

Capacity and willingness of farmers and citizen scientists to monitor crop pollinators and pollination services

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Garratt, M. P. D. ORCID: <https://orcid.org/0000-0002-0196-6013>, Potts, S. G. ORCID: <https://orcid.org/0000-0002-2045-980X>, Banks, G., Hawes, C., Breeze, T. D. ORCID: <https://orcid.org/0000-0002-8929-8354>, O'Connor, R. S. and Carvell, C. (2019) Capacity and willingness of farmers and citizen scientists to monitor crop pollinators and pollination services. *Global Ecology and Conservation*, 20. e00781. ISSN 2351-9894 doi: 10.1016/j.gecco.2019.e00781 Available at <https://centaur.reading.ac.uk/86286/>

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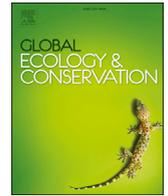
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Capacity and willingness of farmers and citizen scientists to monitor crop pollinators and pollination services

M.P.D. Garratt^{a, *}, S.G. Potts^a, G. Banks^b, C. Hawes^b, T.D. Breeze^a,
R.S. O'Connor^a, C. Carvell^c^a Centre for Agri-Environmental Research, School of Agriculture, Policy and Development, University of Reading, UK^b James Hutton Institute, Invergowrie, Dundee, Scotland^c Centre for Ecology & Hydrology, Maclean Building, Benson Lane, Crowmarsh Gifford, Wallingford, UK

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ABSTRACT

Insects pollinate many globally important crops and therefore rapid and effective means to measure crop pollinators and pollination are required to support national monitoring schemes and allow localised measurements of pollinator supply and demand to crops. We tested user-friendly protocols for assessing pollinators and pollination in crops to better understand the capacity and willingness of a group of farmers and citizen scientists to implement such techniques in the field. We asked the different recorder groups including farmers and agronomists, non-expert volunteers and experienced researchers to complete three pollinator and pollination service assessment techniques: transect walks, pan trapping and pollinator exclusion and supplementary pollination. Recorders provided feedback on each method through a questionnaire and the data collected using different methods were compared. Our volunteer members of the public, and farmers and agronomists were able to implement all assessment techniques in apple, bean and oilseed rape fields. The experienced researchers and volunteer members of the public were more willing to record bumblebees to species level on transects than the farmers and agronomists. There was also a significant interaction between recorder and crop type for certain insect taxa demonstrating that in certain crops some taxa may be easier to record than others. All our recorder groups found transects and pan traps straightforward and enjoyable to implement. Our non-expert volunteers were willing to use pollinator exclusion and supplementary pollination techniques as part of a wider scheme, the farmers and agronomists who implemented the technique were less positive about applying this method more widely. We have demonstrated that volunteer recorders, including farmers and agronomists, can be engaged and are able to implement methods to assess pollinators and pollination, although additional training is necessary to ensure accurate species data collection. For the more direct and time consuming measures of pollination service, both training and additional support may be needed, particularly for farmers. The tools developed and tested here will be valuable for wider pollinator monitoring schemes and for integration into standard agronomic practices.

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* Corresponding author.

E-mail address: m.p.garratt@reading.ac.uk (M.P.D. Garratt).

1. Introduction

Insects provide a critical ecosystem service by pollinating crops of global importance (Kleijn et al., 2015; Rader et al., 2016), yet increasing demand for insect pollinated crops (Aizen et al., 2008) and evidence of pollinator declines (Potts et al., 2016; Powney et al., 2019) threaten this service. Long-term monitoring of pollinators and pollination at regional, national and international scales is necessary in order to understand and address pollinator decline and resulting erosion of pollination services (Dicks et al., 2016). Furthermore an understanding of crop pollination service delivery at smaller scales such as the field or farm is also necessary in order to make effective local scale pollinator management decisions to help match supply with demand and improve the sustainability of crop production (Garibaldi et al., 2014; Isaacs et al., 2017).

Current understanding of the changing status and trends of insect pollinators (focussing particularly on bees and hoverflies) is predominantly based on ad-hoc records of species presence collected and verified by expert volunteer recorders, from which changes in occupancy or distribution can be modelled over time (Carvalho et al., 2013; Powney et al., 2019). While this is invaluable in providing evidence of the changing occurrence of pollinator species across larger scales, these unstructured records are rarely collected in intensive agricultural landscapes or in flowering crop fields directly as recorders will often choose areas of high diversity (Isaac and Pocock, 2015). Therefore pollinator population trends in agricultural areas or specifically for those species known to be frequent crop flower visitors may not be effectively captured using ad-hoc records alone. Acknowledging these limitations in existing data, more systematic pollinator monitoring schemes are being established in the UK (Carvell et al., 2016; Comont and Miles, 2019) and in Europe (Butterfly Conservation Europe <http://bc-europe.eu/index.php?id=291>). These schemes incorporate improved spatial coverage and better representation of different habitats, but to effectively capture trends in crop pollinator populations and their activity in crops then data need to be collected from within the fields themselves.

Emerging pollinator survey schemes use passive (e.g. pan or malaise traps) or active (transect) survey techniques to assess pollinator abundance or relative activity rates on flowers (Carvell et al., 2016), and such metrics can be used as proxies to estimate the level of pollination provided to crops (Garibaldi et al., 2013; Garratt et al., 2014b). The use of these proxies potentially represents considerable added value to any monitoring scheme which measures pollinator activity in agricultural landscapes or in crop fields. However there is increasing evidence that the benefit of insect pollination to crop yields is context dependent, interacting with agronomic and environmental factors (Garratt et al., 2018; Tamburini et al., 2019) as well as depending on crop variety (Hudewenz et al., 2013; Garratt et al., 2016). Therefore data on pollinator abundance or visitation rate alone does not allow direct assessment of the level of contribution to yield, or indeed possible pollination deficits in crops. For this, more direct measures are required, including pollinator exclusion or supplementary pollination techniques (Holzschuh et al., 2012; Garratt et al., 2014a). If a monitoring scheme aims to accurately assess changing levels of pollination service to crops over time or space then it must consider including direct assessments of pollination.

Furthermore in order for farmers and land managers to make effective management decisions to optimise insect pollination for cost effective production, it is critical they are able to assess their current level of supply and demand for crop pollination services, either at the field or farm scale. This can then be used to inform investment in pollination services either through provision of managed species or action to promote pollination by wild pollinators (Garibaldi et al., 2014; Isaacs et al., 2017). In order to allow self-assessment of crop pollination by decision makers there is a need to develop tools for rapid and accurate assessment of crop pollinators and pollination, and consider how these could be incorporated into wider farming activities.

Current strategies have set out plans to support pollinators and pollination services emphasising the need to develop a monitoring framework that integrates both professional and volunteer involvement in generating, processing and interpreting data (DEFRA, 2014). Many existing systematic wildlife monitoring schemes already involve citizen scientists as an effective means of combining ecological research with education and documenting environmental change (Dickinson et al., 2010; Roy et al., 2015). This approach enables the collection of greater volumes of data at larger spatial and temporal scales and finer resolutions than would otherwise be possible or affordable (Kremen et al., 2011; Hochachka et al., 2012). Bees and other insect pollinators present challenges for broadening participation beyond those with taxonomic expertise due to their diversity and difficulty of identification to species level (O'Connor et al., 2019). Nevertheless, pollinators have been the focus of several recent citizen science projects ranging from observations of bumblebees on focal plants of lavender by school children (Roy et al., 2016) to measures of pollination service in *Vicia faba* grown in gardens and allotments (Birkin and Goulson, 2015). To our knowledge however no other study has assessed the capacity for citizen scientists, including farmers, to monitor pollinators or pollination services in commercially managed crop fields.

With a view to supporting wider monitoring schemes or to allow practitioners to self-assess pollination services in crops, this study aimed to better understand the capacity and willingness of a group of UK based farmers and other citizen scientists to survey crop pollinators and pollination services. The specific objectives were to 1) test the feasibility of citizen scientists to use standard protocols aimed at measuring pollinators and pollination in three different crops, 2) compare data collected by experienced researchers, farmers and agronomists, and members of the public when implementing different pollinator and pollination survey methods, and 3) assess the willingness of citizen scientists to implement different survey methods.

2. Materials and methods

2.1. Study sites

This study was conducted across 13 field sites including three oilseed rape fields (*Brassica napus*) and three field bean (*Vicia faba*) fields in Berkshire, England, two oilseed rape and four bean fields in Tayside, Scotland and an apple (*Malus domestica*) orchard in Kent, England. These crops were chosen because they are widespread and economically important in the UK and insect pollinators make a contribution to their yield (Garratt et al., 2014a; Kleijn et al., 2015; Nayak et al., 2015). They also represent a contrast in the flower visiting insect communities which have been observed in each crop (Garratt et al., 2014b, 2016). The fields in the study were conventionally managed and of different varieties of each crop. All survey work was carried out between April and May 2015 in conditions considered suitable for insect pollinator activity (dry weather above 13 °C with low wind).

2.2. Recorder comparisons

Three types of data recorders were compared for this study. 'Research scientists' (hereafter researchers) with experience implementing ecological survey protocols involving invertebrates, a group of 'Farmers and Agronomists' with no previous experience carrying out pollinator or pollination survey protocols and a number of 'Volunteer non-experts' with little or no experience doing ecological surveys or working on farmland. For this study nine agronomists and farmers were recruited through existing farmer networks and with help from an agronomic consultancy (Agrii). Seventeen volunteer non-experts were recruited through adverts at local work places and universities. Finally six experienced research scientists were involved directly from laboratories of the project teams.

In order to test crop pollinator and pollination service protocols and the capacity of different recorders to implement each method, small groups of recorders were accompanied to the study fields and provided with a basic protocol, recording sheets and all necessary equipment to implement three different commonly used pollinator and pollination survey methods: 'transect surveys', 'pan trapping' and 'pollination service assessments' (Supporting Information S1). Recorders were also provided with a basic insect identification guide to help distinguish broad taxonomic groups of crop flower visiting insects as well as common bumblebee species (Supporting Information S2). Each recorder was randomly assigned a study plot 25 m apart and after receiving a brief demonstration of each method the recorders independently carried out the survey methods simultaneously to allow comparison of data collected on each visit.

For the 'transect surveys', recorders were asked to walk a 50 m tramline of flowering crop over 10 min and record all insects they saw visiting crop flowers, within a 1 m square viewing area (oilseed and beans) or along one side of a tree row (apples). Recorders were asked to record flower visitors to as high a taxonomic resolution as they could (including bumblebees to species level where possible) as well as count flower density at two points along the transect. 'Pan trapping' involved recorders placing out three coloured water trap arrays at 25 m intervals along a tramline in flowering crop fields. White, blue and yellow pan traps were placed on a stand and filled with water and a drop of detergent. Pan traps were left out for the duration of the survey visit and at the end of a survey visit, recorders were asked to count what was caught in all pan trap arrays across all study plots and record numbers to the highest taxonomic resolution possible on the data sheet.

For the 'pollination service assessments', recorders were asked to mark three points along their study plots and at each point tag three equivalent stems (oilseed and beans) or branches (apples), assigning one to an 'open' treatment with no experimental manipulation, one 'closed' treatment which had a mesh bag placed over the stem or branch secured with a reusable cable tie, and one to be 'supplementary pollinated' where recorders were asked to collect pollen from neighbouring plants using scissors and a petri dish and apply the pollen to open flowers with a paint brush, recording how many flowers were supplementary pollinated.

2.3. Recorder feedback

After completing their pollinator and pollination assessments, all recorders were asked to complete a series of questions to provide feedback on the methods they had implemented in the field. For each of the survey methods employed, a 5 point Likert scale was used and the recorders were asked if they 'Strongly agree', 'Agree', 'Neither agree or disagree', 'Disagree' or 'Strongly disagree' that 'The method was straightforward to implement', 'The method was enjoyable' and 'I would be willing to use this method as part of a wider monitoring scheme'. Implementing the pollination service assessment involved in this study would ordinarily require a follow up visit close to harvest to assess levels of seed or fruit set, depending on the crop (Garratt et al., 2014a). This follow up visit was not implemented as part of this trial but the necessity for this element of the protocol and exactly what it involves was explained to the participants and they were asked to consider this before completing their methods feedback questionnaires.

2.4. Statistical analysis

Generalised linear mixed effects models were used to analyse effects of recorder type on counts of important crop pollinator taxa recorded on transect surveys. Recorder type (Researcher, Non-expert, and Agronomist/Farmer) and crop

(beans, oilseed and apple) and their interactions were included in the model. ‘Transect location’ (a, b, c, d) nested within ‘Study block’ were included as random effects. A study block represents a directly comparable group of recorders of different types simultaneously implementing survey methods in the same field at the same time. For unidentified bumblebees and hoverflies the number of records was often low so to reduce zero counts and improve model fit the number of records were summed across the transects for each recorder and ‘Transect location’ was removed as a random factor. The response is a count so a Poisson distribution was specified throughout. In order to compare the distribution of questionnaire responses by different recorder groups for different methods, the Likert scale was made numeric and pairwise comparisons between methods within recorder groups were made using two-sample Mann–Whitney U tests. Analysis was carried out in R version 3.4.2 using the lme4 package.

3. Results

Overall, the three recorder groups were able to implement our pollinator and pollination service survey techniques in the field, generating data on pollinator abundance and implementing techniques to allow for assessment of pollination service to all three study crops.

3.1. Recorder comparisons

The non-experts and researchers involved in this study recorded significantly more bumblebees to species than the agronomists and farmers, whilst the farmers and agronomists recorded greater numbers of unidentified bumblebees than our researchers and non-experts (Fig. 1, Table 1). There was a significant interactive effect of recorder type and crop for records of honeybees and hoverflies. A significant effect of crop type on bumblebees recorded to species was also found with greater numbers recorded on beans than oilseed rape. Full outputs from mixed effects models can be seen in Table S1.

Direct comparisons of pan trap catches between different recorders were possible for pan traps implemented on eight of the survey days. The number of specimens recorded by each recorder varied and was rarely exactly the same for any two recorders despite each of the recorders processing the same set of pan traps (Table S2). Notably one non-expert volunteer recorded a very high number of hoverflies while the number of ‘other Diptera’ was often different between individual recorders.

3.2. Recorder feedback

After completing the pollinator and pollination service assessment methods recorders were asked to complete a questionnaire for those methods which they had implemented in the field (Table 2). The responses of our non-experts were broadly positive with regards to the enjoyment, practicality and willingness to implement all three survey methods. When asked if they would be ‘Willing to use the method as part of a wider scheme’, the typical response was ‘Agree’ for all methods and there was no significant difference in the distribution of responses between transect surveys and pan traps ($W = 128$, p -value = 1), pollination service assessments and transects ($W = 50$, p -value = 0.36) or pollination service assessments and pan

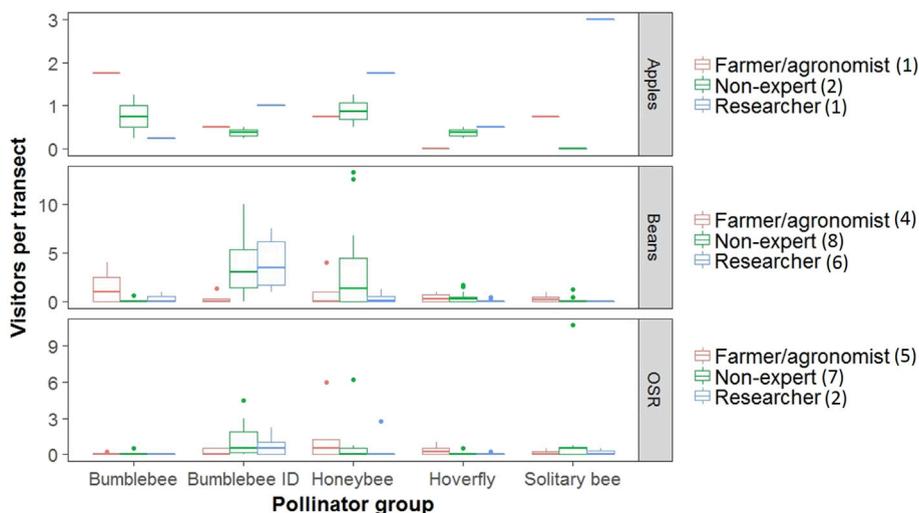


Fig. 1. Number of important crop pollinators recorded by different recorders (n) on transects in apple, bean and oilseed rape (OSR) fields including bumblebees (species not recorded), bumblebee ID (a species record was attempted), honeybee (*Apis mellifera*), hoverfly (*Syrphidae*) and solitary bees (any non *Bombus* wild bee).

Table 1

Statistical outcomes following analysis using generalised mixed effects models of crop pollinator transect counts made by our different recorder groups. Non = Non-expert volunteers, Res = Researcher and F&A = Farmers and agronomists. Significant effects highlighted in bold ($P < 0.05$).

	Bumblebees Identified			Bumblebees Unidentified			Solitary bee			Honeybee			Hoverfly		
	F	P	Effect	F	P	Effect	F	P	Effect	F	P	Effect	F	P	Effect
Recorder	12.62	<0.001	Non,Res > F&A	5.48	0.002	Res,Non < F&A	na	na		na	na		1.97	0.064	
Crop	5.81	0.011	OSR < Beans	1.48	0.22		na	na		na	na		2.38	0.096	
Recorder:Crop	1.68	0.16		0.64	0.40		2.83	<0.001		5.81	<0.001		1.05	0.11	

traps ($W = 50.5$, p -value = 0.36). Our agronomists and farmers were also broadly positive about pan trapping and transect surveys. However with regards their willingness to implement pollination service assessments as part of a wider scheme, of the few who implemented this method, the commonest response of ‘Disagree’ was given. The distribution of responses was significantly different from pan trapping ($W = 35$, p -value = 0.028) but not transect surveys ($W = 32.5$, p -value = 0.069). Pan trapping and transects received a similarly positive response ($W = 33$, p -value = 0.96).

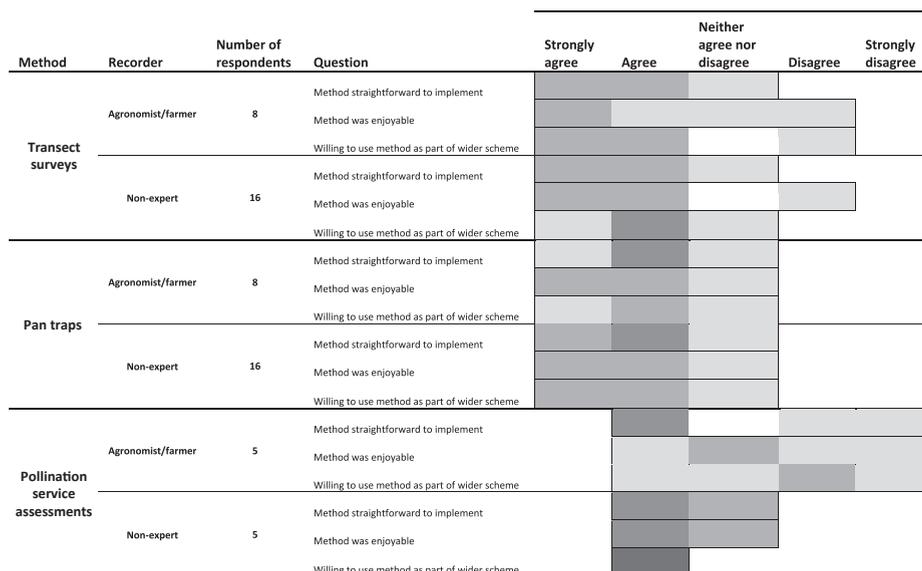
4. Discussion

Our study shows that volunteers, including farmers, agronomists and members of the public with little prior experience, are able to implement pollinator surveys and pollination service assessment techniques in fields of different crops. Some differences in the data collected between our volunteer groups was observed and their ease, enjoyment and willingness to implement methods depended on the assessment technique in question. Our study is one of the first to work with citizen scientists and practitioners to survey pollinators in flowering crop fields but also to implement protocols used to measure pollination service (although see (Birkin and Goulson, 2015) and provides valuable insights into the possibility of including pollination assessments as part of a wider scheme or as part of pollination service self-assessments by farmers.

Our results show that when carrying out pollinator transect surveys in flowering crops, researchers and some non-expert volunteers were more able and/or more willing than our farmers and agronomists to attempt to record bumblebees to species level in the field. The researchers involved in this study had experience implementing pollinator surveys and this would explain their increased capacity to identify bees on the wing. We were not able to assess rates of accuracy in identifications made by our recorders, which have been found in other citizen science-led studies to vary, with a precision rate of 44% in school children identifying bumblebees by colour type (Roy et al., 2016), <50% accuracy when citizen scientists identified bumblebees to species (Falk et al., 2019) and a miss-identification rate of 34% for citizen scientists recording insects on focal

Table 2

Responses given by different recorder groups regarding the enjoyment, practicality and willingness to implement different pollinator and pollination service assessment techniques. Results from questionnaires completed after implementing these methods in the field [■ =>75%, ■ =>50%, ■ =>25%, ■ =>0% of responses].



plants (Deguines et al., 2012). Therefore, the species records made by the non-experts in our study may or may not have been correct, but could reflect their desire to generate species-level data. The confidence of the farmers and agronomists to record species and the accuracy of our non-experts could be improved through training (Kremen et al., 2011; Sharma et al., 2019) if species-level data from transects were considered an essential outcome. However when assessing crop pollination, abundance recorded to broad taxonomic groups is often sufficient to predict levels of pollination service (Rader et al., 2016) but a level of training is still required to ensure this is recorded accurately, even to morphospecies (Rüdissler et al., 2017; Mason and Arathi, 2019). The significant interaction between recorder type and crop for some taxa, namely honeybees and solitary bees, indicates that the crop in which the survey is carried out affects the likelihood of a record being made by our different recorders. Crop pollinator communities vary between crops (Garratt et al., 2014b) and it may be that distinguishing between some of the more challenging taxa such as honeybees and solitary bees is more difficult in crops with reduced visibility and present a constraint on accurate recording in crops where these are the common pollinators. This again could be improved through additional training, perhaps targeted at certain crops. Overall, feedback provided by our volunteers on transects as a survey method was broadly positive for all recorder groups and most would be willing to implement transect surveys as part of a wider scheme. Transects are a relatively quick method requiring no specific equipment, beyond datasheets and ID guides, so their use for surveying pollinators on flowering crops has promise. Similar techniques have been used in other citizen science based surveys schemes, although considerable investment in volunteer training and capacity building was necessary (Comont and Miles, 2019) and would also be required for a scheme involving the use of crop pollinator transects on a large scale.

While flower visitation data is often used as a proxy for pollination services (Kleijn et al., 2015), given the differing effectiveness of pollinators (Garratt et al., 2014b, 2016) and the effects of species richness and other pollinator community metrics on crop pollination (Woodcock et al., 2019), abundance or visitation rates alone do not always accurately reflect pollination service delivery. This must be taken into account if the use of transects is considered to assess pollination service (O'Connor et al., 2019). Furthermore visitation data from transects alone does not provide information on current pollination rates and contributions to yield, which may vary within the context of a particular field (Tamburini et al., 2019), or identify opportunities to increase crop yield by revealing the existence of pollination deficits (Garratt et al., 2014a). For these metrics, pollinator exclusion and supplementary pollination techniques are often used by researchers and were trialled as part of this study. All of the recorders who attempted these methods were able to implement them in the field although our farmers and agronomists, who might find the greatest value from the results, were marginally less positive about using the technique more widely. In this study however we were only able to recruit a limited number of farmers and non-expert volunteers to trial the pollination service methodologies and so the representativeness of our findings are limited. Also our volunteers did not go back and assess final seed set or fruit set following these plant manipulation protocols. It maybe that if the farmers and agronomist could see clear benefits of insect pollination in their crop by employing the methods then they may be more willing to implement them in the future.

Given the time it takes to implement pollinator exclusion or supplementary pollination with sufficient replication within or across fields, it may be used more widely by the farming community for crops where the risks and rewards for optimising pollination management are greatest. Namely high value fruit crops where dependence on pollinators is high (Klatt et al., 2014; Garratt et al., 2016) or where large investments are already made in provisioning pollination services through managed bees (Isaacs and Kirk, 2010; Rollin and Garibaldi, 2019). If it were made part of 'normal' farmer practice or an additional service provided by paid agronomists during 'crop walks', in a similar way to assessing soil fertility or pest pressure, then self-assessment of pollination services could be used widely to target pollinator management at crops and sites for which the benefit would be greatest. However further research involving more farmers and agronomists, particularly from high value insect pollinated crops is required to determine whether they would be willing to undertake this and what training and infrastructure would be required to support them.

In this study we also examined the ability of our recorders to implement pan trapping in crop fields as well as recording feedback on this method. Pan traps are commonly used to survey bee populations and can be used as part of wider pollinator monitoring schemes, provided the study design is appropriate (Lebuhn et al., 2013; Carvell et al., 2016). Our study shows their placement within crop fields by citizen scientists to capture flying insects is possible and so they could be employed in these areas if required. However pan traps only record a certain portion of the insect pollinator community (Cane et al., 2000) and may not accurately reflect those pollinators which are visiting crop flowers, and specimens caught would need to be sent to experts for correct identification to species (O'Connor et al., 2019). Therefore pan traps have limitations as a method for effectively assessing crop pollinators or pollination service delivery.

Ultimately the method employed and who it will be implemented by depends on the desired outcomes of assessing pollinators or pollination services in crops, combined with the availability of resources and capacity to generate accurate data that are fit for purpose. Although based on a limited number of subjects involved we have shown a variety of methods can be employed by different recorder groups, and although the data collected using some methods is affected by the experience of the recorders involved in this study, this could be addressed through training and capacity building if these methods are to be rolled out more widely. Finally, if the appropriate motivations are in place then assessment of crop pollinator activity or direct measures of pollination service could be a valuable tool for farmers and agronomists to help optimise management of crop pollination services in the face of environmental change.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.gecco.2019.e00781>.

References

- Aizen, M.A., Garibaldi, L.A., Cunningham, S.A., Klein, A.M., 2008. Long-term global trends in crop yield and production reveal No current pollination shortage but increasing pollinator dependency. *Curr. Biol.* 18, 1572–1575.
- Birkin, L., Goulson, D., 2015. Using citizen science to monitor pollination services. *Ecol. Entomol.* 40, 3–11.
- Cane, J.H., Minckley, R.L., Kervin, L.J., 2000. Sampling bees (hymenoptera: apiformes) for pollinator community studies: pitfalls of pan-trapping. *J. Kans. Entomol. Soc.* 73, 225–231.
- Carvalho, L.G., Kunin, W.E., Keil, P., Aguirre-Gutiérrez, J., Ellis, W.N., Fox, R., Groom, Q., Hennekens, S., Van Landuyt, W., Maes, D., Van de Meutter, F., Michez, D., Rasmont, P., Ode, B., Potts, S.G., Reemer, M., Roberts, S.P.M., Schaminée, J., WallisDeVries, M.F., Biesmeijer, J.C., 2013. Species richness declines and biotic homogenisation have slowed down for NW-European pollinators and plants. *Ecol. Lett.* 16, 870–878.
- Carvell, C., Isaac, N.J.B., Jitlal, M., Peyton, J., Powney, G.D., Roy, D.B., Vanbergen, A.J., O'Connor, R.S., Jones, C.M., Kunin, W.E., Breeze, T.D., Garratt, M.P.D., Potts, S.G., Harvey, M., Ansine, J., Comont, R.F., Lee, P., Edwards, M., Roberts, S.P.M., Morris, R.K.A., Musgrove, A.J., Brereton, T., Hawes, C., Roy, H.E., 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.
- Comont, R.F., Miles, S., 2019. BeeWalk Annual Report 2019. Bumblebee Conservation Trust, Stirling, Scotland UK.
- DEFRA, 2014. The National Pollinator Strategy: for Bees and Other Pollinators in England.
- Deguines, N., Julliard, R., de Flores, M., Fontaine, C., 2012. The whereabouts of flower visitors: contrasting land-use preferences revealed by a country-wide survey based on citizen science. *PLoS One* 7, e45822.
- Dickinson, J.L., Zuckerman, B., Bonter, D.N., 2010. Citizen science as an ecological research tool: challenges and benefits. *Annu. Rev. Ecol. Evol. Systemat.* 41, 149–172.
- Dicks, L.V., Viana, B., Bommarco, R., Brosi, B., Arizmendi, M.d.C., Cunningham, S.A., Galetto, L., Hill, R., Lopes, A.V., Pires, C., Taki, H., Potts, S.G., 2016. Ten policies for pollinators. *Science* 354, 975–976.
- Falk, S., Foster, G., Comont, R., Conroy, J., Bostock, H., Salisbury, A., Kilbey, D., Bennett, J., Smith, B., 2019. Evaluating the ability of citizen scientists to identify bumblebee (*Bombus*) species. *PLoS One* 14, e0218614.
- Garibaldi, L.A., Carvalho, L.G., Leonhardt, S.D., Aizen, M.A., Blaauw, B.R., Isaacs, R., Kuhlmann, M., Kleijn, D., Klein, A.M., Kremen, C., Morandin, L., Scheper, J., Winfree, R., 2014. From research to action: enhancing crop yield through wild pollinators. *Front. Ecol. Environ.* 12, 439–447.
- Garibaldi, L.A., Steffan-Dewenter, I., Winfree, R., Aizen, M.A., Bommarco, R., Cunningham, S.A., Kremen, C., Carvalho, L.G., Harder, L.D., Afik, O., Bartomeus, I., Benjamin, F., Boreux, V., Cariveau, D., Chacoff, N.P., Dudenhöffer, J.H., Freitas, B.M., Ghazoul, J., Greenleaf, S., Hipólito, J., Holzschuh, A., Howlett, B., Isaacs, R., Javorek, S.K., Kennedy, C.M., Krewenka, K.M., Krishnan, S., Mandelik, Y., Mayfield, M.M., Motzke, I., Munyuli, T., Nault, B.A., Otieno, M., Petersen, J., Pisanty, G., Potts, S.G., Rader, R., Ricketts, T.H., Rundlöf, M., Seymour, C.L., Schüepp, C., Szentgyörgyi, H., Taki, H., Tscharntke, T., Vergara, C.H., Viana, B.F., Wanger, T.C., Westphal, C., Williams, N., Klein, A.M., 2013. Wild pollinators enhance fruit set of crops regardless of honey bee abundance. *Science* 339, 1608–1611.
- Garratt, M.P.D., Bishop, J., Degani, E., Potts, S.G., Shaw, R.F., Shi, A., Roy, S., 2018. Insect pollination as an agronomic input: strategies for oilseed rape production. *J. Appl. Ecol.* 55, 2834–2842.
- Garratt, M.P.D., Breeze, T.D., Boreux, V., Fountain, M.T., Mc Kerchar, M., Webber, S.M., Coston, D.J., Jenner, N., Dean, R., Westbury, D.B., Biesmeijer, J.C., Potts, S.G., 2016. Apple pollination: demand depends on variety and supply depends on pollinator identity. *PLoS One* 11, e0153889.
- Garratt, M.P.D., Breeze, T.D., Jenner, N., Polce, C., Biesmeijer, J.C., Potts, S.G., 2014a. Avoiding a bad apple: insect pollination enhances fruit quality and economic value. *Agric. Ecosyst. Environ.* 184, 34–40.
- Garratt, M.P.D., Coston, D.J., Truslove, C.L., Lappage, M.G., Polce, C., Dean, R., Biesmeijer, J.C., Potts, S.G., 2014b. The identity of crop pollinators helps target conservation for improved ecosystem services. *Biol. Conserv.* 169, 128–135.
- Hochachka, W.M., Fink, D., Hutchinson, R.A., Sheldon, D., Wong, W.-K., Kelling, S., 2012. Data-intensive science applied to broad-scale citizen science. *Trends Ecol. Evol.* 27, 130–137.
- Holzschuh, A., Dudenhöffer, J.-H., Tscharntke, T., 2012. Landscapes with wild bee habitats enhance pollination, fruit set and yield of sweet cherry. *Biol. Conserv.* 153, 101–107.
- Hudewenz, A., Pufal, G., Bogeholz, A.-L., Klein, A.-M., 2013. Cross-pollination benefits differ among oilseed rape varieties. *J. Agri. Sci. First View.* 1–9.
- Isaac, N.J.B., Pocock, M.J.O., 2015. Bias and information in biological records. *Biol. J. Linn. Soc.* 115, 522–531.
- Isaacs, R., Kirk, A.K., 2010. Pollination services provided to small and large highbush blueberry fields by wild and managed bees. *J. Appl. Ecol.* 47, 841–849.
- Isaacs, R., Williams, N., Ellis, J., Pitts-Singer, T.L., Bommarco, R., Vaughan, M., 2017. Integrated Crop Pollination: combining strategies to ensure stable and sustainable yields of pollination-dependent crops. *Basic Appl. Ecol.* 22, 44–60.
- Klatt, B.K., Holzschuh, A., Westphal, C., Clough, Y., Smit, I., Pawelzik, E., Tscharntke, T., 2014. Bee pollination improves crop quality, shelf life and commercial value. In: *Proceedings of the Royal Society of London B: Biological Sciences*, vol. 281.
- Kleijn, D., Winfree, R., Bartomeus, I., Carvalho, L.G., Henry, M., Isaacs, R., Klein, A.-M., Kremen, C., M'Gonigle, L.K., Rader, R., Ricketts, T.H., Williams, N.M., Lee Adamson, N., Ascher, J.S., Baldi, A., Batary, P., Benjamin, F., Biesmeijer, J.C., Blitzer, E.J., Bommarco, R., Brand, M.R., Bretagnolle, V., Button, L., Cariveau, D.P., Chifflet, R., Colville, J.F., Danforth, B.N., Elle, E., Garratt, M.P.D., Herzog, F., Holzschuh, A., Howlett, B.G., Jauker, F., Jha, S., Knop, E., Krewenka, K.M., Le Feon, V., Mandelik, Y., May, E.A., Park, M.G., Pisanty, G., Reemer, M., Riedinger, V., Rollin, O., Rundlof, M., Sardinas, H.S., Scheper, J., Scilligo, A.R., Smith, H.G., Steffan-Dewenter, I., Thorp, R., Tscharntke, T., Verhulst, J., Viana, B.F., Vaissiere, B.E., Veldtman, R., Westphal, C., Potts, S.G., 2015. Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. *Nat. Commun.* 6.
- Kremen, C., Ullman, K.S., Thorp, R.W., 2011. Evaluating the quality of citizen-scientist data on pollinator communities. *Conserv. Biol.* 25, 607–617.

- Lebuhn, G., Droege, S., Connor, E.F., Gemmill-Herren, B., Potts, S.G., Minckley, R.L., Griswold, T., Jean, R., Kula, E., Roubik, D.W., Cane, J., Wright, K.W., Frankie, G., Parker, F., 2013. Detecting insect pollinator declines on regional and global scales. *Conserv. Biol.* 27, 113–120.
- Mason, L., Arathi, H.S., 2019. Assessing the efficacy of citizen scientists monitoring native bees in urban areas. *Global Ecology and Conservation* 17, e00561.
- Nayak, G.K., Roberts, S.P.M., Garratt, M., Breeze, T.D., Tscheulin, T., Harrison-Cripps, J., Vogiatzakis, I.N., Stirpe, M.T., Potts, S.G., 2015. Interactive effect of floral abundance and semi-natural habitats on pollinators in field beans (*Vicia faba*). *Agric. Ecosyst. Environ.* 199, 58–66.
- O'Connor, R.S., Kunin, W.E., Garratt, M.P.D., Potts, S.G., Roy, H.E., Andrews, C., Jones, C.M., Peyton, J., Savage, J., Harvey, M., Morris, R.K.A., Roberts, S.P.M., Wright, I., Vanbergen, A.J., Carvell, C., 2019. Monitoring insect pollinators and flower visitation: the effectiveness and feasibility of different survey methods. In: *Methods in Ecology and Evolution* 0.
- Potts, S.G., Imperatriz-Fonseca, V., Ngo, H.T., Aizen, M.A., Biesmeijer, J.C., Breeze, T.D., Dicks, L.V., Garibaldi, L.A., Hill, R., Settele, J., Vanbergen, A.J., 2016. Safeguarding pollinators and their values to human well-being. *Nature* 540, 220–229.
- Powney, G.D., Carvell, C., Edwards, M., Morris, R.K.A., Roy, H.E., Woodcock, B.A., Isaac, N.J.B., 2019. Widespread losses of pollinating insects in Britain. *Nat. Commun.* 10, 1018.
- Rader, R., Bartomeus, I., Garibaldi, L.A., Garratt, M.P.D., Howlett, B.G., Winfree, R., Cunningham, S.A., Mayfield, M.M., Arthur, A.D., Andersson, G.K.S., Bommarco, R., Brittain, C., Carvalheiro, L.G., Chacoff, N.P., Entling, M.H., Foully, B., Freitas, B.M., Gemmill-Herren, B., Ghazoul, J., Griffin, S.R., Gross, C.L., Herbertsson, L., Herzog, F., Hipólito, J., Jaggard, S., Jauker, F., Klein, A.-M., Kleijn, D., Krishnan, S., Lemos, C.Q., Lindström, S.A.M., Mandelik, Y., Monteiro, V. M., Nelson, W., Nilsson, L., Pattimore, D.E., de O. Pereira, N., Pisanty, G., Potts, S.G., Reemer, M., Rundlöf, M., Sheffield, C.S., Scheper, J., Schüepp, C., Smith, H.G., Stanley, D.A., Stout, J.C., Szentgyörgyi, H., Taki, H., Vergara, C.H., Viana, B.F., Wojciechowski, M., 2016. Non-bee insects are important contributors to global crop pollination. *Proc. Natl. Acad. Sci.* 113, 146–151.
- Rollin, O., Garibaldi, L.A., 2019. Impacts of honeybee density on crop yield: a meta-analysis. *J. Appl. Ecol.* 56, 1152–1163.
- Roy, D.B., Ploquin, E.F., Randle, Z., Risely, K., Botham, M.S., Middlebrook, I., Noble, D., Cruickshanks, K., Freeman, S.N., Brereton, T.M., 2015. Comparison of trends in butterfly populations between monitoring schemes. *J. Insect Conserv.* 19, 313–324.
- Roy, H.E., Baxter, E., Saunders, A., Pocock, M.J.O., 2016. Focal plant observations as a standardised method for pollinator monitoring: opportunities and limitations for mass participation citizen science. *PLoS One* 11, e0150794.
- Rüdiger, J., Tasser, E., Walde, J., Huemer, P., Lechner, K., Ortner, A., Tappeiner, U., 2017. Simplified and still meaningful: assessing butterfly habitat quality in grasslands with data collected by pupils. *J. Insect Conserv.* 21, 677–688.
- Sharma, N., Colucci-Gray, L., Siddharthan, A., Comont, R., van der Wal, R., 2019. Designing online species identification tools for biological recording: the impact on data quality and citizen science learning. *PeerJ* 6, e5965.
- Tamburini, G., Bommarco, R., Kleijn, D., van der Putten, W.H., Marini, L., 2019. Pollination contribution to crop yield is often context-dependent: a review of experimental evidence. *Agric. Ecosyst. Environ.* 280, 16–23.
- Woodcock, B.A., Garratt, M.P.D., Powney, G.D., Shaw, R.F., Osborne, J.L., Soroka, J., Lindström, S.A.M., Stanley, D., Ouvrard, P., Edwards, M.E., Jauker, F., McCracken, M.E., Zou, Y., Potts, S.G., Rundlöf, M., Noriega, J.A., Greenop, A., Smith, H.G., Bommarco, R., van der Werf, W., Stout, J.C., Steffan-Dewenter, I., Morandin, L., Bullock, J.M., Pywell, R.F., 2019. Meta-analysis reveals that pollinator functional diversity and abundance enhance crop pollination and yield. *Nat. Commun.* 10, 1481.