



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

## Pollinator-flower interactions in gardens during the COVID-19 pandemic lockdown of 2020

### Citation for published version:

Ollerton, J, Trunschke, J, Havens, K, Landaverde-González, P, Keller, A, Gilprin, A-M, Rech, AR, Baronio, GJ, Phillips, BJ, Mackin, C, Stanley, DA, Treanore, E, Baker, E, Rotheray, EL, Erickson, E, Fornoff, F, Brearley, FQ, Ballantyne, G, Iossa, G, Stone, GN, Bartomeus, I, Stockan, J, Leguizamón, J, Prendergast, K, Rowley, L, Giovanetti, M, de Oliveira Bueno, R, Wesselingh, RA, Mallinger, RE, Edmondson, S, Howard, SR, Leonhardt, SD, Rojas Nossa, SV, Brett, M, Joaqui, T, Antoniazzi, R, Burton, VJ, Feng, HH, Tian, Z-X, Xu, Q, Zhang, C, Shi, CL, Huang, SQ, Cole, LJ, Bendifallah, L, Ellis, EE, Joar Hegland, S, Straffon Díaz, S, Allen Lander, T, Mayr, AV, Dawson, R, Eeraerts, M, Scott Armbruster, W, Walton, B, Adjlane, N, Falk, S, Mata, L, Goncalves Geiger, A, Carvell, C, Wallace, C, Ratto, F, Barberis, M, Kahane, F, Connop, S, Stip, A, Rosangela Sigrist, M, Vereecken, NJ, Klein, A-M, Baldock, KCR & Arnold, SEJ 2022, 'Pollinator-flower interactions in gardens during the COVID-19 pandemic lockdown of 2020', *Journal of Pollination Ecology*, vol. 31. [https://doi.org/10.26786/1920-7603\(2022\)695](https://doi.org/10.26786/1920-7603(2022)695)

### Digital Object Identifier (DOI):

[10.26786/1920-7603\(2022\)695](https://doi.org/10.26786/1920-7603(2022)695)

### Link:

[Link to publication record in Edinburgh Research Explorer](#)

### Document Version:

Publisher's PDF, also known as Version of record

### Published In:

Journal of Pollination Ecology

### General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

### Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact [openaccess@ed.ac.uk](mailto:openaccess@ed.ac.uk) providing details, and we will remove access to the work immediately and investigate your claim.



## POLLINATOR-FLOWER INTERACTIONS IN GARDENS DURING THE COVID-19 PANDEMIC LOCKDOWN OF 2020

Jeff Ollerton<sup>\*1,2</sup>, Judith Trunschke<sup>3</sup>, Kayri Havens<sup>3</sup>, Patricia Landaverde-González<sup>4</sup>, Alexander Keller<sup>5</sup>, Amy-Marie Gilpin<sup>6</sup>, André Rodrigo Rech<sup>7</sup>, Gudryan J. Baronio<sup>8</sup>, Benjamin J. Phillips<sup>9</sup>, Chris Mackin<sup>10</sup>, Dara A. Stanley<sup>11</sup>, Erin Treanore<sup>12</sup>, Ellen Baker<sup>13</sup>, Ellen L. Rotheray<sup>10</sup>, Emily Erickson<sup>14</sup>, Felix Fornoff<sup>15</sup>, Francis Q. Brearley<sup>16</sup>, Gavin Ballantyne<sup>17</sup>, Graziella Iossa<sup>18</sup>, Graham N. Stone<sup>19</sup>, Ignasi Bartomeus<sup>20</sup>, Jenni A. Stockan<sup>21</sup>, Johana Leguizamón<sup>22</sup>, Kit Prendergast<sup>23</sup>, Lisa Rowley<sup>24</sup>, Manuela Giovanetti<sup>25</sup>, Raquel de Oliveira Bueno<sup>26</sup>, Renate A. Wesselingh<sup>27</sup>, Rachel Mallinger<sup>28</sup>, Sally Edmondson<sup>29</sup>, Scarlett R. Howard<sup>30,31</sup>, Sara D. Leonhardt<sup>32</sup>, Sandra V. Rojas-Nossa<sup>33</sup>, Maisie Brett<sup>34</sup>, Tatiana Joaqui<sup>35</sup>, Reuber Antoniazzi<sup>35</sup>, Victoria J. Burton<sup>36</sup>, Hui-Hui Feng<sup>37</sup>, Zhi-Xi Tian<sup>37</sup>, Qi Xu<sup>37</sup>, Chuan Zhang<sup>37</sup>, Chang-Li Shi<sup>37</sup>, Shuang-Quan Huang<sup>37</sup>, Lorna J. Cole<sup>38</sup>, Leila Bendifallah<sup>39</sup>, Emilie E. Ellis<sup>40</sup>, Stein Joar Hegland<sup>41</sup>, Sara Straffon Díaz<sup>42</sup>, Tonya Lander<sup>43</sup>, Antonia V. Mayr<sup>44,45</sup>, Sophie Katzer<sup>44</sup>, Richard Dawson<sup>46</sup>, Maxime Eeraerts<sup>47</sup>, W. Scott Armbruster<sup>48,49</sup>, Becky Walton<sup>50</sup>, Noureddine Adjlane<sup>51</sup>, Steven Falk<sup>52</sup>, Luis Mata<sup>53</sup>, Anya Goncalves Geiger<sup>54</sup>, Claire Carvell<sup>55</sup>, Claire Wallace<sup>56</sup>, Fabrizia Ratto<sup>57,58</sup>, Marta Barberis<sup>59</sup>, Fay Kahane<sup>9</sup>, Stuart Connop<sup>60</sup>, Anthonie Stip<sup>61</sup>, Maria Rosangela Sigrist<sup>62</sup>, Nicolas J. Vereecken<sup>63</sup>, Alexandra-Maria Klein<sup>64</sup>, Katherine C.R. Baldock<sup>65</sup>, Sarah E. J. Arnold<sup>66,67</sup>

*Author affiliations are included at the end of the article*

**Abstract**—During the main COVID-19 global pandemic lockdown period of 2020 an impromptu set of pollination ecologists came together via social media and personal contacts to carry out standardised surveys of the flower visits and plants in gardens. The surveys involved 67 rural, suburban and urban gardens, of various sizes, ranging from 61.18° North in Norway to 37.96° South in Australia, resulting in a data set of 25,174 rows, with each row being a unique interaction record for that date/site/plant species, and comprising almost 47,000 visits to flowers, as well as records of flowers that were not visited by pollinators, for over 1,000 species and varieties belonging to more than 460 genera and 96 plant families. The more than 650 species of flower visitors belong to 12 orders of invertebrates and four of vertebrates. In this first publication from the project, we present a brief description of the data and make it freely available for any researchers to use in the future, the only restriction being that they cite this paper in the first instance. The data generated from these global surveys will provide scientific evidence to help us understand the role that private gardens (in urban, rural and suburban areas) can play in conserving insect pollinators and identify management actions to enhance their potential.

**Keywords**—bees, flowers, hummingbirds, insects, pollination, species interactions

Journal of Pollination Ecology,  
32(9), 2022, pp 87-96

DOI: [10.26786/1920-7603\(2022\)695](https://doi.org/10.26786/1920-7603(2022)695)

Received 16 March 2022,  
accepted 19 June 2022

\*Corresponding author:  
[jeff.ollerton@gmail.com](mailto:jeff.ollerton@gmail.com)

### INTRODUCTION

Pollinators such as flies, bees, moths, birds, and bats are important components of ecosystems and provide crucial functions and services by facilitating the reproduction of most wild plant species and crop varieties (Klein et al. 2007; Ollerton et al. 2011; Rodger et al. 2021). However, the diversity and abundance of pollinators have declined in some parts of the world, largely driven

by land use changes and agricultural intensification, with concomitant effects on seed set (Potts et al. 2010; Ollerton 2017, 2021; Millard et al. 2021). Domestic and public gardens are increasingly recognised as potential synanthropic hotspots of pollinator diversity within the matrix of human-dominated landscapes that characterises many parts of the world, and as areas that deliver multiple ecosystem services, including pollination of fruit and vegetable crops (Matteson et al. 2008;

Davies et al. 2009; Owen 2010; Erenler 2013; Norfolk et al. 2013, 2014; Camps-Calvet et al. 2016; Foster et al. 2017; Bendifallah & Ortiz-Sánchez 2018; Baldock et al. 2019; Levé et al. 2019; Marín et al. 2019; Majewska & Altizer 2020; Tew et al. 2021; Prendergast 2021; Prendergast & Ollerton 2021). However, the effectiveness of gardens in supporting pollinators varies according to taxon, locality, garden management, and generalization-specialization range of occurring interactions, especially in urban areas (Maruyama et al. 2019; Theodorou et al. 2020; Baldock 2020; Prendergast et al. 2022; Tew et al. 2022).

To date, surveys of pollinators and their interactions with garden plants have usually been constrained in their geographical scope. This limits our understanding of the diversity of pollinators associated with gardens and how they vary globally, and our ability to answer questions such as: Do pollinators interact similarly with flowers in different parts of the world? How are different types of garden crop plants integrated within the wider network of plant-pollinator interactions? Does the role of super-generalist species such as honey bees (*Apis* spp.) vary according to region and garden type? What is the relative value of native versus non-native plant species to pollinators and how does this vary geographically? There is thus a clear need for more geographically extensive data on the relationships between pollinators and garden plants to have a better understanding of how this varies globally and to identify plant species in different regions that are important for supporting pollinators, particularly early and late in the season when little else may be in flower other than exotic garden plants. It could also help us to understand the pollinator and plant traits that distinguish garden communities from non-garden communities. Increasing our understanding of garden pollinators will help identify actions that gardeners can take to support these declining insects.

During the lockdown precipitated by the COVID-19 pandemic of 2020, which limited the movement of individuals within and between countries, the lead author coordinated an *ad hoc* network of ecologists to collect standardised data on plant-pollinator interactions from gardens to which they had access. The purpose of this

impromptu project was fivefold: (1) To take advantage of a difficult situation that would allow ecologists to focus more time and effort into understanding the ecology of their own gardens; (2) To generate a standardised data set that could be used by researchers whose field work had been curtailed by the pandemic; (3) To help to improve the physical and mental wellbeing of those field-based scientists whose access to nature was severely limited; (4) To build a data set that could be used to address unanswered scientific questions such as how the diversity of pollinators varies with garden size and geographic position, and how ornamental and food plants are used by the pollinators in home gardens; (5) To make the data freely available to give it significant future value beyond the immediate generation of research outputs, e.g. for teaching, informing extension and outreach efforts such as “best plants for pollinators”, and so forth.

In this initial paper from the project, we provide an overview of the data set and discuss how it may be used in the future, with encouragement for others to do so.

## METHODS

While recruitment of participants was on an *ad hoc* basis, all had previous experience of pollinator surveys and insect and plant identification in their region. Three protocols for garden data collection were used which we refer to as Type A, B and C surveys. Individuals chose to undertake one, two, or all three types depending on their personal circumstances and time availability.

Type A surveys involved regular walks at a steady pace around the garden, recording the insects and other flower visitors that were active on particular flowers (representing potential pollinators, hereafter for brevity referred to as “pollinators”). Each walk was timed and the amount of time spent surveying was proportional to the size of the garden and the number of plants in flower present. For example, in the first author’s 10 m x 20 m garden he undertook 15-minute walked surveys, always following the same route one way, then returning, pausing to record data. In addition, where possible, the number of inflorescences and flowering area of all plants in bloom were estimated regularly (area in m<sup>2</sup> and number of floral units), including both those plants

that were visited and those not visited by potential pollinators. The frequency with which this occurred varied by observer but was typically whenever a change for a particular species seemed to be happening, most often weekly, or every 1-2 days during periods of rapid change if monitoring was that regular. “Floral units” varied according to taxa, from individual flowers in the case of species with large, distinct blossoms (e.g., species of Malvaceae), to dense inflorescences in the case of many smaller Lamiaceae, or inflorescences (flower heads) functioning as single blooms in species of Asteraceae.

Type B surveys were based on the protocol for the UK Pollinator Monitoring Scheme (PoMS – see: <https://ukpoms.org.uk/> and Carvell et al. 2016). This involved 10-minute timed observations focused on a patch of flowers belonging to one species, in an area no larger than 0.5 m x 0.5 m. The observer recorded all flower visiting insects as well as the number of flowers each pollinator visited and the number of flowers of the target species within the 0.5 m x 0.5 m area.

Type C surveys were *ad hoc* observations of flower visitors made outside the formal periods in which Type A and Type B surveys were undertaken. We include these data as they comprise some rare interactions that were not observed during the formal survey periods, as well as observations by individuals who were not able to complete the Type A and B protocols.

Surveyors were asked to prioritise the collection of data via Type A surveys and this constitutes the majority of the data (86.9%), followed by Type B (11.8%) and Type C (1.3%).

In all cases, flower visitors and plants were identified to the lowest taxonomic level possible given the observer’s skill and ability, most frequently species or genus. Identification advice was provided by local experts where required, using photographs or captured specimens. There were only 17 cases where the plant could not be identified beyond family, and 3,169 where identification was only to genus. These represented just under 13% of the records in the data set. For the flower visitors, almost 70% were identified to species level and only just under 18% could not be identified to at least genus.

Two of the authors (JO and JT) have corrected spellings of species names and updated the taxonomy as far as possible, using a wide range of sources for the animals and the International Plant Names Index (IPNI) ([www.ipni.org](http://www.ipni.org)) for the plants. But anyone using the data in the future is advised to check it for accuracy.

#### THE DATA SET

Formal surveys took place between 16<sup>th</sup> March (day 76) and 14<sup>th</sup> October (day 288) 2020, though we also included some earlier *ad hoc* data that had been collected by participants. Data was collected by scientists from 14 countries, in gardens ranging from 61.18° North in Kaupanger, Norway to 37.96° South in Black Rock, Australia (Fig. 1). Metadata

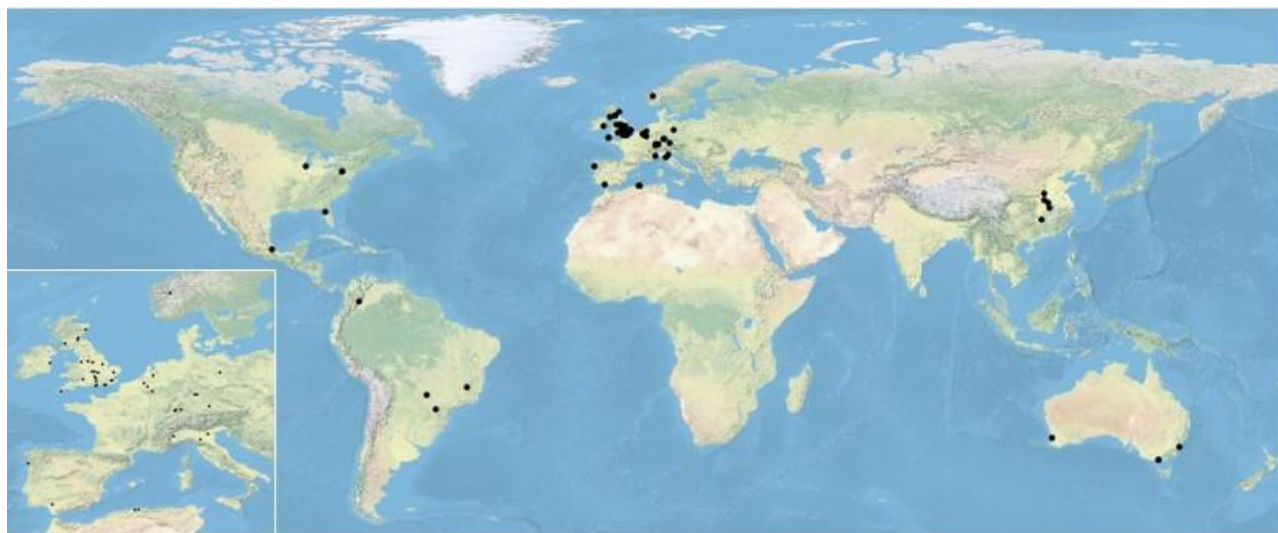


Figure 1: Locations of the gardens surveyed in this study, globally (main map) and within Europe and the Mediterranean (inset map).

for each garden are provided and explained in Table 1 and an explanation of the elements within the data set is given in Table 2. The resulting data set comprises surveys from a total of 67 gardens, ranging in size from c. 5 m<sup>2</sup> to 8,000 m<sup>2</sup> in extent, and from 2 m.a.s.l to 2,655 m.a.s.l in elevation. Twenty-two of the gardens were in a rural setting, 14 in a suburban locality, and 31 were considered urban. Total observations in the gardens involved over 1,000 species and varieties of plants belonging to more than 460 genera in 96 flowering plant families. Importantly, this includes plants to which visits were not observed during the surveys, which provides important information about the relative importance of plants in different contexts.

Almost 47,000 visits to the flowers of these plants were recorded, by more than 650 species of

pollinators, belonging to more than 250 genera in 110 families. In total, the data set comprises 25,174 rows of data arranged in columns according to the headings shown in Table 1. In the data set, 1 row = 1 unique interaction record for that date/site/plant species, recording the flower visitor species and number of individuals or visits, or a zero-visit observation.

The most frequently represented plant species that was visited by pollinators in these gardens was *Taraxacum officinale* agg. (550 records of interactions, that represented 2.5% of the plants observed). The most frequent plant family visited was Asteraceae (2,540 records, 11.6% of the plants) followed by Brassicaceae (1,663 records, 7.6% of the plants) and Boraginaceae (1,214 records, 5.6% of the plants). The pollinator-dependent crop

**Table 1: Explanation of the metadata for the data set. Note that where metadata are missing “NA” has been added.**

Metadata item	Format	Description
Five letter identifier	Text	A code that identifies each garden
Surveyor(s)	Text	The name(s) of the individual(s) who carried out the surveys
Email address	Text	The latest email address of the lead individual surveyor
Locality	Text	The town, city or region where the survey took place
Country	Text	The country in which the survey took place
Latitude	Numerical	The decimalised latitude of the garden in which the survey was conducted. Accuracy is limited to two decimal places for reasons of privacy and security
Longitude	Numerical	The decimalised longitude of the garden in which the survey was conducted. Accuracy is limited to two decimal places for reasons of privacy and security
Elevation (m.a.s.l)	Numerical	The approximate elevation of the garden in which the survey was conducted in metres above sea level
Garden size (m <sup>2</sup> )	Numerical	The approximate size of the garden in which the survey was conducted in square metres
Type	Text	The locality of the garden in relation to its surroundings. Options are “urban”, “suburban”, “rural”
Trees?	Text	The presence or absence of trees in the garden. Options are “yes” or “no”
Shrubs?	Text	The presence or absence of shrubs in the garden. Options are “yes” or “no”
Lawn?	Text	The presence or absence of a lawn in the garden. Options are “yes” or “no”
Herbaceous perennials?	Text	The presence or absence of herbaceous perennials in the garden. Options are “yes” or “no”
Compost heap(s)	Text	The presence or absence of one or more compost heaps in the garden. Options are “yes” or “no”
Age of property (years)	Numerical	The approximate age of the garden
Other relevant information	Text	Some participants included additional information about their gardens

plants within the data set include plums (*Prunus domestica*), apples (*Malus domestica*), soft fruit in the genus *Rubus*, Brazilian pepper (*Schinus terebinthifolia*), coriander (*Coriandrum sativum*) and edible Brassicaceae, mainly *Raphanus* and *Brassica* spp.

The phylogenetic diversity of the pollinators extended across 12 orders of invertebrates, 10 of them insects, and four orders of vertebrates. The most frequently encountered pollinators belonged to the genus *Bombus* (2,566 records, 19.5% of the

pollinators) whilst the single most common species was, unsurprisingly, the ubiquitous Western honeybee (*Apis mellifera*) with a total of 1,536 records (11.7%). Although we have not categorised the plants and flower visitors as native or exotic in the region in which the gardens were surveyed, this could easily be done and would provide important insights into the role of non-native flora in supporting pollinator populations, and the potential for species such as *A. mellifera* to compete with other pollinators.

**Table 2: Explanation of the data set. Note that for some items, where data are missing “NA” has been added.**

Data item	Format	Description
Five letter identifier	Text	A code that identifies each garden (refer to Metadata)
Survey type	Text	Refer to text. Options are “A”, “B”, “C”
Date	Text	The date in 2020 on which the survey was carried out. Format is DD/MM/ (day/month/)
Day of the year	Numerical	The day of the year on which the survey was conducted, with 1 <sup>st</sup> January = 1
Start time	Numerical	The time at which the survey commenced, format = 24-hour clock
Duration (min)	Numerical	The length of the survey in minutes
Plant family	Text	The taxonomic family to which the observed plant species belongs
Plant genus	Text	The taxonomic genus to which the observed plant species belongs
Plant species	Text	The taxonomic identity of the plant species observed
Plant species comments	Text	Relevant information about the plant species concerned, e.g. the variety or common name
Total floral cover (m <sup>2</sup> )	Numerical/Text	The approximate area of flowers of that species. Values are numerical and in square metres, except for very small areas in which the “<” symbol has been used to qualify the number
Number of floral units	Numerical/Text	The approximate number of flowers or inflorescences present. In some cases, this has been qualified with a “+” symbol
Flower visitor order	Text	The taxonomic order to which the observed flower visitor species belongs
Flower visitor family	Text	The taxonomic family to which the observed flower visitor species belongs
Flower visitor genus	Text	The taxonomic genus to which the observed flower visitor species belongs
Flower visitor species	Text/Numerical	The taxonomic identify of the flower visitor species observed. A zero (“0”) indicates that no flower visitor was observed
Sex/caste	Text	The sex (“male”, “female”) or bee caste “worker”, “queen”) when noted
Flower visitor species comments	Text	Some participants included additional information about the flower visitor species
Number of individuals	Numerical	The number of individual flower visitors observed
Number of flowers visited	Numerical	The number of floral units on which the flower visitor foraged
Photo or specimen taken?	Text	Whether or not a physical record of the flower visitor was preserved

#### DATA ACCESSIBILITY

The full data set is included as a CSV file with this publication as Supplementary Information 1; the metadata are included as a CSV file as Supplementary Information 2. In addition, the data and metadata are publicly available in Zenodo:

[https://zenodo.org/record/6342284#.Yikz\\_O7P2kY](https://zenodo.org/record/6342284#.Yikz_O7P2kY)

#### DISCUSSION

This is the largest data set of garden flower visitors ever assembled and is clearly a product of the COVID-19 pandemic; as such we hope that the circumstances under which the data were collected are never repeated. The pandemic, however, provided a unique opportunity for pollinator experts from across the globe to collaborate in the collection of valuable research data. One of the positive aspects of this has been that constraints on field work have resulted in a more local focus on biodiversity that has turned up some surprising results. For example, there is at least one case in our data set of confirmation of a bee species new to a country: *Megachile nigrirostris* new to Belgium, discovered by Nicolas Vereecken. Similarly, the scarce UK species *Andrena labiata* was discovered in the first author's garden, its only record in Northamptonshire in decades. Finally, a close focus on her garden in 2020 enabled Ellen Rotheray to describe the puparium and development site of the hoverfly *Rhingia rostrata* for the first time (Rotheray & Rotheray 2021). This highlights the fact that even trained ecologists are sometimes not fully aware of the species present in their immediate vicinity.

This paper is the first output from the data set and more will appear in the coming years as members of the team focus on a range of questions. For example: how does garden location and structure affect the patterns that we observe; are there differences between urban versus rural gardens; what influence does garden area and landscape structure (habitat area and connectivity) have on pollinator diversity; which ornamental plant species support pollinators of food plants? Our data should also contribute to discussions about the value of native versus exotic garden plants for pollinators (Corbet et al. 2001; Pardee & Philpott 2014; Garbuzov et al. 2014; Salisbury et al. 2015; Rollings & Goulson 2019; Giovanetti et al.

2020; Staab et al. 2020; Mata et al. 2021). With additional data gleaned from the literature it should also be possible to address questions such as: Do pollinators prefer plants of similar nutritional quality across the globe? Does the trait-matching between flower and pollinators change in different gardens or continents?

There are a number of potential biases within this data set that must be acknowledged. The first is that the gardens of pollination ecologists may not be representative of those of the wider population. However significant garden heterogeneity has been documented in other studies of garden pollinators and resources (e.g. Prendergast & Ollerton 2021; Tew et al. 2022). There were also a number of surveyors who were isolating with parents or other relatives and therefore not conducting surveys in their own gardens. In addition, a small number of the gardens were actually public spaces. We note also that during the lockdown period there was greater garden use by occupants, plus a decrease in road and air traffic, and other human activities, that might have influenced the patterns of flower visitation observed.

There are further geographical biases with respect to where the participants lived. The project began as a UK-based initiative, though soon expanded as word spread, and hence there is a high proportion of data from the UK. As with most ecological studies, there is a lack of data from low-income countries, especially in the Global South, but if opportunities arise for additional surveys these could be added, and we would update the data set in Zenodo. Having said that, it's important to emphasise that the locations of the surveys do cover a wide range of climates and elevations, adjacent to a variety of biomes, in different levels of urbanisation, which makes this standardised data set a unique and valuable contribution to researchers interested in flower visitors and their nectar and pollen sources.

In addition to these geographic biases, there will also be a non-random set of plants (and potentially pollinators) included within the surveys because gardeners usually choose plants for their perceived attractiveness and their climatic and edaphic tolerance of where they are planted. These in turn attract flower visitors that are able to exploit those flowers, and which may have a

strong association with human settlements. However, rather than being biases *per se*, we would see these as interesting patterns that could be explored within the data set, for example looking at similarities in the plants and pollinators that widely different types of gardens host. Such phylogenetic patterns are not, of course, independent from geographical biases, nor are they separate from the issue of representativeness. As pollination ecologists, the participants are likely to be more aware than most of the importance of allowing “weeds” to grow that are important for pollinators, such as ragworts, dandelions, and clovers. But again, we see the future potential of comparing such gardens, in which herbicides and pesticides are infrequently or never used, with more typical gardens. The question of the representativeness, or otherwise, of our results is something that could be addressed in the future by comparing these data with previously published studies or by repeat-surveys of some of these sites.

Although we have set up working groups to consider these questions, and others, we wish to make the data set freely available to anyone who wishes to use it in their research, especially those ecologists whose data collection opportunities were curtailed by the pandemic. We ask only that this paper is cited in return.

Finally, we dedicate our paper, with our grateful thanks, to all of the front-line workers, health professionals and scientists who worked hard to steer the world through one of the most difficult periods in modern times.

#### ACKNOWLEDGEMENTS

We acknowledge our various institutions and employers who supported this work in different ways, and thank the two anonymous referees who provided valuable comments on the initial submission.

#### APPENDICES

Additional supporting information may be found in the online version of this article:

Table S1. Site visited, their location and the number of times they were visited

#### REFERENCES

- Baldock KCR (2020) Opportunities and threats for pollinator conservation in global towns and cities. *Current Opinion in Insect Science* 38:63-71.
- Baldock KCR, Goddard MA, Hicks DM, Kunin WE, Mitschunas N, Osgathorpe LM, Morse H, Potts SG, Robertson KM, Scott AV, Staniczenko PPA, Stone GN, Vaughan IP, Memmott J (2019) A systems approach reveals urban pollinator hotspots and conservation opportunities. *Nature Ecology and Evolution* 3:363-373.
- Bendifallah L, Ortiz-Sánchez FJ (2018) Flowering plants preferred by native wild bees (Hymenoptera Apoidea Apiformes) in Algerian littoral region. *Journal of Fundamental and Applied Sciences* 10:172-190.
- Camps-Calvet M, Langemeyer J, Calvet-Mir L, Gomez-Baggethun E (2016) Ecosystem services provided by urban gardens in Barcelona Spain: insights for policy and planning. *Environmental Science and Policy* 62:14-23.
- Carvell C, Isaac NJB, Jitlal M, Peyton J, Powney GD, Roy DB, Vanbergen AJ, O'Connor RS, Jones CM, Kunin WE, Breeze TD, Garratt MPD, Potts SG, Harvey M, Ansine J, Comont RF, Lee P, Edwards M, Roberts SPM, Morris RKA, Musgrove AJ, Brereton T, Hawes C, Roy HE (2016) Design and Testing of a National Pollinator and Pollination Monitoring Framework. Final summary report to the Department for Environment, Food and Rural Affairs (Defra), Scottish Government and Welsh Government: Project WC1101.
- Corbet SA, Bee J, Dasmahapatra K, Gale S, Gorringer E, La Ferla B, Moorhouse T, Trevail A, Van Bergen Y, Vorontsova M (2001) Native or exotic? Double or single? Evaluating plants for pollinator-friendly gardens. *Annals of Botany* 87:219-232.
- Davies ZG, Fuller RA, Loram A, Irvine KN, Sims V, Gaston KJ (2009) A national scale inventory of resource provision for biodiversity within domestic gardens. *Biological Conservation* 142:761-771.
- Erenler H (2013) The diversity of pollinators in the gardens of large English country houses. PhD thesis, University of Northampton.
- Foster G, Bennett J, Sparks T (2017) An assessment of bumblebee (*Bombus* spp.) land use and floral preference in UK gardens and allotments cultivated for food. *Urban Ecosystems* 20:425-434.
- Garbuzov M, Ratnieks FLW (2014) Quantifying variation among garden plants in attractiveness to bees and other flower-visiting insects. *Functional Ecology* 28:364-374.
- Giovanetti M, Giuliani C, Boff S, Fico G, Lupi D (2020) A botanic garden as a tool to combine public perception of nature and life-science investigations on



- native/exotic plants interactions with local pollinators. *PLoS ONE* 15(2) e0228965.
- Klein A-M, Vaissière BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, Tscharntke T (2007) Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society of London B* 274:303–313.
- Levé M, Baudry E, Bessa-Gomes C (2019) Domestic gardens as favorable pollinator habitats in impervious landscapes. *Science of the Total Environment* 647:420–430.
- Majewska AA, Altizer S (2020) Planting gardens to support insect pollinators. *Conservation Biology* 34:15–25.
- Marín L, Martínez-Sánchez ME, Sagot P, Navarrete D, Morales H (2019) Floral visitors in urban gardens and natural areas: Diversity and interaction networks in a neotropical urban landscape. *Basic and Applied Ecology* 43:3–15.
- Maruyama PK, Bonizário C, Marcon AP, D'Angelo G, da Silva MM, da Silva Neto EN, Oliveira PE, Sazima I, Sazima M, Vizentin-Bugoni J, dos Anjos L, Rui AM, Marçal Júnior O (2019) Plant-hummingbird interaction networks in urban areas: Generalization and the importance of trees with specialized flowers as a nectar resource for pollinator conservation. *Biological Conservation* 230:187–194.
- Mata L, Andersen A, Morán-Ordóñez A, Hahs A, Backstrom A, Ives C, Bickel D, Duncan D, Palma E, Thomas F, Cranney K, Walker K, Shears I, Semeraro L, Malipatil M, Moir M, Plein M, Porch N, Vesik P, Smith T, Lynch Y (2021) Indigenous plants promote insect biodiversity in urban greenspaces. *Ecological Applications* 31:e02309.
- Matteson KC, Ascher JS, Langellotto GA (2008) Bee richness and abundance in New York City urban gardens. *Annals of the Entomological Society of America* 101:140–150.
- Millard J, Outhwaite CL, Kinnersley R, Freeman R, Gregory RD, Adedjoja O, Gavini S, Kioko E, Kuhlmann M, Ollerton J, Ren Z-X, Newbold T (2021) Global effects of land-use intensity on local pollinator biodiversity. *Nature Communications* 12, 2902 <https://doi.org/10.1038/s41467-021-23228-3>.
- Norfolk O, Eichhorn M, Gilbert F (2013) Traditional agricultural gardens conserve wild plants and functional richness in arid South Sinai. *Basic and Applied Ecology* 14:659–669.
- Norfolk O, Eichhorn M, Gilbert F (2014) Culturally valuable minority crops provide successional resources for flower visitors in orchard gardens. *Biodiversity and Conservation* 23:3199–3217.
- Ollerton J (2017) Pollinator diversity: distribution ecological function and conservation. *Annual Review of Ecology Evolution and Systematics* 48:353–376.
- Ollerton J (2021) *Pollinators & Pollination: Nature and Society* Pelagic Publishing, Exeter.
- Ollerton J, Tarrant S, Winfree R (2011) How many flowering plants are pollinated by animals? *Oikos* 120:321–326.
- Owen J (2010) *Wildlife of a Garden: A Thirty-Year Study*. Royal Horticultural Society, Peterborough.
- Pardee GL, Philpott SM (2014) Native plants are the bee's knees: local and landscape predictors of bee richness and abundance in backyard gardens. *Urban Ecosystems* 17:641–659.
- Potts SG, Biesmeijer JC, Kremen C, Neumann P, Schweiger O, Kunin WE (2010) Global pollinator declines: trends impacts and drivers. *Trends in Ecology and Evolution* 25:345–353.
- Prendergast KS (2021) Natural history note: Urban domestic gardens support nesting populations of the native bee *Leioproctus (Leioproctus) plumosus*. *Austral Ecology* 47:131–136.
- Prendergast KS, Ollerton J (2021) Plant-pollinator networks in Australian urban bushland remnants are not structurally equivalent to those in residential gardens. *Urban Ecosystems* 24:973–987.
- Prendergast KS, Dixon KW, Bateman PW (2022) A global review of determinants of native bee assemblages in urbanised landscapes. *Insect Conservation and Diversity* 15:385–405. <https://doi.org/10.1111/icad.12569>.
- Rodger JG, Bennett JM, Razanajatovo M, Knight TM, van Kleunen M, Ashman T-LJ, Steets A, Hui C, Arceo-Gómez G, Burd M, Burkle LA, Burns JH, Durka W, Freitas L, Kemp JE, Li J, Pauw A, Vamosi JC, Wolowski M, Xia J, Ellis AG (2021) Widespread vulnerability of plant seed production to pollinator declines. *Science Advances* 7:eabd3524. doi: [org/10.1126/sciadvabd3524](https://doi.org/10.1126/sciadvabd3524).
- Rollings R, Goulson D (2019) Quantifying the attractiveness of garden flowers for pollinators. *Journal of Insect Conservation* 23:803–817
- Rotheray EL, Rotheray GE (2021) The puparium and development site of *Rhingia rostrata* (Linnaeus) and comparison with *R. campestris* Meigen (Diptera Syrphidae). *Dipterists Digest* 28:127–134.
- Salisbury A, Armitage J, Bostock H, Perry J, Tatchell M, Thompson K (2015) Enhancing gardens as habitats for flower-visiting aerial insects (pollinators): should we plant native or exotic species? *Journal of Applied Ecology* 52:1156–1164.
- Staab M, Pereira-Peixoto MH, Klein AM (2020) Exotic garden plants partly substitute for native plants as resources for pollinators when native plants become seasonally scarce. *Oecologia* 194:465–480.

Tew NE, Memmott J, Vaughan IP, Bird S, Stone GN, Potts SG, Baldock KCR (2021) Quantifying nectar production by flowering plants in urban and rural landscapes. *Journal of Ecology* 109:1747-1757.

Tew NE, Baldock KCR, Vaughan IP, Bird S, Memmott J (2022) Turnover in floral composition explains species diversity and temporal stability in the nectar supply of

urban residential gardens. *Journal of Applied Ecology* 59:801-811.

Theodorou P, Radzevičiūtė R, Lentendu G, Kahnt B, Husemann M, Bleidorn C, Settele J, Schweiger O, Grosse I, Wubet T, Murray TE, Paxton RJ (2020) Urban areas as hotspots for bees and pollination but not a panacea for all insects. *Nature Communications* 11, 576 <https://doi.org/10.1038/s41467-020-14496-6>.

#### AUTHOR AFFILIATIONS:

<sup>1</sup>Faculty of Arts, Science and Technology, University of Northampton, Waterside Campus, UK

<sup>2</sup>Kunming Institute of Botany, Kunming, Yunnan, China

<sup>3</sup>Negaunee Institute for Plant Conservation Science and Action, Chicago Botanic Garden, 1000 Lake Cook Road, Glencoe, IL 60022 USA

<sup>4</sup>General Zoology, Institute for Biology, Martin-Luther University Halle-Wittenberg, Hoher Weg 8, 06120 Halle (Saale), Germany

<sup>5</sup>Cellular and Organismic Networks, Faculty of Biology, Ludwig-Maximilians-Universität München, 82152 Planegg-Martinsried, Germany

<sup>6</sup>Hawkesbury Institute for the Environment, Western Sydney University, Hawkesbury Campus, Science Rd, Richmond NSW 2753, Australia

<sup>7</sup>Universidade Federal dos Vales do Jequitinhonha e Mucuri (UFVJM), Faculdade Interdisciplinar em Humanidades, Curso de Licenciatura em Educação do Campo, LEC Sala 157 DEF, Campus JK, Diamantina, Minas Gerais, Brasil

<sup>8</sup>Universidade de São Paulo, Instituto de Biociências (IB-USP), Departamento de Ecologia, São Paulo, Brasil

<sup>9</sup>University of Exeter, Environment and Sustainability Institute, Penryn Campus, University of Exeter, Penryn TR10 9FE, UK

<sup>10</sup>School of Life Sciences, University of Sussex, Brighton, BN1 4GE, UK

<sup>11</sup>School of Agriculture and Food Science, University College Dublin, Dublin 2, Ireland

<sup>12</sup>Department of Entomology, Center for Pollinator Research, Huck Institute of the Life Sciences, The Pennsylvania State University, University Park, PA 16802, USA

<sup>13</sup>University of Oxford, Department of Zoology, South Parks Road, Oxford, OX1 3SZ

<sup>14</sup>Department of Entomology, Millennium Science Complex, University Park, Pennsylvania State University, PA 16802, USA

<sup>15</sup>Faculty of Environment and Natural Resources, University of Freiburg, Tennenbacherstraße 4, 79106 Freiburg, Germany

<sup>16</sup>Department of Natural Sciences, Manchester Metropolitan University, Chester Street, Manchester, M1 5GD, UK

<sup>17</sup>School of Applied Sciences, Edinburgh Napier University, Edinburgh, EH11 4BN, UK

<sup>18</sup>Joseph Banks Laboratories, School of Life and Environmental Sciences, University of Lincoln, Lincoln, LN6 7TS, UK

<sup>19</sup>Institute of Evolutionary Biology, University of Edinburgh, Ashworth Laboratories, Charlotte Auerbach Road, Edinburgh, EH9 3FL, UK

<sup>20</sup>Estación Biológica de Doñana (EBD-CSIC), Avda. Américo Vespucio 26, E-41092 Sevilla, Spain

<sup>21</sup>Department of Ecological Sciences, James Hutton Institute, Aberdeen, AB15 8QH, UK

<sup>22</sup>Grupo de Investigación Biología para la Conservación, Universidad Pedagógica y Tecnológica de Colombia, Avenida Central del Norte 39-115, 150003 Tunja, Colombia

<sup>23</sup>Curtin University School of Molecular & Life Sciences, Kent Street, Bentley, Perth, Western Australia 6102, Australia

<sup>24</sup>Wildlife Trust BCN, Lings House, Lings Way, Northampton NN3 8BE, UK

<sup>25</sup>CREA Council for Agricultural Research and Agricultural Economy Analysis, Research Centre for Agriculture and Environment, Bologna, Italy

<sup>26</sup>Departamento de Biodiversidade e Conservação da Natureza, Universidade Tecnológica Federal do Paraná, Via Rosalina Maria dos Santos 1233, CEP: 87301-899, Campo Mourão, Paraná, Brasil

<sup>27</sup>Biodiversity Research Centre, Earth & Life Institute, UCLouvain, Louvain-la-Neuve, Belgium

<sup>28</sup>Department of Entomology and Nematology, University of Florida, 1881 Natural Area Drive, Gainesville, FL 32611, USA

<sup>29</sup>[home address redacted] St Helens, Merseyside, UK

<sup>30</sup>School of Biological Sciences, Monash University, Clayton, Victoria, Australia

<sup>31</sup>Centre for Integrative Ecology, School of Life and Environmental Sciences, Deakin University, Burwood, Victoria, Australia

<sup>32</sup>Plant-Insect Interactions, Technical University of Munich, Hans-Carl-von-Carlowitz-Platz 2, 85354 Freising, Germany

<sup>33</sup>Department of Ecology and Animal Biology, University of Vigo, Vigo, Pontevedra, Spain

<sup>34</sup>School of Biological Sciences, Life Sciences Building, University of Bristol, 24 Tyndall Avenue, Bristol, BS8 1TQ, UK

<sup>35</sup>Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, Texas 75962, USA

- <sup>36</sup>Department of Life Sciences, Natural History Museum, Cromwell Road, London, SW7 5BD, UK
- <sup>37</sup>Institute of Evolution and Ecology, School of Life Sciences, Central China Normal University, Wuhan, 430079 China
- <sup>38</sup>Integrated Land Management, SRUC, Auchincruive Estate, Ayr, KA6 5HW, UK
- <sup>39</sup>Université M'hamed Bougara de Boumerdes, Faculté des Sciences, Laboratoire des technologies douces, valorisation, physico-chimie des matériaux biologiques et biodiversité, 1 Avenue de l'Indépendance 35000 Boumerdes, Algeria
- <sup>40</sup>Department of Animal and Plant Science, The University of Sheffield, Western Bank, S10 2TN, UK
- <sup>41</sup>Department of Environmental Sciences, Western Norway University of Applied Sciences, P.O. Box 133, NO-6851 Sogndal, Norway
- <sup>42</sup>Department of Agricultural, Forest and Food Sciences, Università degli Studi di Torino, Largo Paolo Braccini, 10095, Turin, Italy
- <sup>43</sup>Department of Plant Sciences, University of Oxford, South Parks Road, Oxford, OX1 3RB, UK
- <sup>44</sup>University of Ulm, Institute of Evolutionary Ecology and Conservation Genomics, Albert-Einstein-Allee 11, 89081 Ulm, Germany
- <sup>45</sup>University of Würzburg, Department of Animal Ecology and Tropical Biology, Biocenter, Am Hubland, 97074 Würzburg, Germany
- <sup>46</sup>[home address redacted] Ashton Under Lyne, Greater Manchester, UK
- <sup>47</sup>Department of Plant and Crops, Faculty of Bioscience Engineering, Ghent University, Ghent, Belgium
- <sup>48</sup>School of Biological Sciences, University of Portsmouth, Portsmouth PO1 2DY, UK
- <sup>49</sup>Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, Alaska 99775, USA
- <sup>50</sup>Sussex Biodiversity Record Centre, Woods Mill, Shoreham Rd, Henfield BN5 9SD, UK
- <sup>51</sup>Département d'Agronomie, Faculté des Sciences, Laboratoire de Bioinformatique, Microbiologie Appliquée et Biomolécules (BMAB), Université M'Hamed Bougara de Boumerdes, Algérie
- <sup>52</sup>Steven Falk: [home address redacted] Kenilworth, Warwickshire, UK
- <sup>53</sup>School of Ecosystem and Forest Sciences, University of Melbourne, Parkville 3010, Australia
- <sup>54</sup>Centre for Agroecology, Water and Resilience (CAWR) Coventry University, Ryton Organic Gardens, Coventry, CV8 3LG, UK
- <sup>55</sup>UK Centre for Ecology & Hydrology, Maclean Building, Benson Lane, Wallingford, OX10 8BB, UK
- <sup>56</sup>University of East Anglia, Norwich Research Park, Norwich, NR4 7TJ, UK
- <sup>57</sup>School of Biology, Faculty of Biological Sciences, University of Leeds, Leeds, LS2 9JT, UK
- <sup>58</sup>Department of Health Studies, School of Life Sciences and the Environment, Royal Holloway, University of London Egham, Surrey, TW20 0EX, UK
- <sup>59</sup>Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università di Bologna, via Irnerio 42, Bologna, Italy
- <sup>60</sup>Sustainability Research Institute (SRI), University of East London, Knowledge Dock Building, Docklands Campus, 4-6 University Way, London E16 2RD, UK
- <sup>61</sup>Dutch Butterfly Conservation, Mennonietenweg 10, 6702 AD Wageningen, The Netherlands
- <sup>62</sup>Laboratório de Polinização, Reprodução e Fenologia de Plantas (LPRF)/InBio, Universidade Federal de Mato Grosso do Sul, Campo Grande/MS, Brazil
- <sup>63</sup>Agroecology Lab CP 264/02, Université libre de Bruxelles (ULB), Av. FD Roosevelt 50, B-1050 Brussels, Belgium
- <sup>64</sup>Nature Conservation and Landscape Ecology, Albert-Ludwigs-University Freiburg, Tennenbacher Str. 4, 79106 Freiburg, Germany
- <sup>65</sup>Department of Geography and Environmental Sciences, Ellison Building, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK
- <sup>66</sup>Natural Resources Institute, University of Greenwich, Chatham Maritime, Kent, ME4 4TB, UK
- <sup>67</sup>Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania