this article, we use bumblebee records from citizen science data across Europe and North America to assess temporal bias on bumblebee data in general and on queen bumblebee winter emergence in particular. Specifically, we focus on the weekend bias, which refers to a distortion in data collection caused by observations or recordings being more frequently made on weekends than on weekdays. In citizen science projects in particular, this bias can appear when volunteers are more likely to engage in data collection during their leisure time on weekends, leading to an overrepresentation of weekend data. As a result, the data may not accurately reflect temporal events or patterns that occur uniformly throughout time (Courter et al. 2013). To specifically assess weekend bias on citizen science collected data concerning bumblebees, we asked: (1) What is the extent of weekend recording in bumblebee phenology? (2) Does weekend bias change over time? (3) Is there weekend bias in bumblebee recording and queen emergence data? (4) Is winter emergence time of some bumblebee species more associated with weekend recording than others? Moreover, we present a case study on queen bumblebee emergence timing where we assess the differences between the same statistical analysis conducted without accounting for weekend bias and with weekend bias correction.

2. METHODS

2.1. Data collection

Bumblebee occurrence data was downloaded from the Global Biodiversity Information Facility (GBIF). We selected only georeferenced records from Europe and North America, covering the period from 1999 to June 2024. Citizen science data was downloaded by filtering "human observations" in the *BasisOfRecord* variable of the Darwin Archive Core, as these data typically belong to citizen science platforms. This resulted in a total of 2,065,696 data points. Similarly, we downloaded data from museum specimens using the same parameters and by filtering "preserved specimens" from the GBIF data. This resulted in 343,914 records. The citizen science dataset is available from GBIF.org (2024; https://doi.org/10.15468/dl.372w4a), and the museum data from GBIF.org (2025; https://doi.org/10.15468/dl.23svan).

2.2. Data cleaning

Citizen science observations with no species data were removed, as well as duplicates based on species, date and geographical coordinates. Moreover, observations from the naturgucker.de platform were excluded, as many bumblebee identification errors were found. Then, occurrence data was cleaned using the 'CoordinateCleaner' package in the R software (R Core Team 2024; Zizka et al. 2019). This R package enables users to conduct various tests on a collection of coordinate records, identifying and eliminating any problematic entries. Coordinates falling in a different country than that one specified in the metadata were removed, as well as those falling onto the sea or missing the country in their metadata. Moreover, as poorly geo-referenced occurrence records are often erroneously assigned to centroids, we removed coordinates within a 1 km radius of country capitals and country centroids. For the same reason, records located within 100 m of a list of biodiversity institutions included in the 'CoordinateCleaner' package were also excluded. In addition to the previously mentioned cleaning steps, occurrence records with low coordinate accuracy (> 25 km) were removed. Coordinates lacking accuracy data were assumed to be as precise as indicated by their decimal places. This resulted in a total of 1,211,937 clean bumblebee occurrence records. Museum specimen data was not cleaned. For details on the data cleaning process, see Table S1 in Supplementary Information.

2.3. Statistical analyses

All statistical analyses were conducted using R 4.3.3 (R Core Team 2024).

(1) What is the extent of weekend recording in bumblebee phenology?

To visualize weekend bias, we calculated the number of records for each day of the week, separately for Europe and North America, across different years and bumblebee species. We then compared these counts to the number of observations that would be expected if they were evenly distributed throughout the week. We did this for both citizen science data and museum specimens. Then, to estimate the probability of an observation occurring on a weekend, we calculated the day of the week (Monday-Sunday) for each bumblebee recording date. We then created a binomial variable, coded as 1 for weekends (*i.e.,* Saturday and Sunday) and 0 for weekdays (*i.e.*, Monday to Friday). To adjust for the relative frequency of weekends and weekdays within a week, we applied weights to each observation based on their inverse frequency: 1/2 for weekends and 1/5 for weekdays. We used logistic Generalized Linear Models (GLMs) with a logit link to assess weekend bias. In these models, the binary weekend variable was the response and the only predictor was the intercept. This provides an estimate of the overall proportion of weekend observations, with the intercept representing the log-odds of an observation being made on a weekend. This model was run separately for citizen science data and museum specimens, as well as for Europe and North America.

(2) Does weekend bias change over time?

To assess any temporal tendencies of weekend bias in citizen science data, we ran logistic GLMs with a logit link. In these, weekend was used as a binary response and the observations' recording year as a predictor. These models were run for all bumblebees together as well as separately for Europe and North America.

(3) Is there weekend bias in bumblebee recording and queen emergence data?

For this analysis, we restricted the data to the occurrences belonging to the ten most common bumblebee species for Europe and North America (Figure 1). We sorted these records in different climatic Köppen-Geiger climate zones using the 'kgc' R package (Bryant et al. 2017). These climatic zones divide regions of the earth by their relative heat and humidity through the year. Since temperature is an important driver of bumblebee emergence from hibernation (Pawlikowski et al. 2020), we selected the first record for each bumblebee species in each year (1999–2024) and Köppen-Geiger climate zone in order to increase our number of data points. This record was considered as the queen's emergence date from hibernation. Records for *Bombus terrestris* (L.), *B. lucorum* (L.), *B. magnus* Vogt, 1911 and *B. cryptarum* (Fabricius, 1775) were joined under the same taxon, as they belong to cryptic species that are difficult to tell apart morphologically in the field (Bossert 2015). Then, we ran the same models as in *question 1* using this new dataset. Only citizen science data was used to answer this question.

(4) Is winter emergence time of some bumblebee species more associated with weekend recording than others?

To assess differences in weekend recording patterns across various bumblebee species, we analysed the frequency of recording of the ten most recorded bumblebee species in Europe and North America in citizen science data. For this, we ran logistic GLMs with a logit link for each species separately. Weekend was used as a binary response, and the intercept as the only predictor. Two different datasets per species were used: one including all occurrence data throughout the flying season of each bumblebee, and one with only the earliest record per species, year and Köppen-Geiger climatic zone.

2.4. Case study

We conducted a case study using queen emergence data from the species *Bombus hortorum* (L.), a common bumblebee found throughout most of Europe with a range that extends from southern Iberia to northern Norway and spans across the entire Siberian region (Rasmont 2016). In this case study, the objective was to determine whether the winter emergence date of this species has advanced over time. To do this, we compared three statistical models: one that ignored whether observations were recorded on weekends and two that accounted for potential temporal recording bias in different ways. We ran Poisson GLMs with a log link for the same dataset, using the 'glmmTMB' function in the package of the same name (Brooks et al. 2017). In these, the response variable was the recording date as a Julian day (*i.e.*, 1–365), and the recording year was the only predictor. To address the temporal structure of the data, the two models that accounted for temporal bias included either the day of the week (*i.e.*, Monday-Sunday) or the weekend status (*i.e.*, weekend-weekday) as a random effect. AIC was used to compare the performance between models.

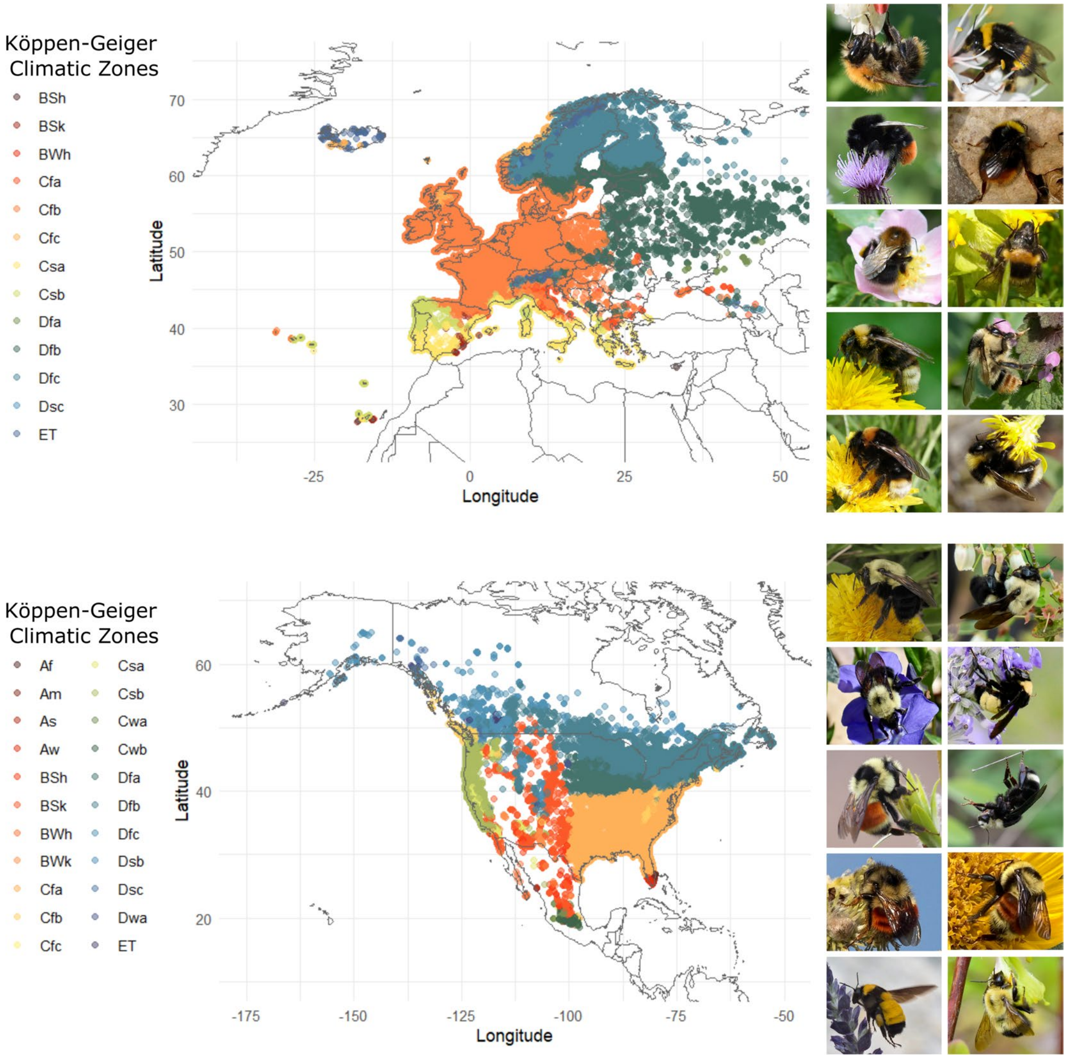

Figure 1. Citizen science bumblebee occurrence locations used in this study. For a clearer visualization, only occurrence data from the ten most common species are depicted. Different colors correspond to different Köppen-Geiger climatic zones: Af (tropical rainforest climate), Am (tropical monsoon climate), As (tropical Savanna with dry summers), Aw (tropical Savanna climate with dry winters), BSh (hot semi-arid climate), BSk (cold semi-arid climate), BWh (hot desert climate), BWk (cold desert climate), Cfa (humid subtropical climate), Cfb (temperate oceanic climate), Cfc (subpolar oceanic climate), Csa (hot-summer Mediterranean climate), Csb (warm-summer Mediterranean climate), Cwa (monsoon-influenced humid tropical climate), Cwb (monsoon-influenced temperate oceanic climate or subtropical highland climate), Dfa (hot-summer humid continental climate), Dfb (warm-summer humid continental climate), Dfc (subarctic climate), Dsc (Mediterranean-influenced subarctic climate), Dsb (Mediterranean-influenced warm-summer humid continental climate), Dwa (monsoon-influenced hot-summer humid continental climate) and ET (Tundra). The ten most reported species per Europe (top) and North America (bottom) are illustrated next to each map. European species from left to right and top to bottom: *Bombus pascuorum*, *B. terrestris*, *B. lapidarius* (all CC BY-NC Joan Díaz Calafat), *B. pratorum* (CC BY-NC "lastovka"), *B. hypnorum*, *B. hortorum* (both CC-BY-NC Joan Díaz Calafat), *B. bohemicus* (CC BY-NC Irina Butorina), *B. sylvarum* (CC BY-NC Miroslav Marić), *B. vestalis* (CC0 Rod Gibson), *B. jonellus* (CC-BY-NC J. Tyllinen), North American species from left to right and top to bottom: *B. impatiens* (CC0 Erik Schiff), *B. griseocollis* (CC-BY-NC Chase Bonanno), *B. bimaculatus* (CC-BY-NC Kurt Herr), *B. pensylvanicus* (CC-BY-NC Tami Reed), *B. ternarius* (CC-BY-NC Joe Bartok), *B. vosnesenskii* (CC-BY-NC Daniel Fitzgerald), *B. melanopygus* (CC-BY-NC Kris Ethington), *B. rufocinctus* (CC-BY-NC Kirsten Bovee), *B. sonorus* (CC-BY-NC Eric Carpenter), *B. perplexus* (CC-BY Bernie Paquette).

3. RESULTS

We obtained a total of 957,585 citizen science bumblebee occurrence records from 62 different species in Europe, and 251,314 records from 58 species in North America. These records originated from 84 different participatory platforms in the European dataset, and only from three in the North American dataset (See Table S2 in Supplementary Information). The ten most common bumblebee species in Europe were: *Bombus pascuorum* (Scopoli, 1763; *n* =244,206), *Bombus terr/luc*. complex (*n* =239,691), *Bombus lapidarius* (L.; *n* =131,493), *Bombus pratorum* (L.; *n* =93,400), *Bombus hypnorum* (L.; *n* =77,809), *Bombus hortorum* (*n* =46,219), *Bombus bohemicus* Seidl, 1838 (*n* =10,872), *Bombus sylvarum* (L.; *n* =9,831), *Bombus vestalis* (Geoffroy, 1785; *n* =9,780) and *Bombus jonellus* (Kirby, 1802; *n* =9,568). For North America, these were: *Bombus impatiens* Cresson, 1863 (*n* =84,270), *Bombus griseocollis* (De Geer, 1773; *n* =33,411), *Bombus bimaculatus* Cresson, 1863 (*n* =21,950), *Bombus pensylvanicus* (De Geer, 1773; *n* =18,007), *Bombus ternarius* Say, 1837 (*n* =11,318), *Bombus vosnesenskii* Radoszkowski, 1862 (*n* =10,024), *Bombus melanopygus* Nylander, 1848 (*n* =8,601), *Bombus rufocinctus* Cresson, 1863 (*n* =7,018), *Bombus sonorus* Say, 1837 (*n* =5,067) and *Bombus perplexus* Cresson, 1863 (*n* =4,951). Regarding museum specimen data, we obtained 81,821 records for Europe and 262,093 for North America.

(1) What is the extent of weekend recording in bumblebee phenology?

We found that 33.14% of European citizen science bumblebee records were reported over weekends, while this was 32.47% for North America. In both cases, this was higher than what is expected by random chance (*i.e.*, 28.57%, or 2 out of 7; Europe: GLM, z= 57.14, $p < 0.001$ and North America: GLM, z= 25.05, $p < 0.001$; Figure 2A). In contrast, only 22.28% of European museum specimen data was collected during weekends, compared to 15.11% in North America – both significantly lower than expected by random chance and showing the opposite pattern to citizen science data (Europe: GLM, z=−24.27, $p < 0.001$ and North America: GLM, z=−94.79, $p < 0.001$; Figure 2B). Despite temporal recording patterns across continents being similar, citizen science reports on Fridays in North America were slightly higher than expected. In contrast, reports on Fridays in Europe were comparable to those on other weekdays.

(2) Does weekend bias change over time?

Weekend bias significantly changed over time, but in opposite directions for each continent (Figure 3). In Europe, the models show an increase in weekend reporting frequency with increasing recording year (GLM, z= 11.54, $p < 0.001$), whilst in North America there is a decrease (GLM, z=−6.724, $p < 0.001$).

(3) Is there weekend bias in bumblebee recording and queen emergence data?

When considering only the earliest record per year and Köppen-Geiger climatic zone for each of the ten most common bumblebee species in Europe and North America, weekend records were significantly higher than expected for both continents (GLM, z= 2.5, $p < 0.05$ and GLM, z= 2.96, $p < 0.005$, respectively).

(4) Is winter emergence time of some bumblebee species more associated with weekend recording than others?

Although weekend bias was observed across most single-species bumblebee datasets, it was only significant in *Bombus hypnorum* when focusing exclusively on winter emergence times (Table I). Moreover, our models identified two additional cases with p-values close to significance, suggesting a potential trend towards weekend bias for *B. sonorous* (p= 0.078) and *B. vosnesenskii* (p= 0.052).

3.1. Case study: *Bombus hortorum*

The earliest record date for *Bombus hortorum* significantly advanced (*i.e.*, the Julian day

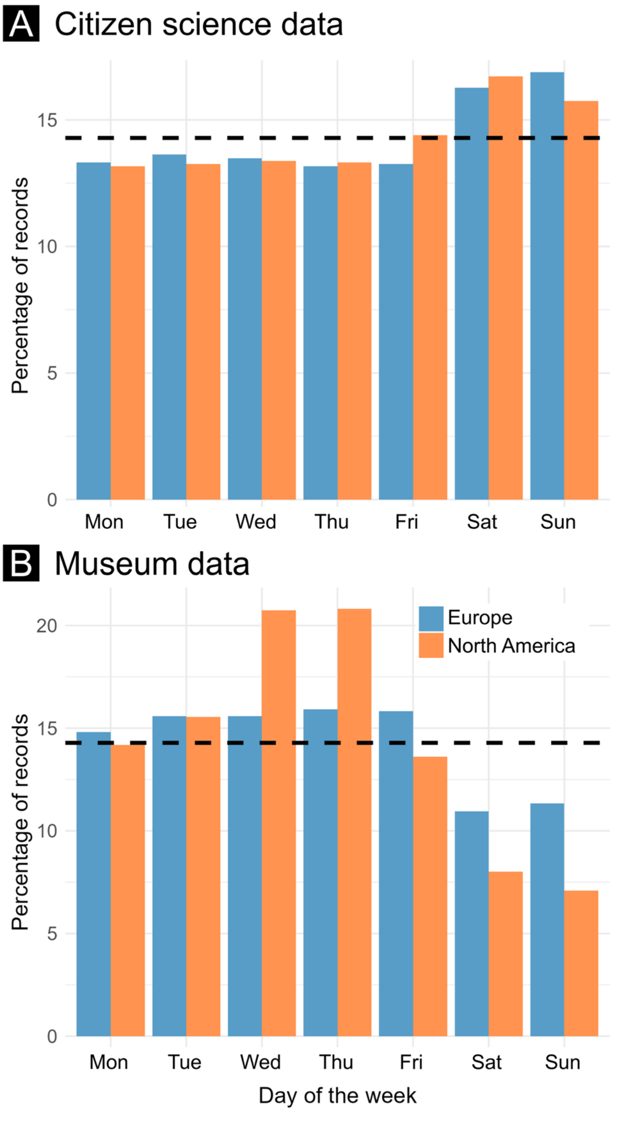

Figure 2. **A**. Percentage of citizen science-based observations from bumblebees reported on each day of the week in Europe and North America. **B**. Percentage of museum bumblebee records captured on each day of the week in Europe and North America. In both cases, the horizontal reference line indicates the percentage of observations expected at random (*i.e.*, 14.3%).

decreased) with increasing recording year (GLM, $z = -2.08$, $p = 0.037$). However, when adding a weekend binary variable as a random factor, the effect of year ceased being statistically significant (GLM, $z = 0.623$, $p = 0.533$). Moreover, accounting for each day of the week separately as a random factor decreased such significance even more (GLM, $z = -556$, $p = 0.578$). When comparing these three models, the AIC values were the lowest for the model that corrected for each day of the week separately (7064.7), followed by the model that did not have any random effect (7093.6) and the model that only corrected for weekends (8774.6).

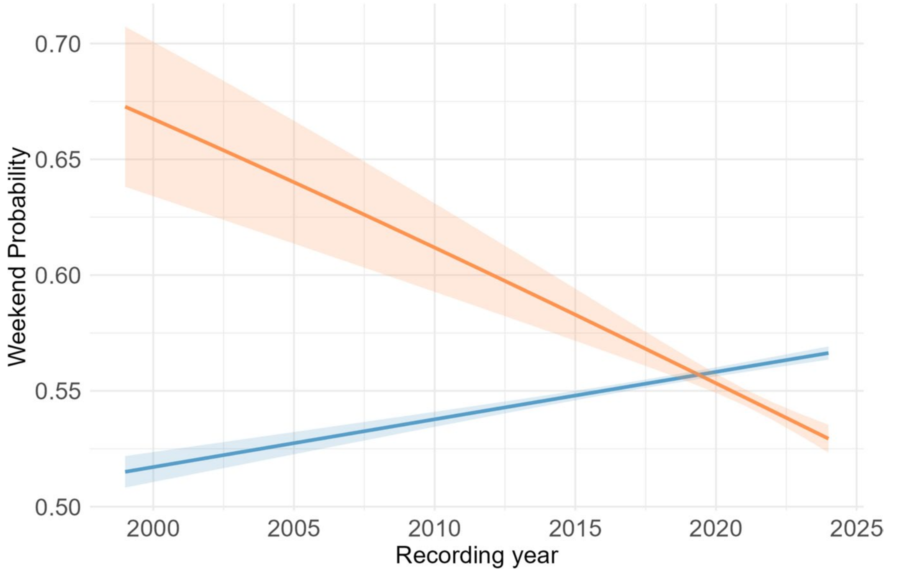

Figure 3. Predicted weekend recording probability for Europe (blue) and North America (orange) based on the recording year.

4. DISCUSSION

Our study reveals a clear weekend bias in bumblebee records submitted to citizen science platforms across both Europe and North America. While this temporal bias has been increasing over time for Europe, it is decreasing for North America. A similar bias is evident in museum specimen data, but in the opposite direction: fewer bumblebees are being collected on weekends. Importantly, we demonstrate that weekend bias influences the recording of phenological patterns, such as bumblebee winter emergence, although its impact may vary among species. Statistical models that disregard this temporal structure of citizen science data produced divergent results compared to models that incorporate the day of the week in their terms, potentially leading to the misinterpretation of the results. This underscores the need to account for such temporal biases in phenological studies, and particularly in those addressing climate change impacts. To our knowledge, we are the first to report this type of temporal bias in crowdsourced insect phenology data.

Weekend bias is a well-known artifact in data collected by volunteers, and has primarily been studied in bird-related data. Previous research has highlighted this bias in various contexts, such as clutch initiation dates of common birds (Cooper 2014), observations of rare bird species (Żmihorski et al. 2012) and the timing of bird migratory arrivals (Courter et al. 2013). The proportion of observations made by volunteers during weekends for bumblebee data (33.14%) is similar to that one reported for migratory bird arrivals (32%−33.7%) in previous studies (Courter et al. 2013), but not as high as that one reported for rare birds (up to 54.9%) by Żmihorski et al. (2012). Overall, this suggests that citizen science efforts are disproportionately concentrated on weekends, regardless of the project focus or taxa studied, likely due to the availability of volunteers.

The temporal patterns of museum specimen data have received relatively less attention. In this study, we show that bumblebees housed in museum collections have been predominantly collected on weekdays, likely because researchers and collectors typically conduct fieldwork

Table I Model output for individual logistic GLMs assessing weekend bias for the ten most common bumblebee species in Europe and North America. In these models, weekend bias was assessed as a binary variable, and recording year was the only predictor used. Two different datasets were used: one with all records available for each bumblebee species throughout the flying season ("all records"), and one with only the earliest record per species, year and Koeppen–Geiger climatic zone ("earliest records"). Note that the model concerning the earliest records of *Bombus bimaculatus* was excluded because there were not enough data points available. Significant p-values appear in bold

		All records		Earliest records	
Continent	Species	Z score	*P* value	Z score	*P* value
Europe	*B. pascuorum*	33.81	**< 0.001**	0.964	0.335
	B. terr/luc complex	30.69	**< 0.001**	−0.534	0.593
	B. lapidarius	19.89	**< 0.001**	0.991	0.321
	B. pratorum	20.15	**< 0.001**	0.697	0.486
	B. hypnorum	21.35	**< 0.001**	1.989	**0.047**
	B. hortorum	12.41	**< 0.001**	0.416	0.677
	B. bohemicus	0.847	0.397	0.436	0.663
	B. sylvarum	0.356	0.722	0.798	0.425
	B. vestalis	4.846	**< 0.001**	1.290	0.197
	B. jonellus	2.448	**0.014**	1.146	0.252
North America	*B. impatiens*	11.21	**< 0.001**	1.146	0.252
	B. griseocollis	6.662	**< 0.001**	0.960	0.337
	B. bimaculatus	7.067	**< 0.001**	-	-
	B. pensylvanicus	11.64	**< 0.001**	0.705	0.481
	B. ternarius	7.262	**< 0.001**	0.834	0.404
	B. vosnesenskii	7.588	**< 0.001**	1.940	0.052
	B. melanopygus	4.628	**< 0.001**	1.466	0.143
	B. rufocinctus	2.336	**0.020**	−0.144	0.886
	B. sonorus	5.034	**< 0.001**	1.765	0.078
	B. perplexus	3.737	**< 0.001**	0.148	0.882

within institutional or academic settings that follow weekday schedules, with limited activity on weekends. The similarity in weekend bias between the two continents highlights a global trend in data collection practices. However, despite this, temporal trends in citizen science seem to diverge. In Europe, weekend reporting has increased over time, while North America shows the opposite pattern. Courter et al. (2013) already showed a decrease over time of weekend reporting on bird migration arrival over time in North America. The increase in weekend reporting for Europe could be probably linked to the growing popularity of citizen science, as well as to the proliferation of region-specific projects and the larger number of different participatory platforms available compared to North America. However, the reasons behind these divergent trends will have to be explored in future studies. Understanding regional differences in public engagement with citizen science projects – and how these differences contribute to bias – is vital for accurate data interpretation. This is especially relevant in contexts where data collection may involve varying levels of bias across regions, or where regional differences influence phenology. For example, the impacts of climate change on phenology can vary significantly between regions (Stemkovski et al. 2023), making it crucial to disentangle the varying levels of bias in citizen-science data from differences in phenology themselves. Moreover, both temperature and citizen science engagement are higher in urban areas (Díaz-Calafat et al. 2024; Heisler and Brazel 2010), meaning that urban records may disproportionately reflect earlier phenological events or extended activity periods, particularly for species sensitive to temperature cues such as bumblebees (Merckx et al. 2021; Stelzer et al. 2010).

We also show the impact of weekend bias on the recording of phenological data in both Europe and North America, particularly regarding the timing of bumblebee queen emergence from hibernation. Weekend bias on winter emergence time was evident when all bumblebee species were analysed together, yet when assessing species individually it became inconspicuous for certain species, illustrating that species-specific traits, such as detectability or habitat preferences, may mediate the extent of bias. For example, observations of winter emergence in *B. hypnorum* were notably more frequent on weekends. This species nests in vertical structures such as trees (hence its English common name: tree bumblebee), but has become quite abundant in urban areas. Urban environments provide numerous well-insulated and well-protected aboveground nesting sites, including within buildings (Prŷs-Jones 2019). We hypothesize that these nesting habits make *B. hypnorum* easier to detect indoors by observers during weekends, as volunteers typically work away from home during weekdays and may spend more time at home during weekends. These findings suggest that such biases might disproportionately affect species with specific ecological traits that align with human activity patterns, which can distort interpretations of climate change impacts on phenology shifts of such species, potentially leading to the implementation of inaccurate policies and the misallocation of conservation priorities, efforts and resources.

Researchers should consider accounting for weekend bias when analysing long-term phenological datasets to avoid over- or under-estimating shifts in species activity. In our case study, the winter emergence date for *B. hortorum* advanced over time, but this trend lost statistical significance when accounting for weekend bias and daily recording patterns, illustrating the importance of disentangling true phenological shifts from recording biases. Based on this, we recommend the inclusion of the day of the week in phenology models, as already suggested by Courter et al. (2013). This seems to improve the performance of the models by accounting for the noise produced by temporal patterns in data structure. In our case study, including the day of the week in the phenology model resulted in a lower AIC value compared to including a binary weekend variable, implying that there may be other temporal patterns affecting data collection beyond the weekend effect (*e.g.*, Díaz-Calafat et al. 2024). In particular, our findings show a higher-than-expected proportion of observations on Fridays, at least in North America, further supporting this idea.

In conclusion, while citizen science offers invaluable opportunities for expanding phenological datasets across large spatial and temporal scales, we call for the careful consideration of the biases inherent to such datasets. Not all ecological questions may be equally suited for unsupervised data collection. Projects relying on precise timing or identification, such as tracking pollinator emergence, may be particularly sensitive to observer biases unless standardized protocols are in place. Implementing rigid data collection guidelines – such as specifying observation timing, effort, and identification criteria – and providing proper training or validation tools (*e.g.*, image recognition, expert verification) can significantly improve data reliability. In the studies where unsupervised participation takes place, incorporating statistical corrections for known biases becomes essential to enhance the reliability of such datasets. Our findings demonstrate how weekend bias can distort interpretations of phenological changes in bumblebee activity. Thus, the success of citizen science depends not only on volunteer engagement but also on thoughtful project design that anticipates and corrects for potential sources of error. Future research should continue to explore these biases to enhance the reliability of citizen science data in tracking species responses to climate change, incorporating insights from both volunteer behaviour and species-specific traits.

SUPPLEMENTARY INFORMATION

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AUTHOR CONTRIBUTIONS

JDC: Conceptualization, Data curation, Formal Analysis, and Software. Both authors: Methodology, Validation, Visualization, Writing – original draft, and Writing – review & editing.

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DATA AVAILABILITY

The data supporting this article can be downloaded from GBIF at https://doi.org/10.15468/dl.372w4a and https://doi.org/10.15468/dl.23svan. The code used for analyses can be found in Zenodo at: https://doi.org/10.5281/zenodo.15252776.

DECLARATIONS

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REFERENCES

Bartomeus I, Ascher JS, Wagner D, Danforth BN, Colla S, Kornbluth S, Winfree R (2011) Climate-associated phenological advances in bee pollinators and bee-pollinated plants. Proc Natl Acad Sci 108(51):20645–20649. https://doi.org/10.1073/pnas.1115559108

Becher MA, Twiston-Davies G, Osborne JL, Lander TA (2024) Resource gaps pose the greatest threat for bumblebees during the colony establishment phase. Insect Conservation and Diversity 17(4):676–689. https://doi.org/10.1111/icad.12736

Blasi M, Carrié R, Fägerström C, Svensson E, Persson AS (2023) Historical and citizen-reported data show shifts in bumblebee phenology over the last century in Sweden. Biodivers Conserv 32(5):1523–1547. https://doi.org/10.1007/s10531-023-02563-5

Bossert S (2015) Recognition and identification of bumblebee species in the Bombus lucorum-complex (Hymenoptera, Apidae) – A review and outlook. Deutsche Entomologische Zeitschrift 62(1):1. https://doi.org/10.3897/dez.62.9000

Brooks ME, Kristensen K, van Benthem KJ, Magnusson A, Berg CW, Nielsen A, Skaug HJ, Mächler M, Bolker BM (2017) glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. The R Journal 9(2):378–400

Bryant C, Wheeler N, Rubel F, French R (2017) kgc: Koeppen-Geiger Climatic Zones. R package version 1.0.0.2. https://CRAN.R-project.org/package=kgc. Accessed 02/12/2024

Calinger KM, Queenborough S, Curtis PS (2013) Herbarium specimens reveal the footprint of climate change on flowering trends across north-central North America. Ecol Lett 16(8):1037–1044. https://doi.org/10.1111/ele.12135

Cooper CB (2014) Is there a weekend bias in clutch-initiation dates from citizen science? Implications for studies of avian breeding phenology. Int J Biometeorol 58(7):1415–1419. https://doi.org/10.1007/s00484-013-0742-z

Courter JR, Johnson RJ, Stuyck CM, Lang BA, Kaiser EW (2013) Weekend bias in Citizen Science data reporting: Implications for phenology studies. Int J Biometeorol 57(5):715–720. https://doi.org/10.1007/s00484-012-0598-7

Díaz-Calafat J, Jaume-Ramis S, Soacha K, Álvarez A, Piera J (2024) Revealing biases in insect observations: A comparative analysis between academic and citizen science data. PLoS ONE 19(7):e0305757. https://doi.org/10.1371/journal.pone.0305757

GBIF.org. (2024). *(26 June 2024) GBIF Occurrence Download* https://doi.org/10.15468/dl.372w4a

GBIF.org (2025). GBIF Occurrence Download https://doi.org/10.15468/dl.23svan

Gurel F, Gosterit A, Eren Ö (2008) Life-cycle and foraging patterns of native Bombus terrestris (L.) (Hymenoptera, Apidae) in the Mediterranean region. Insectes Sociaux 55(2):123–128. https://doi.org/10.1007/s00040-008-0984-7

Hart AF, Maebe K, Brown G, Smagghe G, Ings T (2021) Winter activity unrelated to introgression in British bumblebee Bombus terrestris audax. Apidologie 52(2):315–327. https://doi.org/10.1007/s13592-020-00822-w

Heisler GM, Brazel AJ (2010) The Urban Physical environment: temperature and urban heat islands. In Urban ecosystem ecology (pp. 29–56). John Wiley & Sons, Ltd. https://doi.org/10.2134/agronmonogr55.c2

Kells AR, Goulson D (2003) Preferred nesting sites of bumblebee queens (Hymenoptera: Apidae) in agroecosystems in the UK. Biol Cons 109(2):165–174. https://doi.org/10.1016/S0006-3207(02)00131-3

Kudo G, Cooper EJ (2019) When spring ephemerals fail to meet pollinators: mechanism of phenological mismatch and its impact on plant reproduction. Proc R Soc B Biol Sci 286(1904). https://doi.org/10.1098/rspb.2019.0573

Merckx T, Nielsen ME, Heliölä J, Kuussaari M, Pettersson LB, Pöyry J, Tiainen J, Gotthard K, Kivelä SM (2021) Urbanization extends flight phenology and leads to local adaptation of seasonal plasticity in Lepidoptera. Proc Natl Acad Sci 118(40):e2106006118. https://doi.org/10.1073/pnas.2106006118

Miller-Struttmann N, Miller Z, Galen C (2022) Climate driven disruption of transitional alpine bumble bee communities. Glob Change Biol 28(21):6165–6179. https://doi.org/10.1111/gcb.16348

Pawlikowski T, Sparks TH, Olszewski P, Pawlikowski K, Rutkowski L, Jakubowski R (2020) Rising temperatures advance the main flight period of Bombus bumblebees in agricultural landscapes of the Central European Plain. Apidologie 51(4):652–663. https://doi.org/10.1007/s13592-020-00750-9

Prŷs-Jones O (2019) Preadaptation to the vertical: an extra dimension to the natural history and nesting habits of the Tree Bumble Bee, Bombus (Pyrobombus) hypnorum. J Apic Res 58(5):643–659. https://doi.org/10.1080/00218839.2019.1634462

Pyke GH, Thomson JD, Inouye DW, Miller TJ (2016) Effects of climate change on phenologies and distributions of bumble bees and the plants they visit. Ecosphere 7(3):e01267. https://doi.org/10.1002/ecs2.1267

R Core Team (2024) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/. Accessed 02/12/2024

Rasmont P (2016) Atlas hymenoptera—atlas of the european bees—STEP project. https://web.archive.org/web/20160325032215/http://www.zoologie.umh.ac.be/hymenoptera/pagetaxon.asp?tx_id=3035. Accessed 02/12/2024

Rosário IT, Tiago P, Chozas S, Capinha C (2024) Drivers of temporal bias in biodiversity recording by citizen scientists (p. 2024.07.22.604598). bioRxiv. https://doi.org/10.1101/2024.07.22.604598

Stelzer RJ, Chittka L, Carlton M, Ings TC (2010) Winter Active bumblebees (Bombus terrestris) achieve high foraging rates in Urban Britain. PLoS ONE 5(3):e9559. https://doi.org/10.1371/journal.pone.0009559

Stemkovski M, Bell JR, Ellwood ER, Inouye BD, Kobori H, Lee SD, Lloyd-Evans T, Primack RB, Templ B, Pearse WD (2023) Disorder or a new order: how climate change affects phenological variability. Ecology 104(1):e3846. https://doi.org/10.1002/ecy.3846

Willems FM, Scheepens JF, Bossdorf O (2022) Forest wildflowers bloom earlier as Europe warms: lessons from herbaria and spatial modelling. New Phytol 235(1):52–65. https://doi.org/10.1111/nph.18124

Zizka A, Silvestro D, Andermann T, Azevedo J, Duarte Ritter C, Edler D, Farooq H, Herdean A, Ariza M, Scharn R, Svantesson S, Wengström N, Zizka V, Antonelli A (2019) CoordinateCleaner: standardized cleaning of occurrence records from biological collection databases. Methods Ecol Evol 10(5):744–751. https://doi.org/10.1111/2041-210X.13152

Żmihorski M, Sparks TH, Tryjanowski P (2012) The Weekend bias in recording rare birds: mechanisms and consequencess. Acta Ornithologica 47(1):87–94. https://doi.org/10.3161/000164512X653953

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