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

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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

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^2 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) 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 16th March (day 76) and 14th 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

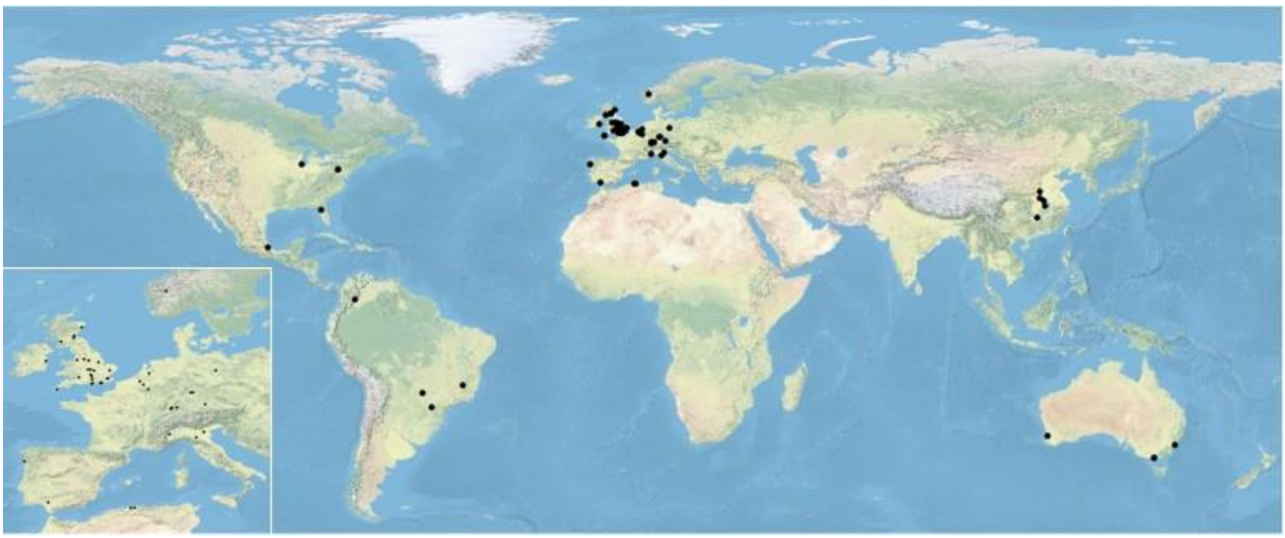

Figure 1: Locations of the gardens surveyed in this study, globally (main map) and within Europe and the Mediterranean (inset map).

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 m² to 8,000 m² 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 (m²)	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 1st 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^2)	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

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 nigriventris* 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 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.

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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

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