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Using Citizen Science to Monitor Pollination Services

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Abstract

1) Pollination by insects is a vital ecosystem service and the need for its assessment is increasing in recognition and political pressure, but there are currently no large-scale systematic monitoring schemes in place to measure the direct provision of this service.
2) This study tested a protocol for using a Citizen science approach to quantify pollination service provision in gardens and allotments, requiring participants to grow *Vica faba* plants and carry out some simple manipulations of the pollination environment (flowers with bees excluded, flowers hand-pollinated, or flowers left for local pollinators to visit). Volunteers assessed yield in the three treatments.
3) Eighty participants from across the UK successfully completed all parts of the protocol; a further ninety three participants were unsuccessful but actively engaged with the project
4) Overall, our results suggest that pollination services for *V. faba* are currently not limiting in gardens or allotments in the UK. It is possible and cost-effective to recruit volunteers to collect data on pollination deficits using this protocol.
5) The approach used in this paper, which could readily be extended to incorporate other plant species reliant on different guilds of pollinators, is feasible for adoption as a national monitoring scheme for pollination services.

Introduction

Human societies receive goods and benefits as a result of natural processes. Such benefits are commonly considered within the developing frameworks of ‘Ecosystem Services’ (Costanza *et al.*, 1997; Haines-Young & Potschin, 2010; Bateman *et al.*, 2013), and in a world ever more influenced by human decisions there is an increasing need for informed consideration of how these services are realised, and how they are affected by anthropogenic actions. Animal-mediated pollination is one such ecosystem service, which is vitally important for the production of many crops, and as a wider contributor to the maintenance of robust natural ecosystems (Dicks *et al.*, 2013; Vanbergen *et al.*, 2014). In temperate regions in particular, the majority of pollination services are provided by insects, especially bees and hoverflies (Klein *et al.*, 2007; Kremen *et al.*, 2007; Jauker & Wolters, 2008).

Realistic assessment of the value of any ecosystem service relies on accurate information about the need for that service and good understanding of the processes involved in the delivery (Costanza *et al.*, 1997; Haines-Young & Potschin, 2010; Bateman *et al.*, 2013), and pollination services are no exception (Winfree *et al.*, 2011). Current valuation estimates of pollination services – based on existing understanding and manipulations of the insect-pollinator relationship – are not without debate (Ghazoul, 2005; Steffan-Dewenter *et al.*, 2005; Klein *et al.*, 2007), but even widely varying estimates illustrate the scale of the service being considered. Recent estimates of the global value of pollination range between $112 to $200 billion annually (Costanza *et al.*, 1997; Kremen *et al.*, 2007), and agricultural pollination alone is estimated as worth €153 billion (Gallai *et al.*, 2009). In Europe, 84% of crop species are dependent on pollination for improving yield and quality to some extent (Klein *et al.*, 2007), and the recent UK National Ecosystem Assessment (NEA) valued the contribution of pollination to UK crop yields at £430 million in 2007, representing 8% of the market at the time (Smith *et al.*, 2011).

To date there is no *standard* method of valuing pollination services and no long-term monitoring programmes in place to collect relevant data, although this is acknowledged as a priority area (Dicks *et al.*, 2013). The recent National Pollinator Monitoring Strategy for England sets out a 10-year plan for supporting pollination services, emphasising the need to develop a monitoring framework for pollinators using 'Citizen Scientists' (Defra, 2014) i.e. volunteers participating in data collection often under instructions from professional scientists. Many existing systematic wildlife monitoring schemes already use that approach (Dickinson *et al.*, 2010), as it enables such schemes to cover much larger spatial and temporal scales than would otherwise be possible, due to time, cost or personnel restrictions, but still gather reliable information (Schmeller *et al.*, 2009; Silvertown, 2009; Kremen *et al.*, 2011). These large-scale observational projects are important sources of information for conservation planning (Mackechnie *et al.*, 2011; Roy *et al.*, 2012).

The requirement for adequate pollination provision is not restricted to agricultural settings or semi-natural areas. As the human population continues to increase, so does the proportion of global land area that can be considered to be ‘urbanised’, and fifty-four percent of the world’s population now live in urban areas (WHO, 2014). These urban environments vary in terms of the characteristics of the ‘green’ spaces present, but pollination is still required for urban / peri-urban agriculture, for garden and allotment produce, and by wild plants growing in built environments. Urban crop yields are not recorded on any systematic basis, and although some studies have shown greater seed set in garden plants (Cussans *et al.*, 2010; Samnegård *et al.*, 2011), it is not known if urban pollination represents a limiting or adequate service provision. Urban environments are particularly amenable to Citizen science schemes, containing a large population of potential observers (Davies *et al.*, 2011) and enabling participants to literally ‘do it at home’.

The intention of our project is to test whether monitoring the level of pollination service provision present in green spaces can be achieved using Citizen science to collect data; and if such an approach reveals a current deficit in the UK. Schemes which aim to survey the make-up of the pollinator community (such as the Urban Pollinators Project, led by the University of Bristol, under the Insect Pollinator’s Initiative), or generate trend data for pollinator populations (particularly schemes such as the Bumblebee Conservation Trust (BBCT) ‘Beewalks’, and the Great British Bee Count), are underway both in the UK and internationally (Westphal *et al.*, 2008). Similarly, the Great Sunflower Project in the US, which requires participants across the country to grow a sunflower at home, and record the frequency of insect visitors (Oberhauser & LeBuhn, 2012) illustrates the ability of Citizen science studies to operate at a national scale. The Urban Pollination Project currently underway at Washington University uses a similarly detailed protocol (with hand-pollinated, local-pollinated and pollinator-excluded plants) on a smaller scale to measure the yield of tomato plants, and pollination success in Seattle community gardens (Potter & LeBuhn, 2015).

However, there are no national-scale monitoring schemes underway that attempt to deploy citizen scientists to assess the provision of the pollination service more directly, examining the level of pollination occurring, rather than extrapolating from the potential population of pollinators present.

In our study, project participants grew pollination-dependent plants, conducted simple manipulations, and recording the resulting yields, to determine if the existing pollinator community was providing an adequate or limiting service. *Vica faba*, commonly known as 'Broad' or 'Field' bean, was selected as the experimental plant, due to its pollination requirement (pollinated primarily by long-tongued bumblebees, with some pollination from smaller bees such as honeybees (Free, 1966; Kendall & Smith, 1975)), its popularity as a garden crop, and the ease of growing the plants from seed and maintaining them once matured. Cage experiments to manipulate pollinator access to *V.faba* flowers have shown that while the plant is capable of some self-compatibility – with the amount varying by cultivar and proportion of hybrid plants – mechanical action by insect pollinators (or by manual 'tripping' of the flowers) increases yield by about a third (Drayner, 1959; Hanna & Lawes, 1967; Kendall & Smith, 1975; Free & Williams, 1976). Yield should thus be sensitive to a deficit of pollinator visits.

Methods

Survey methods

In February 2014 members of the public were invited to participate in the first season of the project, titled "*Bees 'n Beans"* and scheduled to commence in April 2014. Recruitment was primarily achieved via online social media (Twitter, websites and articles in the BBCT newsletters). Volunteers' names, postal addresses, and email addresses were collected online using a poll, with a total of 551 initial participants. No further selection criteria were applied to the volunteers within the sign-up group, all valid addresses were included.

Project kits were posted to the participants in March 2014 (across seven consecutive working days), and contained 12 seeds of a dwarf variety of *V. faba* ("The Sutton", supplied by D.T. Brown Seeds, www.dtbrownseeds.co.uk), 1m^2 of insect exclusion netting, 8x1.5 L fold-down PVC pots, instructions and recording sheets. Updates to the instructions, video recording showing the methodology, and ongoing communication with participants were conducted by email. A help-line was provided by email and telephone to cover requests for assistance.

Participants were required to germinate all seeds in the pack and grow eight plants in the provided pots, using commercially available compost as the growing medium (not provided; purchased by participants). Soil quality, and other environmental conditions were therefore standardised within sites, but not between them. Participants were asked to select four similar sized plants as their experimental plants before flowering began. The treatments were randomly allocated to these plants, using an online random number generator to select which plant received which treatment (http://www.random.org/). One plant had pollinators excluded with the provided netting (the 'netted' plant), one plant would be cross-pollinated by hand every two days (the 'hand pollinated' plant) and one plant was left to the actions of local pollinators (the 'local-pollinated' plant); the spare plant provided pollen for hand-pollination.

Hand-pollination was achieved by removing the anthers from flowers on the spare plant, opening the hand-pollinated plant flowers by pulling down gently on the lower petals, and applying the removed anthers across the stigma of the open flower. Removed anthers were used to pollinate three hand-pollinated flowers, then discarded and replaced. Ten weeks after flowering started, volunteers counted and recorded the resulting pods and their weight, plus the number and weight of beans from each treatment. Electronic kitchen scales, correct to the nearest gram, were generally used to weigh the beans.

During the experiment, participants recorded information about the characteristics of the individual sites involved on the provided recording sheets (the categories are listed in Table 1). Participants were also asked to record any flower visitors seen during 15 minute observation periods during flowering, and to note what proportion of flowers had suffered from robbing. This information was returned to the research group using an online questionnaire.

Participants were asked to inform the research group if their experiment failed and to provide information on why this had occurred. They were encouraged via email reminders to return the final results using the online recording sheet. They were also requested to complete an evaluation form at the end of the project, whether their harvest had been successful or not.

Site characteristics

ARC GIS was used to extract the ‘private garden’ polygons from OS Mastermap Topographic layer, in 500m circles centred around each site address (or postcode centre, if the address could not be geocoded). The area of gardens within each surrounding 500m circle was included in the analysis, to examine if ‘urban’ areas with different proportion of managed garden spaces showed differences in the pollination provision within those sites.

Statistical analysis

Statistical analysis was carried out in SPSS 22, using Generalised Linear Models (GLMs) to compare the yield measurements (number or weight of pods and beans) for each treatment, and by the other factors listed in Table 1. Weights of pods and beans were analysed with normal errors, while pod and bean numbers were over-dispersed counts and so were analysed with negative binomial errors with a log link. All factors listed in Table 1 were fitted to the initial model as main effects and relevant interaction terms, with model simplification via stepwise removal of non-significant factors (Dougherty & Shuker, 2014). Post hoc pairwise comparisons were obtained through the SPSS GLM interface, with dummy-coding of categorical explanatory variables performed automatically by the SPSS software.

Hand-pollination method comparison

The supplementary hand-pollination method used in the protocol requires cross-pollination from spare plants, in accordance with the methods used in agricultural field studies (Free, 1966; Garratt *et al.*, 2014). However, *V. faba* varieties vary in their level of self-compatibility (Drayner, 1959; Hanna & Lawes, 1967). The protocol used cross-pollination because we had not tested if there is a difference in yield produced by cross-pollination and mechanical tripping alone in this variety of *V. faba* (“The Sutton”). The crossing method is more complex, and involves more physical handling of the flowers than tripping requires, so tripping may be more suitable for a citizen science protocol if it is equally effective.

To enable comparison of hand-pollination methods, with the potential to simplify the protocol for citizen scientists in future years, a supplementary study was carried out. Seventy-five seeds were planted in 1.5L pots in a glasshouse at University of Sussex. At seven weeks, before flowering began, 50 plants were paired for growth form (same height, number of stems), and one of each pair assigned randomly to either the hand pollination treatment (using cross-pollination, see *2.1.*), or to a treatment where the flowers were 'tripped' only (opened and closed four times), with no cross-pollination. The remaining plants were kept under the same conditions as a source of pollen.

The test plants were randomly positioned in a pollinator-excluded greenhouse, created by covering all vents in mesh fabric. Plants were kept well watered, hand-pollinated every two days, and fed 25ml of a domestic-use tomato feed ("J. Arthur Bower's – Ready To Use") twice a week. Flowering occurred approximately 6 weeks after planting, and volunteers were asked to harvest pods 10 weeks after flowering, with number and weight of pods and beans recorded. However, because of differences in volunteer access to sites, and participants needing to be away from home during the experiment, there was some variation in the precise timing.

Statistical analysis was carried out in SPSS 22, using Generalised Linear Models (GLM) to compare the yield measurements (number or weight of pods and beans) between treatments. Weights of pods and beans were analysed with normal errors; pod numbers were analysed with Poisson errors with a log link; and bean numbers were analysed with negative binomial errors with a log link.

Results

Completion rates and cost-effectiveness

Of the original 551 participants, 80 participants successfully completed all parts of the experiment and returned a full data set; the statistical analysis was carried out on these 80 returns. A further 96 participants informed the research group that their project had failed over the course of the experiment. While the majority of the data were from England, with a bias towards the south, the spread of successful participants encompassed Wales and Scotland as well (Figure 1).

Most returns were from individual gardens (61/80), with 3 allotments, 2 communal gardens , 2 'other', and 11 non-responses. Gardens were generally small, with 48 sites (60%) under 200 square metres in area. Sites were predominantly in urban/suburban areas: 24 sites had over 50% of the surrounding 500m square classified as private gardens, 32 sites with 25 % – 50% of surroundings as private gardens, and 22 sites with <25% of surroundings as private gardens.

The most common reported reasons for failure to return data were failed germination of the seeds, or loss of plants to pests, or because the participants forgot to water them. Flower visitor observations and robbing counts proved to be difficult for participants to complete, with low visitor numbers, and difficulty identifying and keeping track of robbed flowers commonly reported; the poor response meant these results were therefore not included in this analysis.

Excluding staff time, the project cost £2500 to run in 2013; with most of that cost taken up by printing (£431), postage (£500), the cost of the netting (£468), and membership of the SurveyMonkey website (£200) for online collection of responses. This equates to £31 per set of useable data.

Is there a pollination deficit?

Analysis of results of the citizen science study showed that only the treatment applied (netted, local, or hand-pollinated) was a significant factor influencing the total number of pods (χ^2_2 = 26.8, p = <0.001, Figure 2a), number of beans (χ^2_2 = 41.5, p = <0.001, Figure 2b), or weight of beans (χ^2_2 = 23.4, p = <0.001, Figure 2d) produced by the experimental plants. The total weight of pods produced by each experimental plants was significantly influenced by treatment (χ^2_2 = 25.4, p = <0.001, Figure 2c), and tended to be higher at sites where the participant was growing additional *V. faba* (χ^2_3 = 10.5, p = 0.015; Figure 3).

Post-hoc pairwise comparison through the GLM interface, with local pollination dummy coded as the reference group, showed the same effect of treatment on all yield measures. Netted plants produced significantly fewer pods (Wald χ^2_1= 24.8, p= <0.001), fewer beans (Wald χ^2_1 = 36.0, p = 0.001), a lower total weight of pods (Wald χ^2_1= 21.0, p =0.001), and a lower total weight of beans (Wald χ^2_1 = 18.4, p = 0.001) than the local pollinated plants. Hand-pollinated plants did not produce significantly different numbers of pods (Wald χ^2_1= 0.98, p = 0.382); numbers of beans (Wald χ^2_1= 0.634, p =0.426); total weights of pods (Wald χ^2_1= 0.228, p =0.633); or total weights of beans (Wald χ^2_1 = 0.052, p = 0.820) compared to the local pollinated plants.

There was no difference between the average weight of the individual beans produced by the local pollinated plants and beans from either the netted plants (Wald χ^2_1=0.089, p=0.765) or the hand-pollinated plants (Wald χ^2_1=0.029, p=0.864). Individual beans were lighter from plants where the period between first flowering and harvest was longer (Wald χ^2_1 =4.01, p=0.045).

Hand pollination method comparison

Pods and beans were successfully harvested from the plants under both hand pollination treatments (tripped or cross-pollinated). There was no significant difference found between any of the yield measurements comparing tripped plants with cross-pollinated plants (number of pods: χ^2_1 = 0.005, p = 0.942; number of beans: χ^2_1 = 0.006, p = 0.938; weight of pods: : χ^2_1 = 0.006, p = 0.936; weight of beans: χ^2_1 = 0.035, p = 0.851).

Discussion

The aim of our study was to test whether citizen science can be used to quantify pollination services at a national scale, and if any deficit in pollination can be detected in the UK. Out of the initial 551 volunteers, 176 remained engaged with the project and communicated with the research group over the course of the experiment (173/551 = 32% engagement). Although the rate of successful completion of the experiment was low (80/551 = 14.5%), we nonetheless obtained a large data set from across a large geographic area.

Long-tongued bumblebees such as *B. hortorum* are the most effective pollinators of *V. faba* flowers (Kendall & Smith, 1975), so if there were an inadequate population of these bees in an area then a pollination deficit in the beans should be observable. Overall, the results of our study suggests that pollination services for *V. faba* are currently not limiting in gardens or allotments in the UK; at least not in this particular year (2014) and when only small numbers of plants are grown. This suggests that the population of long-tongued bees in the experimental areas is sufficient for the provision of the pollination service there. This protocol cannot detect pollination surplus, only whether or not pollination is limiting, and so it cannot reveal how close we may be to a pollination deficit. Detailed observation of flower visitors, as undertaken by Garratt *et al.* (2014), might partly provide such data, but this study's methodology was not designed for this sort of observation, and there is a risk of losing volunteer engagement on additional tasks that require a large time investment. Continuation of data collection over multiple years would allow for trends to be tracked and we would expect sporadic local deficits to precede broader national patterns.

The major significant factor affecting all measurements of bean yield was the treatment applied: excluding pollinators from access to the bean flowers resulted in significantly lower measures of yield than yields from plants which received pollination effort (either hand-pollinated, or provided by the local insects). That is the same pattern shown by Garratt *et al.* (2014) in agricultural field-manipulations of *V. faba*, and by earlier work by Free in crop fields (Free, 1966). However, Free & Williams (1976) showed an improvement of yield with hand-pollination compared to local pollination, which neither our results nor those of (Garratt *et al.*, 2014) indicated. It is possible that pollination is not a limiting factor in garden sites; the sites are quite small, the plants were not densely clustered, and pollinator populations may be higher in urban areas compared to farmland (Owen, 1991; Goulson *et al.*, 2002, 2010; Osborne *et al.*, 2008; Ahrné *et al.*, 2009; Samnegård *et al.*, 2011).

The protocol is not able to differentiate between beans that have set as a result of cross-pollination or by tripping by insect visitors. Average weights of beans produced under each treatment are the same (with the only significant effect on individual bean weight being later harvest dates, when the beans would have started to dry out). It would be possible to identify cross-pollination compared to selfing by genetic analysis, or infer it by more detailed observation of the behaviour of flower visitors (similar to Garratt *et al.,* 2014), but both of these are expensive and labour-intensive, and unsuitable for a Citizen science study on this scale.

The weight of pods was shown to be lower on those sites that were *not* also growing extra *V. faba* plants. Additional plants may attract more pollinators to the site, but since we found no evidence for pollinator limitation this seems unlikely to be the explanation, and this effect was seen when considering all plants in an experimental site, including the netted control. It seems more likely that participants who were already experienced at growing *V.faba,* and so had additional plants on site, were better at avoiding or compensating for horticultural problems that arose during the study. This raises the possibility that the gardening experience of the participants may have a direct effect on results. More experienced gardeners will be more aware of plant health and watering requirements in changing weather conditions which may then improve the weight of pods produced; however this should apply equally across treatments, and so not mask differences between treatments.

Improvements to study design

As there was no difference in the resulting yield of beans (pods or seeds) shown between the methods of hand-pollination (tripping, or manual cross-pollinating) in this variety of *V.faba*, the protocol can be updated for future phases to use the ‘tripping’ method. This involves less handling of the flowers overall, and does not need participants to take apart spare flowers for pollen; thus simplifying the experiment and reducing the number of plants needed.

Based on participant feedback, future phases of the project will be adjusted to reduce common problems encountered. Larger pots would reduce the risk of plants drying in hot weather or problems with watering, and provide additional stability. The variety of *V. faba* was appropriate. More detailed pest-control information will also be provided in addition to the other printed materials.

Targeting experienced gardeners may provide a better rate of return. Assessing the experience of gardeners by questionnaire, or deliberately recruiting volunteers from a community of gardeners, may help to make plant care more consistent. Recruitment of volunteers via gardening web sites or magazines could be beneficial in this. In addition, given how rapid sign-up was achieved, it would be possible to do a second selection within the initial sign-ups to future phases to improve the spread of the geographical coverage and reduce the clustering around the South of England.

Use of “Bees ‘n Beans” as a monitoring scheme

This study has shown that it is possible to recruit volunteers to conduct a simple experiment to measure pollination services, using citizen science to gather data on geographical scales that would be vastly more costly to achieve with professional scientists (Dickinson *et al.*, 2010). With the release of the new National Pollinator Strategy in the UK (Defra, 2014), and the specific inclusion of an action to develop monitoring schemes for pollinators / pollination, this project is of particular potential importance.

The effectiveness of Citizen science schemes at engaging a population of recorders on a large scale when established can be seen in the engagement success shown in the Great Sunflower Project (Oberhauser & LeBuhn, 2012), and the Urban Pollination Project (Potter & LeBuhn, 2015). The success of both projects in recruiting volunteers to participate illustrates the potential of such citizen science protocols to gather useful data

Even with the relatively low rate of return of complete data sets from this first phase, the volume of data obtained for the cost expended is high (roughly £31.25 per successful return), and could be improved with more targeted recruitment, and some modification to the protocol. This does not include the staff time cost of handing, data curation and analysis, as this was carried out as part of PhD research; if the study were to be continued beyond this, further methods for funding the project would have to be found. However, much of the existing set up can be re-used (the website, surveys, and instruction sheets), improving spend efficiency in subsequent years.

The approach could readily be extended to other plants dependent on different pollinator guilds, and with targeted recruitment of farmers or those living in rural areas it could be extended to assess rural pollination services. We therefore suggest that this protocol could form a basis for a large-scale, long-term, cost-effective monitoring scheme, addressing an urgent and well-recognized need for systematic data collection on pollination service provision.

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Contribution of authors

Project design, data collection, analysis and paper writing by L.J.Birkin, with advice on all sections, editing and supervision by D. Goulson.

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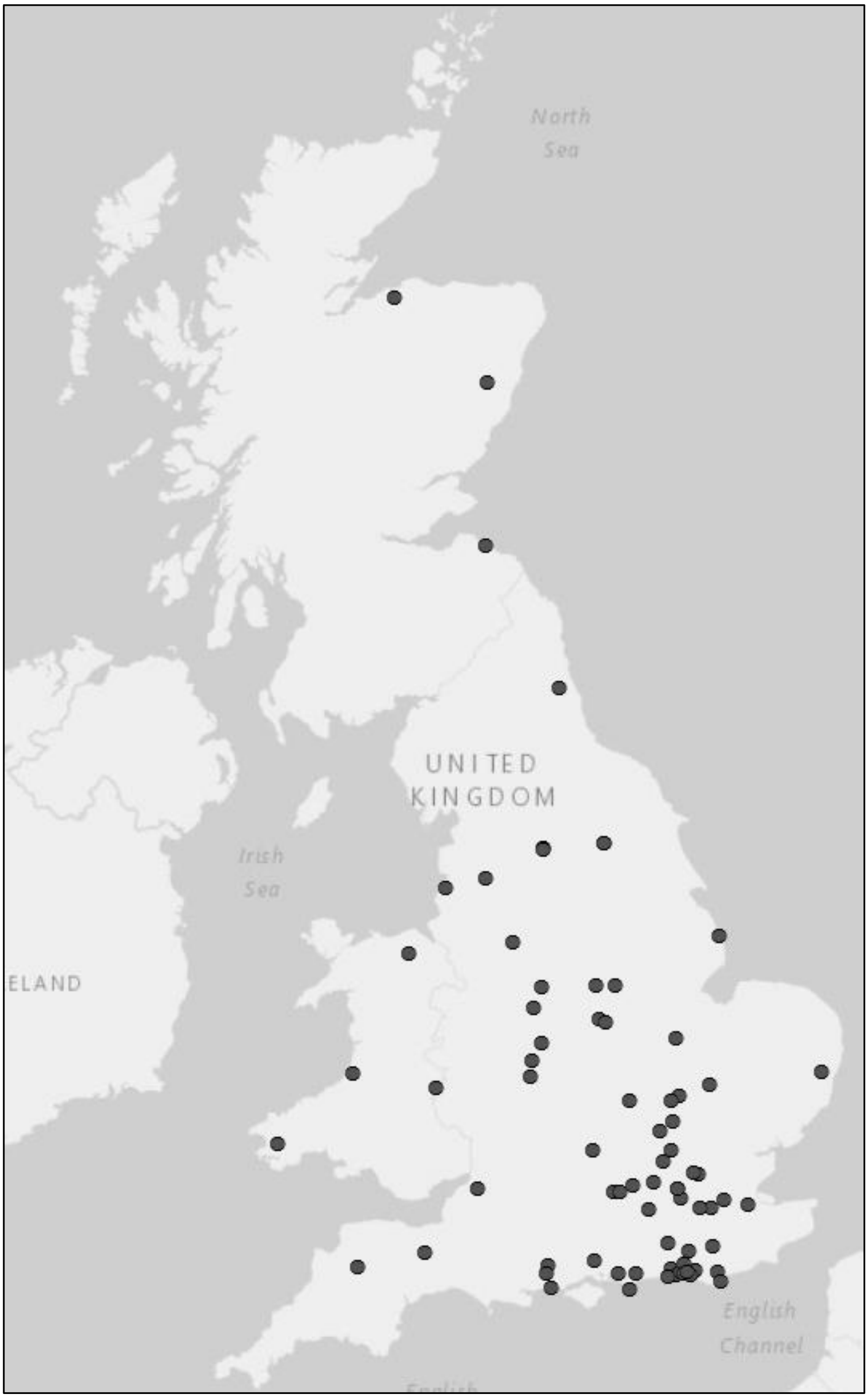
Table 1: Factors included in the GLMs for *V. faba* yields from *"Bees 'n Beans"* returns.

Factor/covariate	Measurement
Treatment Category	Local pollinated / netted / hand-pollinated
Size of garden / allotment	In m2
Latitude	Latitude of site postcode
Location type	Garden: Individual Garden: Communal Allotment Other
Area of surrounding gardens	Area of gardens in the surrounding 500m circle
Extra Beans Grown	*Were additional broad beans grown on site?* Yes; no flowering overlap Yes; flowering overlap No
Flowering vs. Harvest	Days between first flowering time, and date of harvest.

503 

504 Figure 1: Location of completed returns (n=80) from *Bees 'n Beans*

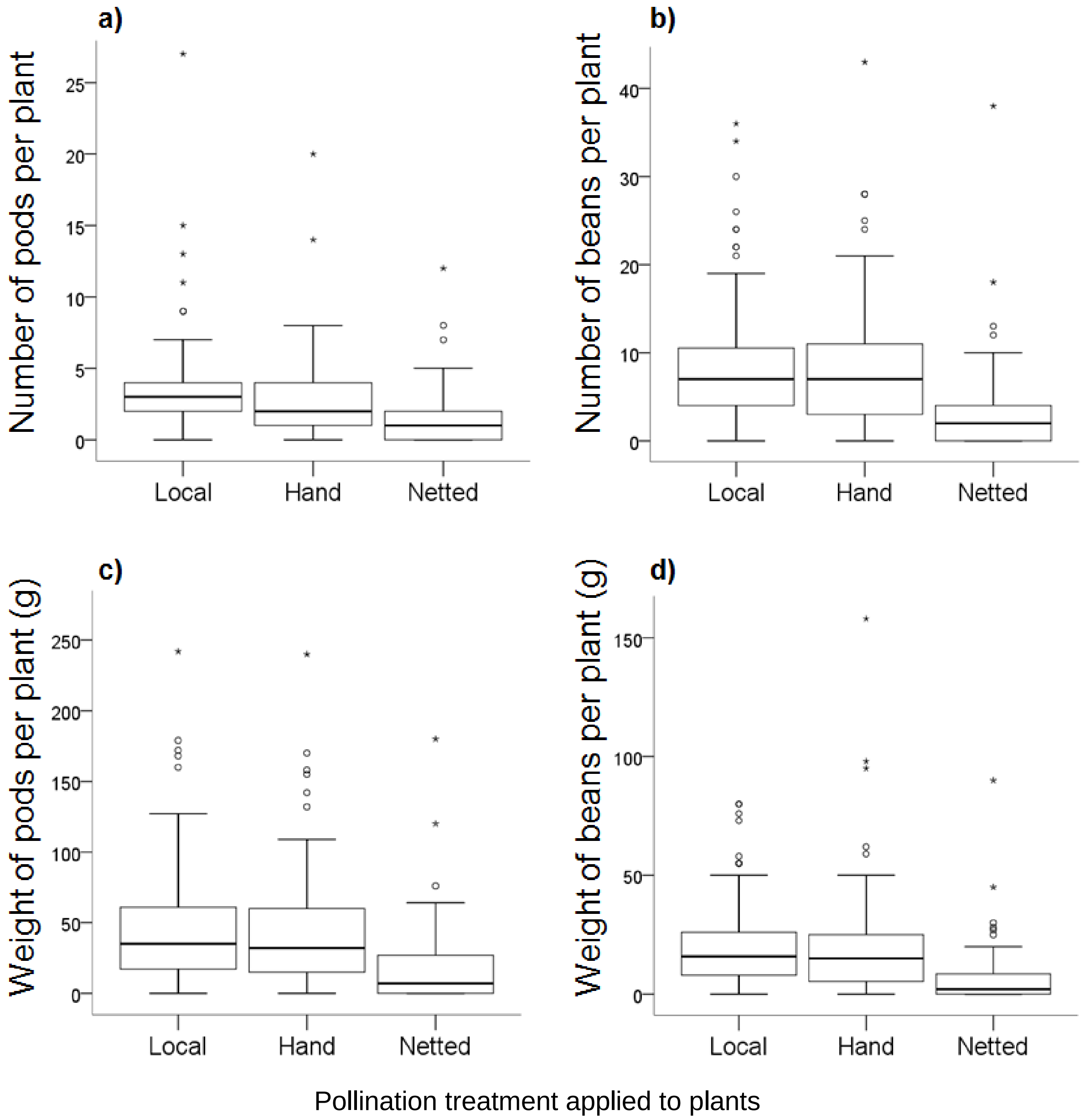


Figure 2: Number of pods (a), number of beans (b), weight of pods (c), and weight of beans (d) produced by experimental plants, compared across Treatment Categories. The difference between treatments was highly significant in all four cases ($p<0.001$) and post hoc tests revealed ‘local’ yields were significantly different from 'netted' but not from 'hand'.

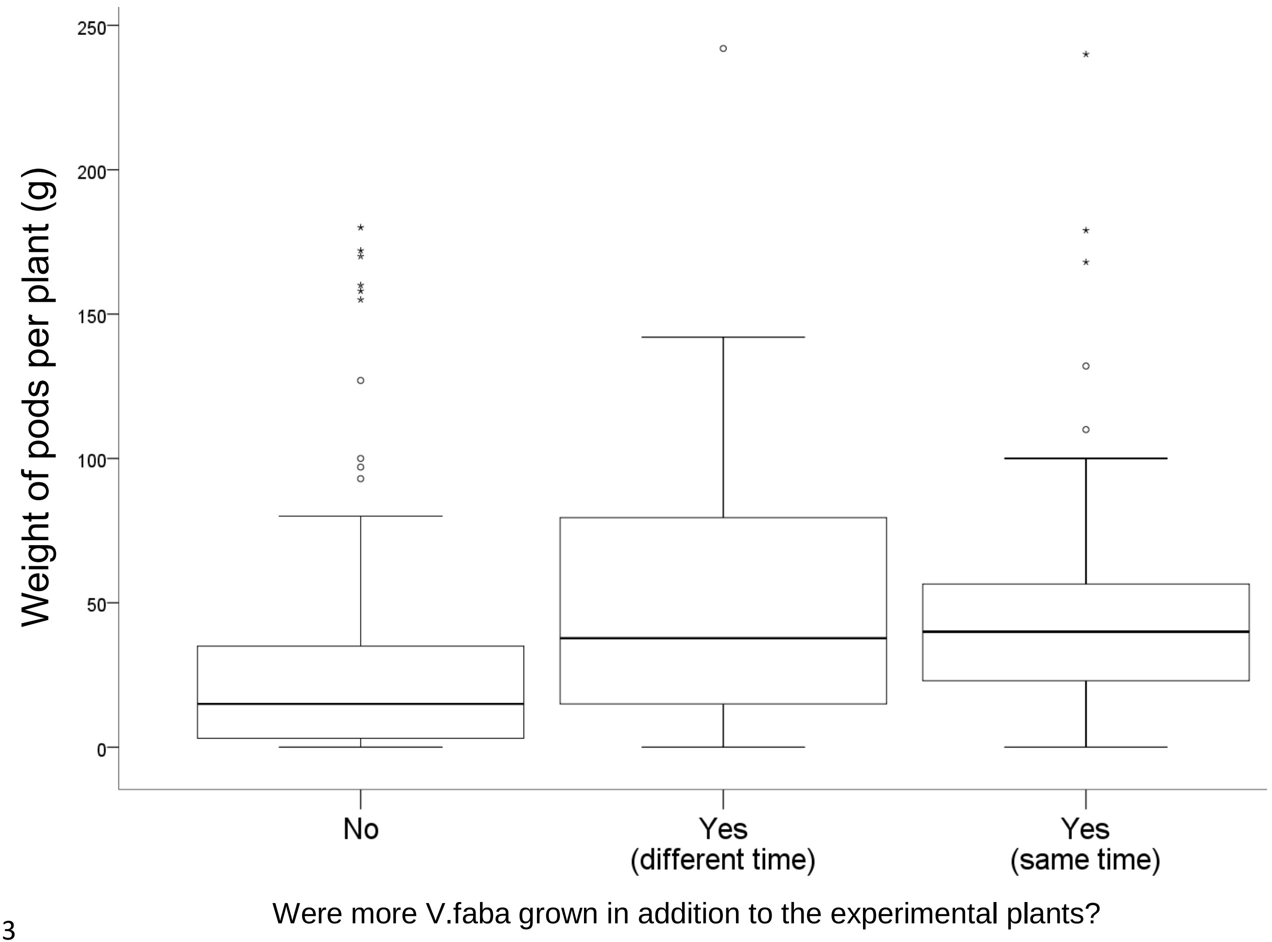


Figure 3: Weight (in g) of pods produced by experimental plants, according to whether additional broad beans were grown at the same time at the same site, and whether flowering overlapped with the experimental plants.