Design and Testing of a National Pollinator and Pollination Monitoring Framework




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Project details

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Front cover photos:
Bombus ruderatus queen © Claire Carvell (top left)
Lasioglossum fulvicorne male © Steven Falk (top right)
Undertaking a fixed transect walk to record flower-visiting insects © Heather Lowther (bottom left)
Water-filled pan traps as a standardised passive sampling method © Claire Carvell (bottom right)

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Contents

Executive Summary

Insect pollinators provide a vital economic and ecological service through the pollination of crops and wildflowers. However, many insect pollinators are becoming less widespread in Britain and elsewhere and we have a poor understanding of the effect of these changes on the so-called "pollination services" provided by these insects. This is largely due to the *lack of long-term standardised monitoring of wild bees and hoverflies*. Here we describe a two-year research project which developed and tested a range of approaches to derive a National Pollinator and Pollination Monitoring Framework (NPPMF[note1]). The NPPMF aims to address two core questions, with a focus on wild bees and hoverflies, and on pollination services to *crops* rather than wildflowers, but with overall scope to better understand changes in population status of the full community of flower-visiting insects across GB:

a) How is the *status of insect pollinator populations* and communities changing over time in both agricultural landscapes and the wider environment?

b) How are *pollination services* to agricultural and horticultural crops changing over time?

We addressed the following five **Objectives**:

1. Review existing schemes, datasets and methods for measuring status and trends of UK pollinators and pollination services to identify key strengths and limitations of each in terms of scientific robustness, statistical power, cost and appeal to volunteer recorders;

2. Develop a variety of robust and realistic survey methods, specifically assessing their suitability for use by both professional and volunteer recorder groups;

3. Identify appropriate sampling frameworks for selected methods to ensure that monitoring will be representative from regional to national (GB) scales and capable of detecting spatio-temporal changes for different pollinators and pollination services;

4. Conduct a pilot study of the proposed NPPMF, testing best methods across a sub-set of potential sites and produce detailed protocols, including cost-benefit analysis, for successful delivery of each potential component highlighting appropriate statistical methods and the requirements necessary to support the scheme (validation, verification, data flow and data management);

5. Build on our partnership with the voluntary recording network and explore other relevant Citizen Science initiatives.

Key findings can be summarised as follows (referring to numbered Sections within this report):

- A review of existing National Recording Schemes and Societies (NSS), projects and datasets highlighted the value of verified (high quality) occurrence records compiled by experts within BWARS and HRS[note 1] for estimating long-term trends in species distributions. There are no long-term (>2 year) datasets, collected using systematic methods, that show changes in pollinator abundance or pollination service levels, and those datasets that do exist are small and biased towards England (Section 1.1).
- New modelling approaches using NSS datasets allowed robust estimates of species-level trends in occupancy of 1km squares across Britain to be made for around 50% of bee and hoverfly species over a 30 year time period (1980-2010). Of these, 28-51% became less widespread, whereas only 14-27% became more widespread, with the remaining species classified as stable (depending on the criteria used to classify change). During a similar time

[1] Guide to main acronyms: NPPMF = National Pollinator and Pollination Monitoring Framework; NSS = National Recording Schemes and Societies; BWARS =Bees, Wasps and Ants Recording Society; HRS = Hoverfly Recording Scheme; NPS = National Pollinator Strategy.

period, the demand for pollination services to crops and the area of insect pollinated crops have risen by more than 20%. The precision of these trend estimates would be improved, for some species at least, by combining the NSS occurrence data with stratified systematic surveys (Section 1.2).

- There are around 268 bee species and 284 hoverfly species in the UK. The majority of crop pollination is provided by a small proportion of common, widespread species that are effective in transferring pollen between flowers. We present a list of candidate species, meeting these and other criteria, for analysis from any long-term monitoring scheme, given that even a well-designed systematic scheme is unlikely to detect reliable trend estimates for all species (Section 1.2).
- We estimated the sample sizes and site networks required from different methods to achieve statistical power to detect trends in key measures relating to *pollinators* (e.g. abundance at species or 'group' level) and *pollination services* (e.g. pollination deficit) over a 10 year period. This suggested that between 20 and 75 sites across GB could provide sufficient power (>80%) to detect a 30-50% change over 10 years (equating to 3.5 – 7% annual change) for *widespread, common species or groups* (eg. summed abundance of bumblebees) with initial annual counts of *10 or more individuals* per site. More sites would be required (ca. 145) for species or groups occurring in small numbers (initial counts of 1 per site) or to detect smaller changes. Between 100-200 *fields per crop* would be required to detect 10-year changes of 30% in direct measures of pollination service or deficit, though ideal detection levels are likely to vary between crops with per hectare value and level of dependency on insect pollination (Sections 1.3 and 4).
- The costs associated with collecting data on pollinators vary greatly depending on approach. The highest cost/record research project (IPI Agriland), was also the most rigorous as it included many sites not typically visited by volunteers. However, the NSS represent substantial value. Assessment of the time spent on co-ordination and administration of BWARS and HRS revealed that equivalent professional staff would cost ~£143,000/year, in addition to time spent by volunteers in gathering and submitting the ca 51,000 records received each year (Section 1.4).
- For monitoring *pollinators* in the wider environment, we present a standardised protocol designed to be implemented by one person on one day (with four repeat site visits per year). A pilot study of this protocol carried out by different recorder groups, across 14 sites in England, Scotland and Wales, identified a combination of water-filled pan traps, fixed transect walks and timed floral observations as providing a comprehensive toolkit for assessing pollinator diversity and wildflower visitation. This protocol would generate sample sizes required to assess long-term trends in abundance at broad group level (bumblebees, solitary bees, hoverflies) but probably only at species-level for a few common species (e.g. 21% of the 108 species sampled in the pilot) (Section 3.1). Small scale field trials were also conducted to refine different methods and develop robust protocols for monitoring pollinators and pollination services to crops (Section 2.1).
- *Pan traps* (typically of three colours set at vegetation height to mimic flowers and collected after a standardised time) provide the least biased approach to sampling a wide range of pollinators, being particularly effective for many of the smaller solitary bee and hoverfly species (Section 3.1a). Trials of a 6-7 hour trapping duration performed as well as 24 hours with regard to number of insects caught, providing data of sufficient quality for quantitative analysis (Sections 2.1a, 3.1a).
- *Fixed transect walks* sampled comparable numbers of individuals and species of bumblebee to pan traps. Numbers of hoverflies on transects were similar to those in co-located pan traps but the number of species sampled was significantly less and for solitary bees transects were less effective than pan traps for numbers of individuals and species (Section 3.1a). A

transect width of 1m width is recommended if all flower-visiting insects are to be recorded, rather than the 4-5m used by other single-taxon monitoring schemes (eg. UKBMS, BeeWalks), to minimise bias towards more conspicuous species (Section 2.1a). Transects present an accessible method for recorders at different levels, can provide data on insect-flower interactions and estimates of pollinator density per unit area (Section 3.1a).

- *Timed focal flower observations* (10-minute watches of insect visits to defined plant species within a 50x50cm quadrat) offer an accessible and enjoyable approach to generating data on abundance and visitation rates at least to group level, which are shown to correlate with those from fixed transects. With training, they could be implemented by volunteers as part of a wider citizen science initiative. Selecting from a defined list of common plant species would help standardise observations, though further development is required to understand trade-offs between the area, duration and number of observations required and data quality (Section 2.1a, 3.1a).
- For all three methods it is important to factor in information on the availability of flowers, as this will have an influence on the number of insects recorded (Section 2.1a).
- For *pollination services to crops*, transect walks in flowering fields can be used to monitor changes in crop pollinator activity, generating counts of flower visitors by broad groups or to species level for a few easily recognised species. However, *direct* measures of pollination using hand pollination and bagging experiments remain the most reliable way to detect changes in pollination service or identify possible deficits that are independent of agronomic or regional variation (Section 2.1b).
- A better understanding of the relationship between pollinator activity, pollination service levels and crop yield for different crops is required before estimates of changing crop production, due to insect pollination, can be made based on detecting changes in pollinator activity or crop pollination alone. Based on findings from this project, the use of simple measures such as seed set show potential for some crops but require further development and testing (Section 2.2).

Presenting a Framework and costed scenarios for monitoring pollinators and pollination services

Here we summarise the research findings as five potential scenarios/options with varying levels of professional and volunteer involvement, which range both in cost (£49K - £8.6M over 10 years; between £4.5K - £851K annually for years 2-10) and in the specific metrics they can deliver. We set out the components included within each scenario along with consideration of the sampling design and assumptions, support requirements, likely costs, benefits and limitations of each. The scenarios are not mutually exclusive and indeed may be complementary, offering overall cost savings if particular options are implemented in combination; Scenarios 1 – 4 represent *potential new activities* in order of increasing volunteer involvement and decreased likely cost, and Scenario 5 represents existing biological recording activity with a simulated 10% increase in number of usable records:

SCENARIO 1: Professionally-led systematic repeated sampling of a stratified network of 1km squares across GB
SCENARIO 2: Professionally-led repeated systematic sampling focussed on crop pollination
SCENARIO 3: Volunteer-led pan trap network (using conventional taxonomy or DNA barcoding)
SCENARIO 4: Timed floral observations on existing scheme sites or as a wider citizen science activity
SCENARIO 5: Biological recording through National Recording Schemes and Societies (NSS)

Through an online survey of experts from across Europe, we identified that variations of Scenario 1 or 2, with 75 - 150 sites and detection of ≤5% annual changes, would meet the criteria to fully assess the sampling needs of eight key research questions on the drivers of pollinator decline, four of which would meet the expert's ideal standard. As such, the monitoring networks proposed have the potential to supply very large amounts of high quality data to answer key research questions, in turn providing substantial benefits by reducing research investments needed (Section 5).

There are many opportunities but also challenges for increasing volunteer involvement in pollinator monitoring. These challenges relate to:

i) *taxonomy* (currently a limited pool of skilled taxonomists; reliable identification to broad groups may be learnt quickly but identification to species level often takes years to become accomplished);
ii) *sampling methods* (collection of standardised data requires the consistent use of reliable methods, potentially involving capture of specimens, with associated requirements for training and support);
iii) *recruitment and retention* (potentially only ca. 50 active volunteer experts within BWARS and HRS combined with skills for species-level identification of bees and hoverflies, but with limited time to engage with training and supporting new recorders);
iv) *data verification and management* (current efforts of volunteer NSS organisers in record verification are unsustainable; online systems (e.g. crowd-sourcing identifications from photographs) and novel technologies (e.g. DNA barcoding) offer potential for increasing numbers of verified records and supporting volunteers but none are yet sufficiently developed for implementation and the capacity for verification remains limited) (Section 4).

In conclusion, there is considerable scope to enhance monitoring of *pollinators* and *pollination services* to ensure a robust and rigorous evidence-base to support the needs of policy, however this project has demonstrated clear trade-offs between likely cost and data quality, especially in terms of the taxonomic resolution and accuracy of species identifications. Currently the volunteer sector, namely the NSS, provides the expertise to deliver monitoring of changes in species occurrence or distributions at a national scale for many, but not all, species. Indeed the total value of voluntary work provided by BWARS and HRS under Scenario 5 is estimated, based on current levels, to reach in excess of £5M over ten years. Repeated systematic sampling from a stratified network of sites not typically covered by the NSS has the potential to add considerable value, providing data on pollinator abundance that may link with provision of pollination services and filling gaps in the spatial extent and species coverage. Enhancements to improve the range and accuracy of monitoring *pollinators* and *pollination services* over large spatial and temporal scales will depend on adequate resources to support capacity building, coordination and implementation.

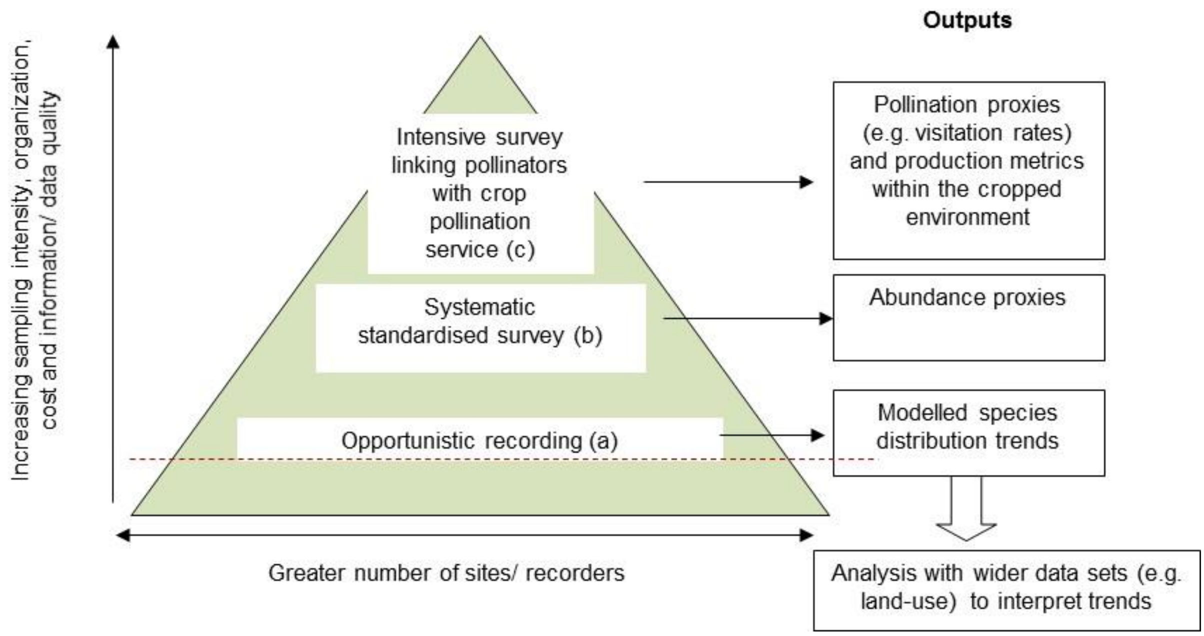
Introduction – why monitor pollinator populations and pollination services?

The National Pollinator Strategy (NPS) was published by Defra in November 2014[1], setting out an integrated approach to address the threats faced by pollinating insects in England. Many of these threats, the species facing them and the most appropriate conservation actions are common across Great Britain, indeed the Action Plan for Pollinators in Wales (2013)[2] preceded the NPS and similar strategies are being developed in Scotland and Ireland. The NPS sets out 11 key Actions to improve evidence on the status of pollinators and the service they provide, with the first of these being to:

"*Develop and field-test a new (sustainable, long-term) monitoring framework that can be implemented by professionals and volunteers*".

This report summarises the findings of a project undertaken during 2014-2015 by a team of Research Institutes, Universities, NSS and NGOs to address this evidence action. We present a framework with costed scenarios for potential new monitoring activities that range in levels of professional and volunteer involvement (see Fig. 1.0 and Section 4).

A report (hereafter Status Report) was published alongside the NPS summarising current evidence on the status of pollinators in GB, the economic and ecological benefits of both managed and wild pollinators (their contribution to GB crop production being valued at £630M pa[note2] based on the dependence and production value of insect pollinated crops in the UK including field crops, top fruit, soft fruit and horticultural crops) and the pressures on them from various environmental drivers[3]. The Status Report concluded that there is good evidence that species diversity and distributions of wild bees are changing in Britain, with more areas showing a loss of species than increase. However, it also highlighted the lack of *long-term standardised monitoring of wild bees and hoverflies*, the most important pollinators of crops and wild plants in GB.



[2] Updated from 2007 using 2012 Defra agricultural statistics using the methodology from the UK National Ecosystem Assessment (2011) Chapter 13.

Figure 1.0. Illustration of the over-arching objectives for pollinator monitoring in GB. The red dashed line shows the current position, with the potential quality and relevance of data outputs increasing as more intensive sampling strategies are employed from levels a - c (modified from Isaac & Pocock (2015)[4] and M. Stevenson pers. comm.).

Since publication of the NPS and Status Report, several new studies have added to the growing evidence of declines in pollinators, linked in particular to large-scale agricultural changes during the 20th century[5-8]. Each one of these publications has used *opportunistic records* of *species occurrence* submitted by *volunteer recorders* (Fig. 1.0 Level a) across Britain. These large-scale and long-term distribution datasets offer unparalleled opportunities for tracking *large-scale changes in species distributions*, but provide no information on abundance and hence population sizes and are known to be temporally and spatially biased because people record wherever and whenever they choose[4]. Furthermore, their application to the recent European Red List of Bees concluded that the majority of species, 57%, were 'data deficient' and hence threat status could not be assigned[9]. For UK butterflies and moths, repeated standardised counts of individual insects along fixed transect routes or sampled in light traps since the 1970s have provided powerful means of monitoring *trends in population size*, and indeed the latest analyses of these large-scale and long-term abundance datasets reveal significant declines[10]. However, despite their shared use of floral resources, the major life history differences between butterflies or moths and other pollinator taxa make them a weak proxy for other species[3]. Aside from the Bumblebee Conservation Trust's network of ca. 280 'BeeWalk' bumblebee transects running since 2012, there are currently no equivalent standardised data on changes in abundance of bees or hoverflies (Fig 1.0 Level b) for any country across the globe. To date there are no schemes or frameworks for monitoring pollination services to crops or wild plants (Fig. 1.0 Level c).

Understanding of the functional links between insect pollinators and the production of crops which benefit from insect pollination is improving, however much of the evidence is correlative rather than based on direct evidence[11,12]. Several studies show that wild insects, and not honeybees, are the main providers of crop pollination services (Fig. 2.0)[11,13,14], and that in general just a small handful of common species provide the vast majority of services. Similarly much of the evidence for relationships between land use or habitat management and pollinator populations is indirect and/or correlative, limiting our ability to assess the impact of interventions at representative scales (e.g. from farm-country). For example a large-scale experiment showed that where flower-rich habitats for pollinators were sown along field margins, within-field yields of crops such as field beans significantly increased over time[15]. Likewise, research in towns and cities has revealed a wealth of pollinating species where favourable habitats exist. This suggests that pollinator-friendly actions, as encouraged through the NPS and the new Countryside Stewardship scheme in England[note 3], can reduce the loss of pollinators and resulting erosion of the pollination services and other benefits we derive from nature. However, better evidence informed by standardised monitoring of pollinating insects and pollination would improve our ability to accurately predict the effects of conservation measures, future land-use changes and other environmental pressures on pollinators and pollination services from local to national scales[16].

Monitoring pollinators will be *more challenging* than for some already monitored taxa such as birds, because: i) there are *many more species*; ii) most of these cannot be *identified to species in the field* so capture of specimens becomes necessary; iii) there are comparatively *few volunteer recorders* or citizen science initiatives focussed on pollinating insects; and iv) identification of collected specimens is time-consuming and requires *specialist skills*. Therefore, the sampling design, taxonomic resolution and range of species or groups to be monitored, levels of volunteer and professional involvement, data handling and support tools will all be critical to the success of any long-term pollinator monitoring framework (Fig. 1.0).

[3] https://www.gov.uk/government/collections/countryside-stewardship-get-paid-for-environmental-land-management

Figure 1.1. Bumblebees (left, the rare *Bombus ruderatus*, Large Garden Bumblebee ©C. Carvell) and **solitary bees** are considered the most effective and important wild pollinators; **honeybees** (centre, *Apis mellifera*: ©M. Nowakowski) can be important crop pollinators in the vicinity of hives, though may be less effective per visit if, as shown here visiting apple blossom, not transferring pollen via stigmal contact; **hoverflies** (right, the common *Episyrphus balteatus*, Marmalade hoverfly: ©N. Mitschunas) carry less pollen than bees but their large numbers and diversity often make them important pollinators of crops and wild plants (see Section 1.2b).

The level of *taxonomic resolution* required depends on the question, policy need or hypothesis being tested. Species-level data are required for assigning conservation status[9], understanding the direction and magnitude of change in population sizes and in patterns of species diversity. Species-level data has added importance given the potential turnover in species and communities with environmental change[17] that could see dominant crop types or native plant communities and their key pollinators change in the future. However, given the challenges of identification to species for many insect groups and sampling intensities required to detect changes for the less common species (addressed in this report), higher-level taxonomic groupings are often used. Studies suggest that analysis at genus-level does not affect our ability to discern changes in community composition for some invertebrate assemblages[18], but the relationship has not been tested for pollinators and even identification to genus level is challenging for many bees and flies. Use of broader taxonomic groupings (e.g. total bees or separating to bumblebees, solitary bees and honeybees) offers more potential for non-expert involvement, especially if standardised counts and/or flower visitation rates can be generated. These metrics provide a proxy for changing levels of pollination service to crops and wildflowers, but a better understanding of the links between pollinator abundance and service provision is still required (as discussed and tested this report, see Section 2). We also consider the potential value of DNA barcoding techniques and online crowd-sourcing with photographs for specimen identification to support large-scale monitoring (Section 4).

We focus here on *bees* (considering bumblebees, solitary bees and honeybees as distinct taxonomic groups) and *hoverflies* (Fig. 1.1), although the methods proposed are appropriate to sampling a wide range of other flower-visiting insects that may be important pollinators in some contexts. Where we refer to "pollinators", this term is broadly used to describe *all flower-visiting insects*, with the caveat that their particular behaviour, morphology, activity period and hence "efficiency" at transferring viable pollen between flowers will be the true determinant of their effectiveness as pollinators[19].

Project Aims and Objectives

The overarching aim of this project was to design and test a National Pollinator and Pollination Monitoring Framework (hereafter NPPMF) that will provide the scientific evidence base for assessing changes in UK pollinator populations (abundance and distribution) and communities (diversity and composition) and the pollination services they provide to crops.

The NPPMF will aim to address two core questions and evaluate the interrelationship between them:

a) How is the *status of insect pollinator populations* and communities changing over time in both agricultural landscapes and the wider environment?

b) How are *pollination services* to agricultural and horticultural crops changing over time?

For each of these questions we addressed the following five **Objectives**:

1. Review existing schemes, datasets and methods for measuring status and trends of UK pollinators and pollination services to identify key strengths and limitations of each in terms of scientific robustness, statistical power, cost and appeal to volunteer recorders;

2. Develop a variety of robust and realistic survey methods, specifically assessing their suitability for use by both professional and volunteer recorders;

3. Identify appropriate sampling frameworks for selected methods (from Tasks 1 and 2) to ensure that monitoring will be representative from regional to national (GB) scales and capable of detecting spatio-temporal changes for different pollinators and pollination services;

4. Conduct a pilot study of the proposed NPPMF, testing best methods agreed from Task 2 across a sub-set of potential sites and produce detailed protocols, including cost-benefit analysis, for successful delivery of each potential component highlighting appropriate statistical methods and the requirements necessary to support the scheme (validation, verification, data flow and data management);

5. Build on our partnership with the voluntary recording network and explore other relevant Citizen Science initiatives.

This report provides a summary of project findings and key recommendations, presented under the two core themes relating to a) pollinators and b) pollination services to crops where these were addressed under separate tasks. Full details of methods and results are provided within technical Annexes (A – G), and within two accompanying Electronic Appendices. The scope of the project extended in most cases to the *GB-level* (in terms of pilot testing, stakeholder and Steering Group involvement), however the relevant National Recording Schemes and Societies (NSS) operate at UK-level and the new status and trend analyses presented in Section 1.2 include data from N Ireland.

1: Review of existing schemes, datasets and methods for measuring status and trends in pollinators (Objective 1).

A variety of approaches are currently used to gather information on insect pollinators and pollination services across GB, from mass participation citizen science to hypothesis-led research projects that between them encompass a wide range of volunteer and professional recorders spanning from novice to expert.

The aim of this Objective was to review existing schemes, datasets and methods for measuring status and trends of UK pollinators and pollination services to identify the key strengths and limitations of each in terms of scientific robustness, statistical power, cost and appeal to volunteer recorders.

1.1 Metadata capture from existing schemes and datasets

The project team (comprising a broad range of taxonomic expertise and spanning professional and volunteer sectors) compiled information on a range of relevant schemes (including NSS), projects and datasets covering wild and managed bees, hoverflies, butterflies and measures of pollination service in crops and wild plants. Table 1.1 provides examples, and a full catalogue is provided in Electronic Appendix 1, including information on ownership, survey design, spatial and temporal scale, survey methods and taxonomic coverage.

For *pollinators*, a total of 7 NSS or established volunteer recording networks; 11 citizen science initiatives or projects involving public participation in recording pollinators (many now inactive) and 35 different large-scale datasets from systematic surveys or research projects were identified.

For *pollination services*, 47 potentially relevant datasets were identified from 11 distinct research projects, covering the field crops oilseed rape and beans, top fruits (including apples and pears) and the soft fruits strawberries and blackcurrants. Data from a number of different standardised survey methods were available (including pan traps, fixed transects, timed observations and hand pollination and bagging experiments).

For *pollinators* and *pollination services* there was a clear *shortage of long-term systematic datasets* of >2 years involving repeated sampling of the same locations, and a general bias towards England in coverage. Furthermore, even large-scale systematic surveys being undertaken by professionals as part of funded research projects do not always generate species-level data on bees and/or hoverflies (depending on their overall aims), and where they do, these records are often not submitted (as standard practice) to the relevant NSS.

Table 1.1. Examples of schemes and projects involving volunteers that generate data on UK pollinators. See Glossary for project aims or definitions; key to categories below.

Scheme/ Project Name	V/ P	Routes to involvement	Quality assurance	Training	Annual no. participants	Average annual no. records vs = verified to species level	Response measures	Weblink
Bees Wasps and Ants Recording Society (BWARS)	V	Website, annual meeting, training courses, forum, social media	High	Courses (members only); forums	400 members	25,000 vs (bees)	SP; DO; FD; SD	http://www.bwars.com/
Hoverfly Recording Scheme (HRS)	V	Website, annual meeting, training courses, forum, social media	High	Paid and members only courses; forums	>1000	26,293 vs (hoverflies)	SP; DO; FD; SD	http://www.hoverfly.org.uk/portal.php
BeeWalks	P	Website, training courses	Medium	Online & paper ID resources; photo support; forum	232	30,000 mostly vs (bumblebees)	SP; DO; FD; SD; AbGp; AbSp bumblebees only; Hab	http://www.beewalk.org.uk/
BeeWatch	P	Website	Medium	Online ID resources; photo support; forum	920	2,141 vs 2,800 total	SP; DO; FD; SD bumblebees only	http://bumblebeeconservation.org/get-involved/surveys/
UK Butterfly Monitoring Scheme (UKBMS)	P	Website, annual meeting	High	Online materials	630	563,000 vs (butterflies)	SP; DO; FD; SD; AbGp; AbSp butterflies only; Hab	http://www.ukbms.org/
Wider Countryside Butterfly Survey (WCBS)	P	Website, annual meeting	Medium	Online materials	643	101,000 vs (butterflies, moths, dragonflies)	SP; DO; FD; SD; AbGp; AbSp butterflies only; Hab	http://www.ukbms.org/wcbs.aspx
Open Farm Sunday Pollinator Survey	P	Website, attendance at participating farm	Low (untrained volunteers) to high (professional surveys)	On-line podcasts and guidance from ecologists on selected farms	480	11,000 (flower visitors)	AbGp; VR; Hab	http://www.farmsunday.org/ofs12b/open/PollinatorSurvey.eb
Great British Bee Count	P	Smartphone app; Website	Low	Online materials	23,732	832,110 (bees)	AbGp; SP for ~10 targeted bee species (2014)	https://www.foe.co.uk/what_we_do/the_bee_cause_home_map_393
Big Bumblebee Discovery	P	Website; on-line supporting materials; Log books and materials sent to schools	Low to Medium (sample of records checked)	On-line podcasts	13,000	4,000	AbGp; VR bumblebees only	http://jointhepod.org/campaigns/campaign/31

V/P Volunteer or Professional-led (whether coordinated by volunteers or paid professionals); **Quality assurance** (degree of data verification by experts), **Annual number of participants** (annual average from the lifespan of the project; in many cases only a small proportion are 'active' regular recorders); **Average annual number of records** (annual average from the lifespan of the project, in the case of BWARS and HRS, averages between the years 2008-2012); **Response measures** that could be assessed from the data generated (SP = species presence; DO = species distribution/ occupancy; FD = functional diversity; SD = species diversity; AbGp = abundance at group level; AbSp = abundance at species level; VR = visitation rate; Hab = habitat type within area sampled). All schemes/ projects are currently active with the exception of the Big Bumblebee Discovery. Note that the rigour of the response measures is dependent on quality of the data submitted. All projects cover the UK in scope except for BWARS (GB and Ireland) and HRS (GB only) but data from all projects is currently biased spatially and temporally. There is one citizen science project currently generating data on pollination service through growing beans in gardens and urban green spaces ('Bees n Beans' http://www.ljbees.org.uk/[20]).

1.2 Understanding status and trends from existing National Recording Schemes and Societies and other datasets

1.2a) Pollinators

Aims: using a combination of volunteer-collected occurrence and systematically collected data, to:

i) Estimate reliable trends in occupancy (distributions) of all UK bees and hoverflies between 1980 - 2010;
ii) Investigate the added value to status and trend estimates from systematically collected data.

1.2a i) New trend estimates for bees and hoverflies using volunteer-collected occurrence data

Volunteer-collected occurrence data from NSS provide valuable information about changes in species' *distributions and status*. However, extracting this information and using it to analyse trends over time is difficult, because records are not collected in a standardised way and are subject to many forms of bias[4]. Techniques have been developed to account for these biases in recording effort and currently, *occupancy-detection models* are considered to provide the most robust results[10,21].

Here, we use occupancy models to estimate reliable species-specific trends for all hoverfly species and all wild bee species considered to be 'pollinators' in GB (based on expert opinion). The same occupancy models were also used to assess composite trends across multi-species 'Indicator' groups[22]. Occupancy models estimate the proportion of 1km grid cells occupied by each species, each year, while simultaneously estimating and accounting for variation in detection probability. To maximise the robustness of trend estimates, only 1km cells with at least 3 years of data were included. Final datasets consisted of 38,229 visits across 3234 cells for 159 bee species and 67,074 visits across 5882 cells for 263 hoverfly species. A visit is a record of any species within the target group. Each model was run in a Bayesian framework with 20000 iterations per species. The 95% credible intervals of each estimate were used to assess uncertainty and determine the statistical significance of the trend. Note these analyses were conducted at the UK scale (including N Ireland) for consistency with the Indicator work, but records from N Ireland constituted a very small proportion of the total.

Species-level trends

Two occupancy trend estimates were calculated for each species: a long-term 30-year (1980 to 2010) and short-term 10-year (2000 to 2010) trend. Species trends were calculated as the percentage change in fitted occupancy over each time period. Statistically robust trend estimates could be made for only *approximately 50% of species*, due to data limitations (the Bayesian occupancy approach is data hungry, requiring multiple visits to each grid cell within a year, therefore our ability to estimate robust trends for species with few records was limited).

Trend estimates for all species are given in Annex A, with examples in Figure 1.2 and Table 1.4. Overall, a greater proportion of species *significantly decreased* than increased in occupancy of 1km squares in both the *long-term* (28% of species decreased; 14% increased) *and short-term* (11% of species decreased; 9% increased). Patterns varied between bee and hoverfly groups (Figure 1.1), and bumblebees showed contrasting patterns between time periods with 40% of the 10 modelled species increasing and 60% remaining stable over the long-term but 46% of the 11 modelled species decreasing over the short-term.

The annual variation in the occupancy estimates (Figure 1.2), and contrasting patterns between time periods (Figure 1.1) may be partly explained by variation in weather conditions, although a number of pressures (including climate, land-use and management intensity) are likely to impact on local pollinator distribution and abundance[23]. It is not known whether the more recent decreases in occupancy of several bumblebee species since 2000 represent the start of a longer-term trend or a short term fluctuation, or some un-modelled source of bias (e.g. a tendency among recorders to submit fewer records of common bumblebee species). We note that this assessment covers relatively recent patterns of change (1980-2010) and many species are likely to have experienced most severe declines in the period before 1980[24]. Furthermore, the degree to which these trends in occupancy are accompanied by changes in abundance is not known. As individual species become more or less widespread, their relative abundances are likely to change and the communities in a given area become more or less diverse. This has implications for pollination service since more diverse pollinator communities are more effective at pollinating a range of crops[11] and wild plants (see Section 2.2).

a) Long-term trends (1980 – 2010)

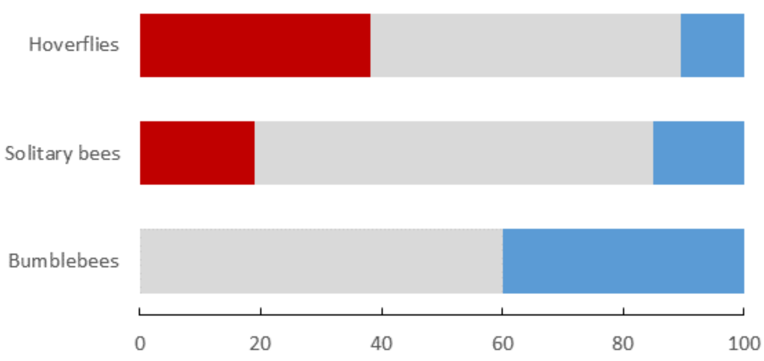
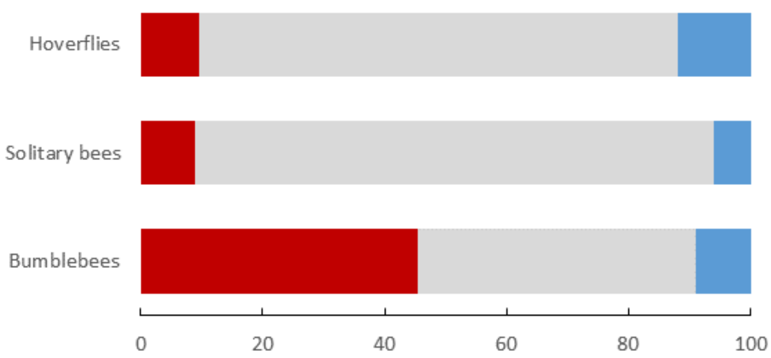


Figure 1.1. The percentage of species in each taxonomic grouping that had increased (blue), were stable (grey) or declined (red) in occupancy of 1km squares across the UK between a) 1980 to 2010 (long-term, top graph) and b) 2000 to 2010 (short-term, bottom graph). Figure is based only on those species where a trend could be reliably estimated (long-term = 58% and 40% of all bee and hoverfly species respectively, short-term = 62% and 48% of all bee and hoverfly species respectively).

b) Short-term trends (2000 – 2010)



For the long-term trend (a) the figure is based on 82 solitary bee species, 10 bumblebee (*Bombus*) species, and 105 hoverflies, while the short-term trend (b) is based on 87 solitary bee species, 11 were *Bombus* species and 126 hoverflies. The correlation between the long-term and short-term trend was low.

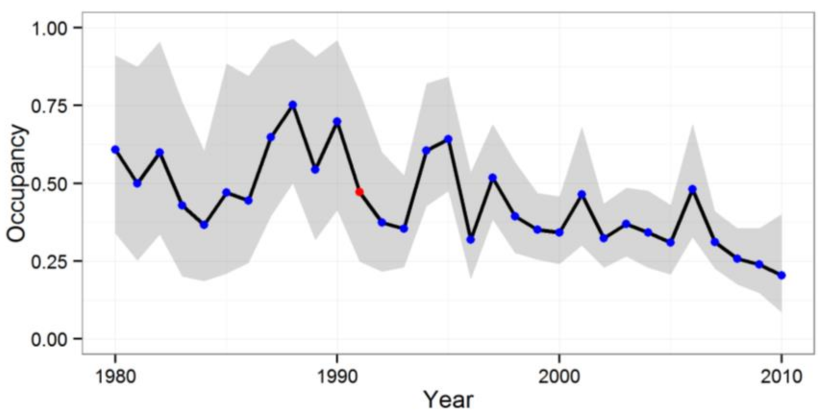


Figure 1.2. Annual occupancy estimates for *Andrena fulva*, the Tawny mining bee (right, © Steven Falk), a relatively common species and crop visitor that has undergone a significant decrease in occupancy of 50% since 1980. The grey band represents the 95% credible interval surrounding each annual occupancy estimate as a measure of uncertainty, hence we can be 95% certain that the true value falls within this range. The red point highlights an unreliable occupancy estimate where the model failed to converge. Note inter-annual variability that is likely to be partly explained by annual variation in weather.

Pollinator indicator

Our headline figure of 28% is lower than the 51% of bee and hoverfly species that were reported to have become less widespread as in the recent 2015 Indicator of Pollinating Insects[22]. The two values were based on the same data and occupancy models, but differ in the way that the trend estimate was calculated. For the pollinator Indicator, species were classified according to the 'best estimate' of their trend, and a decrease was defined as a reduction in occupancy of at least 1% per year in line with thresholds applied to other indicators (eg. for birds). By contrast, the figure of 28% presented in this report is the proportion of species for which we are at least 95% confident that occupancy has decreased. Most of the discrepancy consists of species for which our best estimate is that they decreased by more than 1% per year, but we are rather uncertain about this value (i.e. the decrease is substantial but not 'significant' in a statistical sense). However, there is a small number of species for which the converse is true (i.e. we are very confident that they declined, but the magnitude of the decline was smaller than 1% per year). In reality, the true proportion of species in decline is between the 28% reported here (more conservative estimate) and the 51% reported in the Indicator.

Note that all species are given equal weight in the pollinator Indicator; effectively assuming species are equally valuable in terms of their contribution to pollination services. However, contribution to pollination is known to vary between species and with overall abundance, and groups other than bees and hoverflies such as anthomyid or muscid flies may be important in certain situations (see Sections 1.2b and 2.2). Future work will examine the feasibility of weighting the Indicator to take account of this variation in species' importance as pollinators and to include trends from other taxonomic groups known to pollinate crops and wild plants (see Section 1.2c).

1.2a ii) Preliminary analysis of added value from systematically collected data

The project considered the capacity to build on existing NSS activities using, where relevant, systematically collected data in combination with unstandardised occurrence records. Such a combination has the potential to add value to the current occupancy modelling approach by a) reducing uncertainty in current estimates of status for multiple species and b) improving the spatial resolution or reducing patchiness of current recording activity. To demonstrate this potential, we present a *preliminary* analysis using the occupancy-detection models described above for two bee species comparing and combining occurrence data (BWARS) from a single year (2012) with systematically collected data from the IPI Agriland project (see Glossary) in which professional researchers surveyed 96 predominantly agricultural sites on three occasions during 2012 for pollinators using pan traps. The approach is based on the principle that adding more records to a model will almost always increase its precision; an important question is whether the improvement per record from systematic surveys is greater than adding the same number of unstructured records. Note that we make the simplifying assumption here that recording scheme datasets are a random draw from across the UK, which as explained is not the case, and is likely to lead to different forms of bias for habitat specialists compared with those occurring across the wider countryside.

The total number of unique bee records across all species (where a record is defined as a survey event on which a species is recorded) in BWARS and Agriland for 2012 were very similar (2367 and 2596 respectively) despite a ten-fold difference in the number of sites (1047 vs 96). Occupancy estimates for the two datasets were quite different (Table 1.2), as expected because they sampled both the landscape and the bee species differently. BWARS sites are biased towards semi-natural habitat in southern England with direct observations of individuals being made on an ad-hoc basis, whereas Agriland sites were stratified across gradients of land-use intensity in six regions of England and Scotland (thus can be considered more representative of GB as a whole than the BWARS data) with bees sampled passively in pan traps. Moreover, no sites were shared between datasets. However, for each species the occupancy estimates from both datasets combined were intermediate between those from the individual datasets. For *Bombus pascuorum*, the more widespread of the two species, precision (the converse of uncertainty as referred to in Figure 1.2) was considerably improved when datasets were combined. This was not the case for *Andrena haemorrhoa*, for which the estimate from Agriland was more precise than the combined estimate.

Table 1.2. Results of occupancy models for two bee species using volunteer-collected records (BWARS) and systematic repeated sampling (Agriland) during 2012.

Dataset	*Bombus pascuorum*			*Andrena haemorrhoa*		
	Records	Occupancy	Precision	Records	Occupancy	Precision
BWARS	169	0.819	237	40	0.961	116
Agriland	87	0.745	145	41	0.333	816
Combined	256	0.771	356	81	0.460	149

Bombus pascuorum is common and widespread; *Andrena haemorrhoa* is more patchy in its distribution. Agriland data were treated as presence/absence rather than abundance. 'Occupancy' = the mean (modelled) proportion of occupied sites; 'Precision' = the reciprocal of variance in the occupancy estimate across all model runs for each species.

These preliminary results suggest firstly that modelled estimates of occupancy or distribution may differ depending on survey and sampling approaches. Secondly they suggest that combining occurrence records with systematically collected data may influence precision of the estimates in ways that vary among species depending for example on whether they are habitat specialists or more generalist and widespread. Repeated systematic sampling from a stratified network of sites not typically covered by NSS therefore has the potential to improve both the precision of current occupancy estimates and fill gaps in the spatial extent of typical recording activity for some (especially widespread) species. However further research is required to understand how recording bias across habitats or towards particular species may affect the relative differences between resulting occupancy or trend estimates.

1.2b) Pollination Services

Aims: using existing survey data sets, the wider literature and current national scale crop data, to:

i)) Identify key crop pollinators in GB to inform any targeted crop pollinator monitoring scheme;
ii) Estimate recent trends in the demand for crop pollination across GB and at a country level.

1.2b i) Identifying key crop pollinators

The capacity of a pollinator to provide pollination services to a crop is a product of its abundance and visitation rate to crop flowers in the field, and the efficiency of those visits in transferring viable pollen and improving fruit set or seed set. Using existing data sets produced by the IPI Sustainable Pollination Services for UK Crops Project[note4], we identified the species that were the *most abundant flower visitors to four key UK crops in our study regions*: oilseed rape (Yorkshire), field beans (Berkshire and Oxfordshire), strawberries (Yorkshire) and apples (Kent). Combining these observations with experimental data on pollination efficiency from the wider literature (with broader geographic coverage), potentially important taxa providing pollination services to these crops can be summarised as follows (see Annex A for full details):

- The most abundant visitors to apple flowers in the Kent orchards surveyed were solitary bees, constituting over 49% of visitors. Abundant species included *Andrena haemorrhoa*, *Andrena nitida* and *Andrena dorsata*. More widely, *Andrena* species are efficient apple pollinators and can be more effective on a per visit basis than honeybees and bumblebees.
- *Bombus terrestris/lucorum*, *Apis mellifera* and *Bombus lapidarius* were the most abundant *field bean* flower visitors observed on fields in Oxon and Berks, constituting more than 77% of visitors. More widely, *Bombus terrestris* is an efficient bean pollinator when not involved in 'nectar robbing' behaviour (making holes in the flower corolla to allow direct access to the nectaries) and the long-tongued species *Bombus hortorum* and *Bombus pascuorum* are also effective pollinators.
- Common flower visitors to *oilseed rape* (on fields in Yorkshire) included *Apis mellifera*, *Bombus terrestris/lucorum* and some hoverfly species. The most common hoverfly species were *Melanostoma mellinum/ scalare* and *Platycheirus manicatus*. Many species have been shown to be effective pollinators of oilseed rape, including hoverflies, and solitary bees for which the likelihood of pollen transfer may be greater than for honeybees or bumblebees.
- Strawberries were visited most often by *Apis mellifera*, *Bombus terrestris/lucorum* and *Bombus lapidarius* (on fields in Yorkshire). More widely, honeybees and species of bumblebee, solitary bee and hoverfly can all be efficient strawberry pollinators.

1.2b ii) Trends in supply and demand for crop pollination

Quantifying the demand for pollination services to crops is challenging. Most accurately, "demand" can be defined as the sum number of pollen grains that need to be transferred to receptive flowers, however this is currently unknown and very difficult to estimate for most crops. Furthermore, the demand for pollination services to crops will change spatially and temporally due to a range of climatic and economic factors, including those which limit crop production and their subsequent dependence on pollination by insects. Consequently, the area of insect pollinated crop is often used as a proxy for demand[25,26]. However, the efficiency of pollinators and the demands for pollination can vary between crops, so some studies have instead quantified demand as the number of honeybee colonies required to provide recommended levels of pollination[13]. The supply of and

[4] http://www.reading.ac.uk/caer/Project_IPI_Crops/project_ipi_crops_index.html

demand for wild pollinators required for crop pollination is extremely difficult to quantify as their abundance and diversity are affected by multiple environmental factors and there is no standardised and systematic monitoring of their populations.

The demand for honeybee pollination services (using data from Defra, 2015, and the methods of Breeze et al, 2011[27]) and the area of insect pollinated crops have risen by 54% and 23% respectively between 1992 and 2012 (Annex A). The uneven distribution in demand for crop pollination is highlighted by a comparison across Scotland, Wales and England (Table 1.3). It is possible to determine areas particularly at risk of reduced production, in the face of increased demand for or reduced supply of pollination service, at fine spatial scales and target any crop pollination service monitoring to the most vulnerable areas. Spatial maps of pollination service have been developed for a limited number of UK crops including field beans[25] and apples[26], but data to do this for all UK insect pollinated crops is currently lacking.

Table 1.3. Demand for pollination services in England, Scotland and Wales (2012)

		Scotland		Wales		England	
Crop	Hives/ha	Area (ha)	Demand (hives)	Area (ha)	Demand (hives)	Area (ha)	Demand (hives)
Orchard fruits	1.3	89	113	365	464	24,200	30,769
Oilseed Rape	1	39,603	39,603	5,628	5628	756,000	756,000
Strawberries	1.2	186	223			3300	3,960
Other Soft Fruit	1.6	622	970	408	636	6100	9,516
Beans (not combined)	1.8	1,193	2,088				
Field Beans	2.5	3,789	9,472			96,000	240,000
Total		45,482	52,469	6,401	6,729	913,600	1,040,245

Crop = crop group. As the cited references often do not specify the exact area of specific crops these broad categories are used instead. **Hives/ha** = the lowest recommended stocking rates reported in Breeze et al. (2014). For crop categories, an average of all applicable UK crops was used. **Area** = the area (in ha) of crop reported in Defra (2012), SAG (2015) and WAG (2015). **Demand (hives)** = demand for pollination services, measured as the total number of honeybee hives required to provide pollination services at the recommended stocking rates. Note that as data sources differ between this table and the more comprehensive information in Annex A some differences may be observed.

1.2c) Moving towards a list of candidate species for long-term monitoring?

Given limited resources, even a well-designed systematic monitoring scheme is unlikely to be able to detect reliable trend estimates for all species (see Sections 3 and 4). We therefore propose a list of candidate species for analysis from any long-term systematic monitoring effort, selected on the basis of being widespread and abundant in the wider countryside or suburban areas across GB (using detectability within a large-scale pan trapping study as a proxy) *and/or* abundant visitors to key UK crops (see 1.2b) (Table 1.4). Species within the list show both decreasing and increasing recent long- and short- term trends in occupancy, these trend estimates tending to have less uncertainty than those for the rarer species (Annex A) given that the widespread species are usually associated with more records. These species are likely to be encountered *in sufficient numbers across different regions* to detect long-term changes in their populations and many are *functionally important* pollinators of crops and wild plants in the current climate. Such changes could therefore act as a measure of the long-term capacity of the pollinator community to provide pollination services, alongside measures of overall grouped abundance and species diversity (see Framework, Section 4). A better understanding of species ecology, pollination efficiency and how this varies between regions and crops is required to refine any list of appropriate indicator species for monitoring.

Table 1.4. Candidate species for long-term systematic monitoring.

						Extent of occupancy			Trend in occupancy	
Species name	Group	Ease of ID	Flight season	Detect ability	Crop visitor	Eng-land	Wales	Scot-land	Long-term 1980-2010	Short-term 2000-2010
Bombus hortorum	BB	3	Mar-Sep	1	Y	94	43	92	32.66 (3.71 - 69.47)	-29.2 (-41.42 - -14.35)
Bombus lapidarius	BB	1	Mar-Oct	1	Y[2]	104	126	31	49.82 (25.8 - 76.36)	-22.2 (-32.39 - -10.54)
Bombus lucorum s.l.	BB	1 - 5*	Mar-Oct	1	Y[1=]	101	75	107	NA	NA
Bombus pascuorum	BB	2	Mar-Oct	1	Y[7]	109	133	94	53.2 (34.81 - 74.05)	-17.87 (-26.51 - -8.53)
Bombus pratorum	BB	3	Mar-Sep	1		97	105	53	15.74 (-3.65 - 38.67)	-37.93 (-49.47 - -24.24)
Bombus terrestris	BB	1-5*	Feb-Oct	1	Y[1=]	97	54	26	11.18 (-9.69 - 34.6)	-34.65 (-43.49 - -24.13)
Apis mellifera	HB	1	Jan-Dec	1	Y	55	6	22	NA	NA
Andrena cineraria (S)	SB	1	Mar-June	0	Y	47	19	0	322.19 (179.13 - 557.59)	46.4 (1.82 - 124.01)
Andrena dorsata	SB	3	Mar-Sep**	0	Y[9]	49	0	6	331.46 (201.18 - 527.11)	8.94 (-16.54 - 46.98)
Andrena flavipes	SB	2	Mar-Sep	0	Y[4]	48	10	6	60.41 (27.43 - 104.51)	-9.74 (-28.63 - 12.44)
Andrena fulva	SB	1	Mar-June	1*	Y[8]	62	21	0	-49.53 (-65.3 - -30.5)	-38.82 (-60.98 - -7.52)
Andrena haemorrhoa	SB	1	Mar-Jul	1	Y[5]	75	37	19	-5.74 (-19.35 - 12.28)	-0.86 (-24.67 - 27.69)
Andrena nitida (S)	SB	2	Mar-Jul	0	Y	52	32	6	55.84 (14.21 - 113.76)	-14.48 (-38.48 - 17.61)
Andrena scotica	SB	3	Mar-Jul	0	Y[6]	72	41	22	-6.32 (-25.66 - 18.34)	11.95 (-22.11 - 50.61)
Anthidium manicatum	SB	1	May-Aug	1*		36	13	0	32.3 (-32.77 - 128.23)	-47.19 (-69.8 - -9.95)
Anthophora plumipes	SB	2	Feb-May	1*		53	4	0	77.73 (-3.74 - 178.02)	-14.59 (-36.98 - 18.35)
Lasioglossum albipes	SB	3	Mar-Sep	1		59	25	7	-12.67 (-38.44 - 28.36)	-12.59 (-46.56 - 39.15)
Lasioglossum calceatum	SB	3	Mar-Oct	1	[10]	81	47	18	-1.35 (-16.83 - 17.96)	11.76 (-12.31 - 38.86)
Osmia bicolor	SB	2	Mar-Jul	1		21	0	0	12.44 (-54.01 - 119.03)	15.92 (-33.03 - 144.2)
Osmia bicornis (S)	SB	1	Mar-Jul	1*		87	43	10	-16.28 (-42.03 - 11.75)	-48.38 (-62.73 - -29.31)
Episyrphus balteatus	HF	1	Jan-Dec	1		113	130	120	6.96 (0.15 - 14.04)	-6.83 (-12.39 - -1.02)
Eristalis abusivus	HF	3	Mar-Oct	1		26	27	18	NA	NA
Eristalis arbustorum	HF	2	Apr-Nov	1		107	130	82	-22.68 (-28.88 - -16.52)	-12.41 (-21.85 - -1.76)
Eristalis pertinax	HF	1	Mar-Nov	1		111	128	112	12.86 (5.69 - 21.25)	1.63 (-4.93 - 8.77)
Eristalis tenax	HF	1	Jan-Dec	1		111	130	82	-20.01 (-27.52 - -12.25)	-16.2 (-23.71 - -7.7)
Eupeodes corollae	HF	2	Mar-Nov	1		99	117	49	-27.67 (-36.91 - -16.17)	-7.91 (-26.41 - 16.35)
Helophilus hybridus	HF	2	Apr-Oct	1		59	42	15	-14.08 (-41.22 - 24.97)	27.83 (-23.7 - 103.98)
Helophilus pendulus	HF	2	Apr-Nov	1	Y	109	127	102	-10.43 (-15.55 - -5.03)	-2.9 (-10.27 - 4.26)
Melanostoma mellinum	HF	2	Apr-Oct	1	Y	107	127	110	-20.79 (-28.77 - -12.49)	3.06 (-8.19 - 16.33)
Melanostoma scalare	HF	2	Apr-Nov	1	Y	108	124	112	14.55 (5.07 - 25.76)	25.79 (13.15 - 40.62)
Neoascia podagrica	HF	3	Apr-Nov	1		93	114	74	-38.39 (-47.4 - -27.49)	-13.43 (-33.07 - 11.8)
Platycheirus albimanus	HF	2	Mar-Nov	1	Y	109	124	111	1.77 (-4.54 - 8.99)	-0.96 (-9.08 - 7.49)
Platycheirus granditarsus	HF	1	May-Oct	1		79	118	48	-24.08 (-39.63 - -2.02)	19.77 (-7.65 - 57.48)
Platycheirus manicatus	HF	2	Apr-Nov	1	Y	77	48	76	-27.73 (-43.09 - -8.7)	-38.79 (-59.82 - -4.17)
Rhingia campestris	HF	1	Apr-Oct	1		106	126	83	-4.93 (-13.09 - 3.83)	-7.94 (-17.14 - 2.35)
Sericomyia silentis	HF	1	May-Nov	1		70	110	107	-10.6 (-29.71 - 11.29)	-5.3 (-20.35 - 13.03)
Syrphus ribesii	HF	3	Mar-Nov	1		107	118	89	-4.36 (-12.2 - 5.26)	33.47 (18.63 - 51.74)

BB = bumblebee; SB = solitary bee; HB = honeybee; HF = hoverfly. Species were assessed according to their **Ease of ID** (identification difficulty scores representing ease of ID by any recorder regardless of experience; generated by NSS experts. 1 = Can be identified at sight in the field by anyone with a bit of experience. Species with which the beginner rapidly becomes familiar. Usually identifiable from a photo; 2 = Can be identified in the field with care and experience. Needs a good view or the netting of a specimen to check, but the specimen can then be released. May be identifiable from a good photo, or series of photos; 3 = Identification only accepted from known recorders or else needs confirmation from vice county recorder; 4 = Species needs confirmation from national expert; 5 = Voucher specimen required to be examined by national expert.) 1-5* denotes that for *B. lucorum* and *B. terrestris*, queens may be easily identified but workers are difficult to separate, and *B. lucorum* includes a 'complex' of three species which require expertise to reliably separate; **Flight period** (months during which the species is typically on the wing, ** two generations Mar-May/Jul-Sep); **Detectability** (a proxy based on the large-scale Agriland pan trapping study: 1 = mean annual abundance per site >1 and/or detected in pan traps at 40 or more out of 96 sites; 0 = mean annual abundance <1 and/or detected at fewer than 40 sites (* species not abundant in pan traps in countryside but frequently seen in gardens/parks)); whether key **Crop visitors** (most abundant flower visitors to four key UK crops in IPI crops project, see above 1.2b; [1-10] indicate rankings of European crop pollinators from a recent meta-analysis, also including IPI UK Crops Project data (Kleijn et al. 2015)); E**xtent of occupancy in England, Scotland and Wales** (% coverage based on BWARS/ HRS records from 1996-2010 applied at country level); **Long and short-term trends** (% change in occupancy at UK level based on occupancy-detection model output; species where the 95% credible intervals s (in brackets) span zero were defined as stable, status of the others was classified as either increasing or decreasing based on their trend). Species with (S) are listed on the Scottish Biodiversity List as priorities for conservation, no other species currently of conservation concern in England, Wales or Scotland.

1.3: Statistical power analyses using existing datasets to inform sampling design

Appropriate design and statistical power are essential to any biodiversity monitoring scheme if the resulting data are to be widely accepted as credible indicators of change. Here, we conducted statistical power analyses using available datasets from systematic surveys measuring pollinators and pollination services to UK crops (identified in 1.1), simulating a range of potential scenarios of change over a 10 year period.

Aims: To estimate the minimum levels of replication (primarily at the site or field level) required to detect changes in:

i) abundance and species richness of the different key pollinator groups (bumblebees, honey bees, solitary bees and hoverflies) sampled using either pan traps or transect methods, and

ii) measures of pollination service provision (deficits and visitation rates) for oilseed rape, field beans and apples.

Input data (likely initial count values and parameters representing variation in counts and in rates of change over time between sites) for the power simulations were derived from systematic survey data from the IPI AgriLand and IPI Crops projects (see Glossary). Various scenarios were explored that differed in initial pollinator abundance or levels of service provision, degree of % change over 10 years and number of sites monitored (full details given in Annex B).

Results suggest that between 20 and 75 sites across GB could provide sufficient power (>80%) to detect a 30-50% change over 10 years (equating to 3.5 – 7% annual change) for *widespread, common species or pollinator groups* (eg. summed abundance of bumblebees) with initial annual counts of *10 or more individuals* per site. Standardised surveys using pan traps and/or transect methods applied at least three times during the pollinators' flight period could be used to generate such counts. Higher numbers of sites would be required (ca. 150) for species or groups occurring in small numbers (initial counts of 1 per site) or if lower rates of decline are to be detected (ca. 1000 sites to detect ≤10% change over 10 years, equating to a 1% annual decline). Note however that it is difficult to estimate the likely *variability in pollinator numbers* over a 10-year period with existing datasets which typically span up to 3 years, show large variation between sites and seasons and contain many zero values. In a recent analysis of the number of farms required across different European countries to detect changes in species richness of plants, earthworms, spiders and bees, bees demonstrated the highest data variability and therefore required the largest farm sample size of all groups[28]. Our estimates of likely power should therefore be considered as coarse rather than precise indications, contingent on building up data over the initial 5-10 years of any future scenario, and using summed abundances to group level where species-level counts are insufficient to show robust trends.

Data generated by crop pollinator surveys (e.g. transect counts of crop visitors) were similar to those of the broader pollinator surveys. The number of sites required to detect a change in *direct measures of pollination service* varies considerably between crops and whether a deficit or change in pollination service is being detected. In all cases, at least 100 and possibly up to 200 sites (*fields per crop*) are needed to detect 30% changes in pollination service or deficits over 10 years (except service in oilseed rape). In most cases, detecting a change in service levels requires fewer sites than detecting a change in deficits, due to the lower initial estimates of deficit in all crops except Gala apples. Note that we are not referring here to direct measures of deficit in crop yield but to deficits measured as *the difference in proportion of pods or fruit set between open and hand-pollinated flowers*.

Defining the level of change in population size or pollination service that should be detectable from a monitoring scheme

An important question is whether a detection level of 30% over 10 years (or 3-4% annual change) is sufficiently sensitive, for example, to allow for mitigation responses to be implemented within adequate time frames to reverse pollinator declines, or to meet the thresholds that growers would tolerate or need to respond to in different crops. Outcomes of the benefits survey of expert researchers (Section 5 and Annex C) offer valuable insight, suggesting that detection rates of 5% annual decline (equating to a 40% decline over 10 years) for each pollinator response measure, and 10% annual decline in crop output would meet expert recommendations for an effective monitoring network. The detection of a 30% decline in population size over 10 years also matches the criterion applied under the IUCN Red List (www.iucnredlist.org) to categorise a species within the lowest threat category of 'vulnerable', as recently used to produce the European Red List of Bees[9].

Since our understanding of the relationship between local crop pollinator abundance and service is quite limited and varies with crop type and context (Section 2.2), it is not yet possible to define levels of pollinator population change that would significantly compromise crop pollination services. We focussed instead on direct measures of change in crop pollination service. The percentage change in production directly related to animal pollination that growers may tolerate will of course vary between crops depending on factors such as per hectare value and level of dependency on insect pollination. Where the latter is low, such as in oilseed rape (typically 20-25%), detection of a 10% change in pod set may be adequate. Where per ha values and dependency on insect pollination are high, such as in apples (usually >50%[29]), a fruit grower may be interested in a very small % change, closer to between 1-3%. The sampling networks proposed in the costed scenarios (Section 4) have used the outputs of these power analyses as a guide to likely levels of replication required from systematic surveys. Ultimately, detection levels are likely to vary depending on the key question or response measure and the level of resourcing available to run a viable monitoring scheme.

1.4: Cost-efficiency analysis of existing National Recording Schemes and Societies and associated datasets

Aims: To assess the relative cost-efficiency of monitoring schemes and research projects in collecting and identifying records for use in scientific analysis and to identify the otherwise uncaptured value of voluntary labour.

i) Costs of existing recording schemes and systematic monitoring of bees and hoverflies

The costs of existing NSS (BWARS, HRS, the Wider Countryside Butterfly Survey and Garden Bird Watch) were derived from data supplied by participating organizations. This included the average number of voluntary hours that scheme coordinators had worked annually over the 5 year period 2008-2012. Data were not available to calculate the time taken by volunteer recorders to collect and submit records. The effective economic value of this voluntary labour was estimated using the replacement cost method, which equates the monetary value of a scheme with the costs of hiring professional consultants to undertake the work (at £40/hr).

Costs for generating records from research projects were estimated from the projects within the Insect Pollinator Initiative (IPI) and the Status and Trends of European Pollinators (STEP) conducted by the University of Reading and the University of Leeds. For the AgriLand project, costs are subdivided into Agriland (max), the core 96 sites, and Agriland (Lite) which covers the additional 24 sites surveyed by the University of Reading as part of the project. These are presented together as Agriland (All). These costs do not include the costs of data analysis or dissemination work.

Table 1.5. Cost efficiency per record from existing NSS and studies.

Scheme/study *	Base costs	Unpaid labour (hours)	Value of unpaid labour	Full costs	Records	Cost/ Record (base)	Cost/Record (full)
Bees Wasps and Ants Recording Society	£7,543	1700	£70,000	£77,543	25000 vs	£0.30	£3.10
Hoverfly Recording Scheme	£16,000	1832	£73,280	£89,280	26293 vs	£0.60	£3.40
Wider Countryside Butterfly Survey	£45,000	620	£31,000	£76,000	29300 vsb	£1.54	£2.60
Garden Bird Watch	£150,000	NA†	NA	£179,750	130000 bb	£1.15	£1.38
Big Bee Project	£106,118	NA	NA	£221,165	18022 vs	£5.89	£12.27
IPI Agriland (All)	£97,062	NA	NA	£446,587	29530 vs	£3.29	£15.12
IPI Agriland (Lite)	£30,215	NA	NA	£76,055	9347 vs	£3.23	£8.14
IPI Agriland (Max)	£66,848	NA	NA	£370,531	20183 vs	£3.31	£18.36
IPI Crops	£55,905	NA	NA	£112,741	13007 vs	£4.30	£8.67
Status and Trends of European Pollinators	£28,058	NA	NA	£82,486	32214 vs	£0.87	£2.56

***NSS and ongoing surveys in white; previous studies or projects in blue. **Base costs** = paid administrative costs, field staff, mandatory training costs for recorders and materials costs. **Unpaid labour (hours)** = the number of hours of administration, identification and data management undertaken by experts in the scheme (NOT including hours spent by volunteer recorders on WCBS and GBW; †primary support costs associated with bird recording). **Value of unpaid labour** = sum value of all voluntary hours at £40/hr **Full costs** = the total costs of the scheme, including the value of paid or unpaid labour, all field staff, fuel costs and identification work. **Records** = the number of records of bees and/or hoverflies at species, genus or family level collected annually; '**vs**' = records that are **verified to species level; vsb** = butterfly records; '**bb**' = unverified records of bees (ca. 40,000) and butterflies (ca. 90,000). Costs and records are based on an annual average from the lifespan of the project or, in the case of BWARS and HRS – the years 2008-2012.

The findings indicate that the full costs of generating records are generally lower for NSS than for research studies due to the substantial costs of travel and staff involved in field data collection. This is particularly pronounced in the IPI Agriland project due to the project's comprehensive random sampling network design that included a number of very remote sites that required vehicle hire to access. The differences in costs are similarly pronounced when only the base costs are considered due primarily to the higher administrative costs at professional research organizations.

The results also illustrate the substantial value added by NSS, with scheme coordinators committing the equivalent of 447 working days of labour to the NSS, worth ~£143,000/year in equivalent salaried staff time between BWARS and HRS alone. The NSS make substantial contributions to research and policy [22] . Not only are the contributions from NSS either low or no cost but the taxonomic resolution and quality of the records are high. Verified records of species have considerably more value for assessing trends in *pollinators* and associated *pollination services* than unverified records or records for which the taxonomic resolution is low (broad or functional groups). The NSS are the major contributors of the expertise necessary for verification to species level across the breadth of insects considered as important pollinators. It is critical that the capacity and expertise represented by the NSS is maintained and ideally enhanced.

Key findings (Section/Objective 1)

- A review of existing National Recording Schemes and Societies (NSS), projects and datasets highlighted the value of verified occurrence records compiled by experts within the NSS, specifically the Bees, Wasps and Ants Recording Society (BWARS) and Hoverfly Recording Scheme (HRS), for generating estimates of species-level status and long-term trends in distribution. There is a clear shortage of long-term systematic datasets of >2 years including measures of abundance for both pollinators and measures of pollination service, with existing datasets showing a bias in coverage towards England.
- New modelling approaches allowed robust estimates of trends in occupancy of 1km squares across GB to be made for around 50% of bee and hoverfly species over a 30 year time period (1980-2010). Of these, 28-51% became less widespread, whereas only 14-27% became more widespread, with the remaining species classified as stable (depending on the criteria used to classify change). During a similar time period, the demand for pollination services to crops and the area of insect pollinated crops have risen by more than 20%. The precision of these trend estimates and our ability to quantify the demand for wild pollinators required for crop pollination would be improved, for some species at least, by combining the NSS occurrence data with stratified systematic surveys.
- To understand the degree to which these trends in occupancy and distribution are accompanied by changes in abundance, and hence their likely impacts on pollination services, additional systematically collected data coupled with a better understanding of important crop pollinators across different regions are required.
- Statistical power analyses suggest that between 20 and 75 sites across GB could provide sufficient power (>80%) to detect a 30-50% change over 10 years (equating to 3.5 – 7% annual change) for *widespread, common species or pollinator groups* (eg. summed abundance of bumblebees) with initial annual counts from systematic surveys of *10 or more individuals* per site. More sites would be required (ca. 145) for species or groups occurring in small numbers (initial counts of 1 per site) or to detect smaller changes. Between 100-200 fields per crop would be required to detect changes of 30% in direct measures of pollination service or deficit over 10 years, with ideal detection levels likely to vary between crops with per hectare value and level of dependency on insect pollination.
- It is difficult to estimate likely *variability in pollinator numbers* over a 10-year period with existing short-term datasets which show variation between sites and seasons and contain many zero values. Our estimates of likely power should therefore be considered as coarse rather than precise indications, contingent on building up data over the initial 5-10 years of any future scenario, and using summed abundances to group level where species-level counts are insufficient to show robust trends.
- Assessment of the costs of collecting pollinator records through research projects indicates that they vary greatly in their costs/record, depending largely on the number of sites sampled and the distribution of these throughout the UK. The highest cost/record research project (IPI Agriland), was also the most rigorous as it included many sites that are not

typically visited by volunteers. Costs/record are much lower for voluntary NSS, but increase when identification is conducted to species level.

- The UK's main voluntary recording societies (NSS) represent substantial added value. Assessment of the time spent on co-ordination and administration of BWARS and HRS revealed that equivalent professional staff would cost ~£143,000/year. This figure is an underestimate of the total 'in-kind' value of effort into these schemes as data is not available to accurately estimate the time spent by volunteers in gathering and submitting the ca 51,000 records that the NSS receive each year.

2: Developing robust and realistic survey methods for monitoring pollinators and pollination services (Objective 2).

The last section dealt with how more could be gleaned from existing datasets and emerging analytical tools. The following sections deal with how these could be supplemented using standardised survey methods to provide additional information on changing pollinator populations, starting with consideration of the suitability of different methods for different recorder groups and then improving their effectiveness in the field.

Aims: to develop and test survey methods, focussing on their suitability for use by different types of recorder (professional to volunteer) via a combination of:

i) Assessment of the capacity of different 'recorder groups' and sampling methods to provide data on different measures of interest, through a scoring exercise conducted by the project team and at stakeholder workshops;

ii) Small-scale field trials to refine methods and protocols for monitoring pollinators and pollination services and inform the design of larger-scale pilot studies for 2015.

2.1 a) Pollinators

i) Assessing the capacity of recorder groups and methods for monitoring pollinators

A range of potential methods for surveying pollinators were assessed for their capacity to provide measures relevant to informing longer-term monitoring (e.g. abundance of key pollinator groups or species, species richness), when implemented by different types of recorder (professional experts or non-experts and volunteer experts or non-experts; see Glossary for descriptions of methods and terms). An assessment 'matrix' was used to systematically assign scores to each Recorder – Method – Measure combination, based on whether it could be achieved and what degree of training might be required. This exercise was conducted first by the project team using expert opinion and published research and considering up to 15 different methods (full scores and means across each method provided in Electronic Appendix 2). The same assessment matrix was then used at a stakeholder workshop (December 2014), during which a range of methods were discussed but with the scoring exercise focussing on *pan traps, transect walks* (either observational or using hand netting to collect specimens) and *timed floral observations* as the likely 'front runner' methods for pilot testing. Participants at the workshop represented the volunteer recording community, NSS, NGOs, Agencies and academics (see Annex G for stakeholder workshop scores and a full report of attendees and issues explored; these have also been referred to under the Scenarios in section 4).

The methods assessment can be summarised as follows:

- Current monitoring based on ad-hoc records submitted to NSS scored poorly for all potential measures of community composition relating to *abundance*. It was thought possible that additional metadata could be collected, for example whether a complete list of species was included for each visit, but it is very uncertain whether this is achievable.

- Professional and volunteer experts were generally considered capable of collecting and processing specimens or records using most methods, but could not consistently provide data to species level when the method was entirely based on field observations (ie. specimens would need to be collected on transects for identification).
- There was little confidence in the ability of non-experts (professional or volunteer) to provide data from any method at the resolution of species, and in some cases even at the resolution of broad groups (separating solitary bees from honeybees, bumblebees or flies), with the possible exception of bumblebees on transects. At best a large amount of training and investment would be required for identification to species level in the field or from collected specimens.
- Collecting data on the abundance of ‘less common’ and ‘rare’ species is unlikely to be achieved without the use of targeted surveys.
- There was general consensus between the mean scores from the ‘expert’ and stakeholder workshop assessments, with both reflecting low confidence in the ability of non-experts to provide data at the resolution of species. However, for the observational methods (transects and timed floral observations), workshop participants scored the capacity of non-experts lower than the expert assessment, suggesting less confidence in the chance of adequately training non-experts in species identification.

ii) Small-scale field trials to refine methods and protocols

A key challenge to monitoring pollinating insects is ensuring that sampling methods provide adequate amounts of data whilst minimising bias and remaining feasible. Pan traps, transects and timed focal floral observations were all used in the 2015 pilot, but in 2014 and 2015 additional small trials were conducted for each method to identify the optimal protocol for each (see Annex D for study design, analysis, full results of trials):

Figure 2.1. Standardised methods for monitoring pollinators. Pan traps (left ©C. Carvell); **transect walk** (centre © H. Lowther) and **focal floral observations** (right ©M. Harvey).

Pan traps are a passive sampling approach using water-filled bowls, typically of three colours set on stakes at vegetation height to mimic flowers and collected after a specified duration. Trials showed that the duration traps were left out in the field only slightly influenced total catch, with higher total abundance and species richness of bees and hoverflies over 48 hours, but no difference between 6-7 hour and 24-hour trapping periods[5]. Bowl size affected the total catch across all insect groups, but had variable effects on bees and hoverflies, leading to our choice of three 12oz (341 ml) bowls (as shown in Fig. 2.1) for the pilot study (Obj. 4). Results also showed that the number of bees caught

[5] Results refer throughout to tests for statistical significance at the 95% level ($p<0.05$): full results given in Annex D.

was positively influenced by the number of flowers surrounding a trap and so data on floral resources should also be collected.

Transect walks describe linear transects of defined width and length (up to 1km) over which insects seen visiting flowers (or in flight) are recorded during good weather; they can include netting for identification to species level. Trials showed that whilst increasing the width of transects from 1m to 2m can increase the number of insects recorded, this leads to a larger increase in the number of bumblebees recorded than for hoverflies. This is probably because larger, more conspicuous insects remain visible at larger distances while smaller insects are harder to see. As such, when collecting data for such diverse groups as all bees and hoverflies, a 1m transect width is recommended to avoid creating a bias for recording larger species. Trials also confirmed that the abundance of pollinators on transects can be strongly influenced by the number of flowers, especially for bumblebees, hence data on the availability of floral resources should also be collected.

Focal floral observations (FFOs) involve a standardised floral resource being observed over a set period of time to record all insects visiting flowers. Visits to flowers from a list of 25-30 'top' plants for pollinators within a 0.5 x 0.5m quadrat (Fig. 2.1) were observed for 10 minutes during our 2015 pilot. Trials revealed that increasing observation time to 20 minutes and the area observed to $1m^2$ increases the number of insects recorded, but risks increasing the number of smaller insects recorded (such as hoverflies) more than the number of larger insects (such as bumblebees). This is problematic given that it was much harder to keep track of hoverflies when observing $1\ m^2$, reducing the reliability of counts. Observing a $0.25m^2$ area for 10 minutes is a good compromise for maintaining data quality, whilst collecting sufficient observations for monitoring purposes, although greater replication or longer observation times may be required during times of the year when general flowering and flying activity are low.

In order to further develop specific methods and protocols and to underpin the pilot field test in 2015, two additional sub-projects were run in 2014:

1. How well do pan traps and transects represent the abundance of different pollinator species? A trial on the Isles of Scilly

A study was carried out during the summer of 2014 on two islands of the Isles of Scilly, with the aim of assessing how well pan traps and transects represented the actual abundance of different pollinator species. Standardised pan trapping and transect methods were conducted alongside an in-depth Mark-Release-Recapture (MRR) study of individual bees and hoverflies which attempted to estimate population sizes for individual species. The results showed pan traps and "free" transects (used in MRR surveys) captured more species than standardised transects, and pan traps caught many more small solitary bees than did either of the transect methods (as undertaken by research staff). MRR population estimates could only be made for 2-3 species that had recaptures on each island. Overall, these estimates fell between pan traps and standardised transects on Little Ganilly, whereas on Great Ganinick the MRR estimate differed from both standardised methods. In general, low confidence in population size estimates from the MRR mean that no solid conclusions can as yet be drawn as to whether pan trap or transect methods provided a better estimate of abundance.

2. Comparing bumblebee transect walks between expert and non-expert volunteers

The aim of this trial was to compare data collected by 'self-selected' volunteer recorders with that collected by an expert with many years' experience of bumblebee recording, for bumblebee monitoring, using the BeeWalk protocol. Expert and non-experts (with a range of levels of training through the Bumblebee Conservation Trust) followed identical protocols across a total of nine transect walks on eight sites in July and August 2014. Analyses showed there to be close similarity in species community composition between the expert's sightings and those of the volunteers, considered with each section of transect as a separate site. The expert's impressions of volunteer ability were generally good: volunteers were able to accurately follow the recording protocol, and when dealing with unusual bumblebees they correctly recorded individuals they were uncertain of as '*Bombus* sp.' rather than recording with spurious accuracy.

2.1b) Pollination Services

i) Assessing the capacity of recorder groups and methods for monitoring pollination services

Potential methods for monitoring pollination services were assessed by the project team (full scores and means provided in Electronic Appendix 2) and with representatives of the stakeholder community on their capacity to provide different measures of interest (e.g. abundance of key pollinator groups, direct measures of service provision), using the same assessment 'matrix' and scoring system as for pollinators in 2.1a. At the stakeholder workshop on monitoring crop pollination services (held in December 2015) participants represented farmers, agronomists, pollination service suppliers, NGOs and academics. Three key questions were explored in breakout groups (see Annex G for full workshop report):

(1) What should a National monitoring scheme deliver? This identified which crops, geographic areas, response variables and detection thresholds were most relevant.

(2) What methods should be used? This included the assessment matrix to consider the feasibility, pros and cons of different recorder groups (growers, agronomists, pollination service suppliers, researchers and novice volunteers) using different methods (pantraps, transects, observation plots, and service/deficit measures).

(3) How to build a user community? This explored who could potentially be involved in a recorder community, what incentives and barriers there are for these groups and what support and training would be needed

This assessment suggested that all recorder groups have the capacity to implement all pollinator survey methods on crops, but the level of training required is considerable for non-experts, and again non-experts would not be able to provide species level data for those methods that require it. Pan trapping scored highest because it would require less training than other methods. *With training*, some pollination service measures taken directly from the crop (e.g. using bagging experiments) could be implemented by all recorder groups. However access to field level crop production data could be achieved only with the involvement of farmers or agronomists, and pollen deposition experiments would not be possible for non-experts.

ii) Small-scale field trials to refine methods and protocols

In 2014, three field trials were implemented with three distinct aims; 1) to test if pollination service monitoring techniques can be implemented by novice volunteers following a basic protocol, 2) understand if standard measures of pollination service and deficit in oilseed can be used to detect pollinator contributions to crop yield or a yield deficit and 3) to refine methods for measuring pollination service and deficits in strawberries (See Annex D for experimental details and results). In summary, these trials showed that:

- it is possible to develop a protocol for measuring crop pollinators and crop pollination services which can be implemented by novice volunteers although some variability in the data collected was apparent.
- standard bagging and hand pollination measures of pollination service and deficits in oilseed do reflect crop yield responses to pollination, provided the correct pollination metrics are used.
- it is possible to effectively measure levels of pollination service in strawberries using flower bags but hand pollination to simulate maximal pollination is not effective. If pollination deficits in strawberries are to be monitored long term then an effective method needs to be developed.

Figure 2.1. Standardised methods for measuring pollination service to crops. Transect walk to count crop flower visitors (left); and direct measures of pollination using **bagging** (apple blossom covered with mesh bag to exclude insects and assess pollination deficit - centre) and **hand pollination** ('maximum' pollen transfer mediated using a paintbrush to assess pollination service - right). All photos ©M. Garratt.

In 2015, wider scale pilot studies were carried out to build on previous work and these had two primary objectives:

i) Establish a link between the *level of activity of pollinators* visiting crops and *measures of crop pollination service*.

ii) Further understand the relationship between measured levels of *crop pollination* by insects and *actual crop yield* responses.

To address these objectives, field trials were set up in oilseed, beans and apple crops. Large field cages were used to manipulate levels of pollinator activity during flowering so that crops received normal insect pollination, reduced pollination or no insect pollination. Measures of crop pollination (eg. seeds per pod) and standard measures of pollination service and deficit were taken to assess the impact of these pollinator community manipulations on pollination and resulting yield (See Annex D for full study design, analysis, results and discussion).

Crop pollinator manipulations using field cages affected crop production with greater crop yield following normal insect pollination compared to reduced pollination or no insect pollination for oilseed and apples although this was only statistically significant for apples[6]. Other measures of crop pollination including oilseed seeds per pod, seeds per apple, apple size and fruit number per tree also responded significantly to pollination treatments with more seeds and more fruit under insect

[6] Results refer throughout to tests for statistical significance at the 95% level ($p<0.05$): full results given in Annex D.

pollination treatments (Fig. 2.2). Bean yield, oilseed percentage pod set, bean pods per plant and beans per plant did not respond significantly (Annex D). These results show that a number of crop pollination metrics, and particularly seed set in oilseed and apples, respond to levels of insect pollination and could therefore be used to monitor levels of crop pollination by insects across time and space. The exact nature of the relationship between pollinator activity and crop pollination responses needs to be well established for different crops so predictions about levels of insect pollination can be made in line with Objective i.

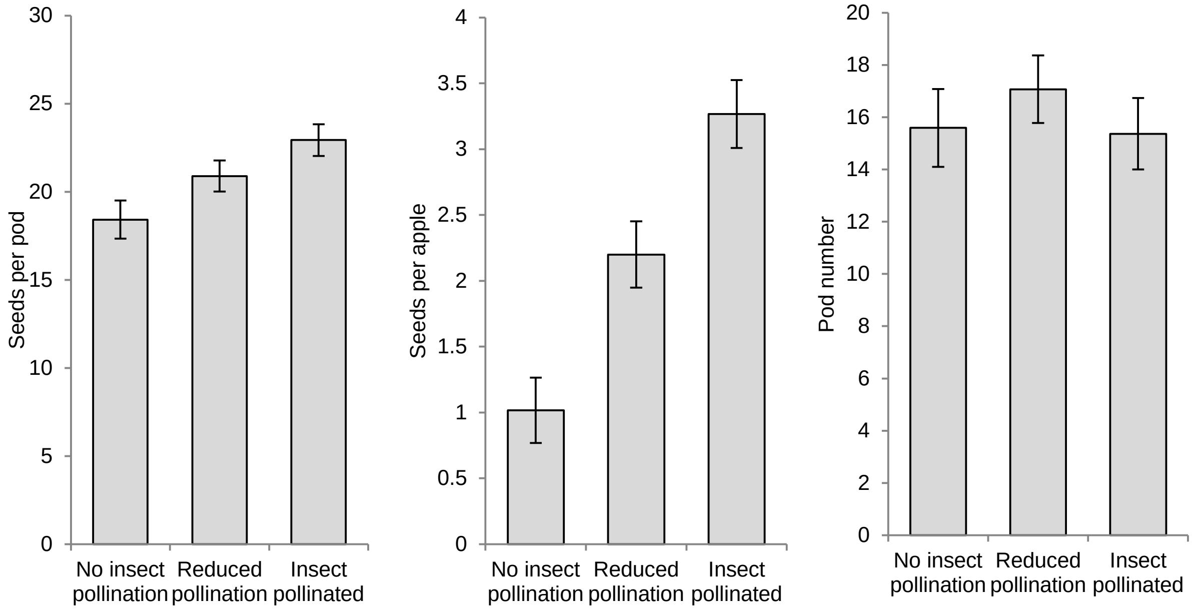


Figure 2.2. Pollination of oilseed (left), apples (centre) and field beans (right) following field cage manipulations to reduce or exclude insect pollinators.

Levels of pollination service and deficits detected using hand pollination and bagging experiments followed the expected pattern with greater levels of pollination service apparent in insect pollinated plots than pollinator excluded plots for both oilseed rape and beans, although this was not significant for oilseed. Similarly, pollination deficits were detected in pollinator excluded plots and deficits were not apparent in insect pollinated plots (Annex D). No clear pattern was seen for apples and this is possibly due to the use of fruit set as a metric rather than apple quality or seed set. These findings demonstrate that these bagging and hand pollination techniques for measuring pollination service and deficits can be effective and appear to reflect levels of pollination by insects but correct metrics need to be used and replication needs to be adequate to ensure statistical power and to quantitatively link measures of crop pollination with crop pollinator activity in any given locality (Objective i).

In order to address Objective ii, this experimental design enables us to link metrics of crop pollination, pollination service and pollination deficits with *final crop output*. Analysis of simple proxies of crop pollination, some of which have been shown to respond to levels insect pollination (Fig 2.2), such as seeds per pod in oilseed, seeds per apple or pods set per floral node in beans, were investigated to see if these could be used to accurately predict final crop output. Both oilseed seeds per pod and seeds per apple were strongly positively correlated with final crop yield, but this was not the case for pods set in beans (Fig. 2.3). With regards to linking hand pollination and bagging measures of pollination service and deficit with crop yield, for oilseed this seems to hold with greater service apparent in insect pollinated plots which in turn had greater yield, and deficits in pollinator excluded plots which had lower yield although due to low replication these were not statistically significant. However, in the case of beans, a large pollination deficit was detected by the hand pollination experiment but resulting bean yield was similar under all field pollination treatments suggesting no yield deficit and plants were able to compensate for reduced pollination.

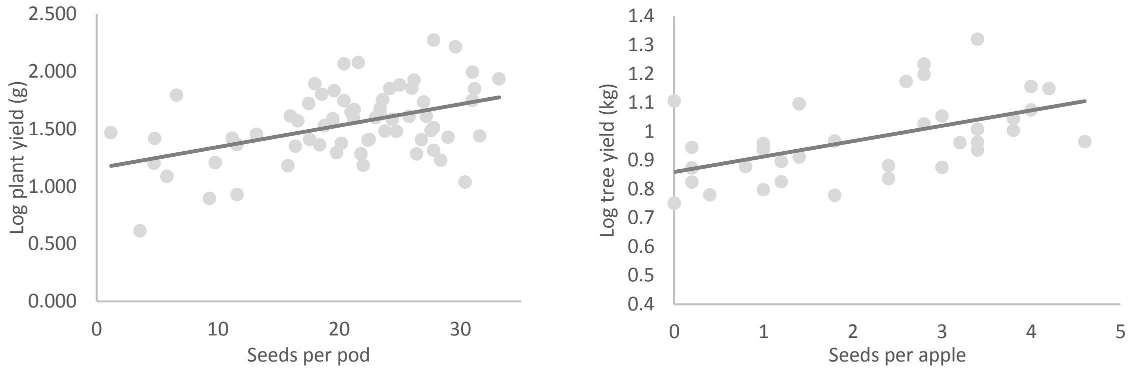


Figure 2.3. Relationship between metrics of crop pollination and final crop production in oilseed (left) and apples (right).

In summary, some metrics of crop pollination including *seeds per pod* or seeds per apple were highly sensitive to field cage treatments with *significant reductions in seed set following the exclusion of pollinators*. Therefore, these simple measures of crop pollination could be used to assess levels of insect pollination in the field in line with Objective i and could be used to monitor changes in the activity of crop pollinators in space and time. That these measures were also highly correlated with final crop yield presents the possibility that they could also be used to anticipate final yield and how this may be affected by changing levels of insect pollination in any given locality, as outlined by Objective ii. Hand pollination and bagging methods are more labour intensive, but these methods have the advantage of controlling for agronomic and regional variability. However, the level of replication and metrics used need to be appropriate and in some cases such as for beans in this study, they may not reflect final crop yield deficits. Again links between pollinator activity measures and service and deficits detected (Objective i) and final crop production metrics (Objective ii) need to be well established for the crop to be monitored.

2.2) Further understanding the links between pollinators and pollination services

Current evidence from a wide range of studies suggests that both the diversity and abundance of pollinator communities (those insects seen visiting flowers) are positively related to the delivery of pollination services to both pollinator-dependent crops[11] and wild flowers[30]. However, the form of the relationship between these pollinator community attributes and the level of service is highly dependent on crop type[31] or environmental context. For instance, the agronomic context, such as nutrient availability, drought stress and pest pressure will affect crop demand or dependence on insect pollination[32-34]. Furthermore, the visitation to crops by local pollinator communities is also influenced by the environmental context beyond the field or farm scale. For example, visitation rates are governed by geographic location, time (year, season, time of day), local plant and pollinator community structure and landscape composition. For the UK, datasets (e.g. from the IPI Sustainable Crops project[35]) and work carried out as part of this project are available to characterise the relationship between the pollination of some crops and wildflowers and their flower visiting community in particular locations[36]. However, the *ability to generalise the relationship between pollinators and pollination services is limited.*

Emerging findings from the NPPMF project indicate that some measures of crop pollination, such as seed set, respond to levels of insect pollination and are linked to final crop yield, but these relationships need to be quantified for different crops and varieties if these metrics are to be used as part of a crop pollination service monitoring scheme. *Direct measures* of pollination services (e.g.

using pollinator exclusion and hand pollination methods) are currently the *best way to quantitatively assess pollination service* delivery (i.e. the contribution of insect pollinators to crop pollination) and pollination service deficits (i.e. the gap between ambient and maximum potential pollination). Visitation rates to crops of known pollinating species or taxa (see key crop visitors, Table 1.4), could be used as a crude proxy of pollination, and may be useful for comparing relative levels of service provision. However, they are *not sufficiently robust* to quantify the level of pollination service contributing to crop production itself given confounding effects of other variables affecting crop productivity. The NPPMF project cannot inform on the utility of monitoring wild flower pollinators as a proxy for wild flower pollination as this aspect was outside the tender remit; however, the same limitations are likely to apply as for crop pollination.

Further synthesis and meta-analysis of UK (and selected European) datasets are needed to: (i) further characterise the relationship between pollinator visitation and crop pollination services; (ii) assist in the identification of suitable proxies of service provision or identify where no suitable proxy is currently available; (iii) understand how geographical location, particularly across the UK, affects the pollinator communities servicing crops and (iv) highlight key gaps in our knowledge where new empirical data is needed to characterise the linkages between pollinators and services and develop proxies (e.g. for particular crops and varieties).

Key findings (Section 2)

- Small-scale field trials were conducted to test for effects of pan trap size and duration on insects caught. The largest bowl size (12oz) caught the largest number of insects, but a 6-7 hour trapping duration performed as well as 24 hours with regard to number of insects caught (typically on average 3-4 bees and hoverflies per set of three traps left out for one day) and should provide data of sufficient quality for quantitative analysis (Sections 2.1a and 3.1a). Increased floral resources surrounding a trap also increased the number of bees caught and so floral resources should be recorded.
- With fixed transect walks, increasing the width of transects from 1m to 2m could lead to a bias towards recording larger, more conspicuous insects, since they remain visible at greater distances than smaller insects. As such retaining a 1m transect width is recommended if all flower-visiting insects are to be recorded, rather than the 4-5m used by other single-taxon monitoring schemes (eg. UKBMS, BeeWalks). An increase in the number of flowers on a transect can increase the number of insects recorded, so floral resources should be recorded.
- With timed focal flower observations, observing a 0.25m^2 area for 10 minutes is a good compromise for maintaining data quality, whilst collecting sufficient observations for monitoring purposes, although greater replication or longer observation times may be required during times of the year when general flowering and flying activity are low. The type of flower chosen will influence the types of insect recorded. Selecting from a defined list of common plant species would therefore help standardise observations across regions and habitats, though further development is required to understand trade-offs between the area, duration and number of observations required, data quality and the volunteer ‘experience’.
- For *pollination services to crops*, transect walks in flowering crop fields can be used to monitor changes in crop pollinator activity, generating counts of flower visitors by broad groups or to species level for a few easily recognised species. However, *direct* measures of crop pollination using hand pollination and bagging experiments remain the most reliable way to detect changes in pollination service or identify possible deficits that are independent of agronomic or regional variation.

- A better understanding of the relationship between pollinator activity, measures of pollination service levels and crop yield for different crops is required before estimates of changing crop production, due to insect pollination, can be made based on detecting changes in pollinator activity or crop pollination alone. Based on findings from this project, the use of simple measures such as seed set show potential as simple measures for some crops but require further testing.

3: Pilot study of proposed best methods (Objective 4)

The methods selected by the project team, in consultation with stakeholders at the workshop described above, as the most promising for standardised monitoring of pollinators and pollination services to crops were refined to ensure suitability for a range of end-users. We then conducted a pilot study during 2015 across a range of agricultural and semi-natural sites in England, Scotland and north Wales. **Aims:**

i) Compare methods for sampling pollinators, in terms of their complementarity and ability to generate sample sizes suitable for detecting trends over time (Section 3.1a, Annex E and F);
ii) Compare the capacity of different 'recorder' groups to implement different survey methods and protocols (Table 3.1) and how this influenced the data generated (sections 3.1a and 3.1b, Annex E and F);
iii) Gather feedback from recorders on the survey methods and protocols used, including how straightforward and enjoyable they were to implement and whether people would be willing to apply them as part of a wider pollinator or pollination service monitoring framework (questionnaire results; sections 3.1a and b).
iv) Generate detailed information on implementation costs and support requirements for each method or combined protocol (section 4, Annex C).

Table 3.1. Methods tested by different recorder groups across 1km squares and crop fields.

Method (report section)	Replication within 1km square or field	Research staff	Professional Experts (consultants)	Volunteer Non-experts (novice)	Farmers/ agronomists
Pan trapping 1km square (3.1a)	5 sets of 3 pans	Y (sp)*	N	Y (with research staff)	NA
Fixed transects pollinator survey (3.1a)	5 transects of 200m each	Y (sp)	Y (sp)	Y (grp)	NA
Fixed transects flower survey† (3.1a)	5 transects of 200m each	Y	Y	Y	NA
Timed focal flower observations (FFOs)†† (3.1a)	2 (50x50cm quadrats)	Y (grp)	Y (grp)	Y (grp)	NA
Timed 'free search' pollinator survey in good habitats (3.1a)	2 fixed areas of 1000m^2 for 30-mins	N	Y (sp)	N	NA
Pan trapping crop fields (3.1b)	3 sets of 3 pans	Y	N	Y	Y
Transect walk through crop (3.1b)	3 transects of 50m down tramlines	Y	N	Y	Y
Hand pollination and bagging (3.1b)	Max 3 sampling points on transect	Y	N	Y	Y

(sp) = data collected at the species level for bumblebees, honeybees, solitary bees and hoverflies; (grp) = all insects classified into broad taxonomic groups (e.g. the above four groups and other flies, wasps, beetles, butterflies, moths). * all specimens sampled in pan traps under 3.1a have been sent to the Natural History Museum to aid the development of DNA barcoding approaches for species-level identification. † 3 quadrat samples (spaced at 100m intervals) in which all open animal-pollinated flowers were recorded to species, and an overall (scaled) estimate of flower abundance across the whole transect. †† Plant species were selected from a list of 25 common species providing nectar and/or pollen resources, including examples flowering during each month of the survey (Annex Fi).

3.1a) Pollinators in agricultural landscapes and the wider environment

This pilot was run across a total of 14 sites in four regions: N. England (two sites around Leeds), S. England (two sites around Wallingford and two west of Salisbury), N. Wales (one being the Environmental Change Network site at Snowdon and one on a coastal farm), and Scotland (six sites south of Edinburgh in the Lothians and Scottish Borders). In each region both agricultural and semi-natural sites were surveyed, mostly selected from the network of 1x1km squares that form the new National Plant Monitoring Scheme (NPMS, led by CEH, BSBI and Plantlife). Each site was surveyed four times between early May and September 2015. A set of sampling methods was implemented according to a 'one day by one person' protocol for each "sampling round" (Fig. 3.1), with different recorder groups working at varying levels of taxonomic resolution as summarised in Table 3.1.

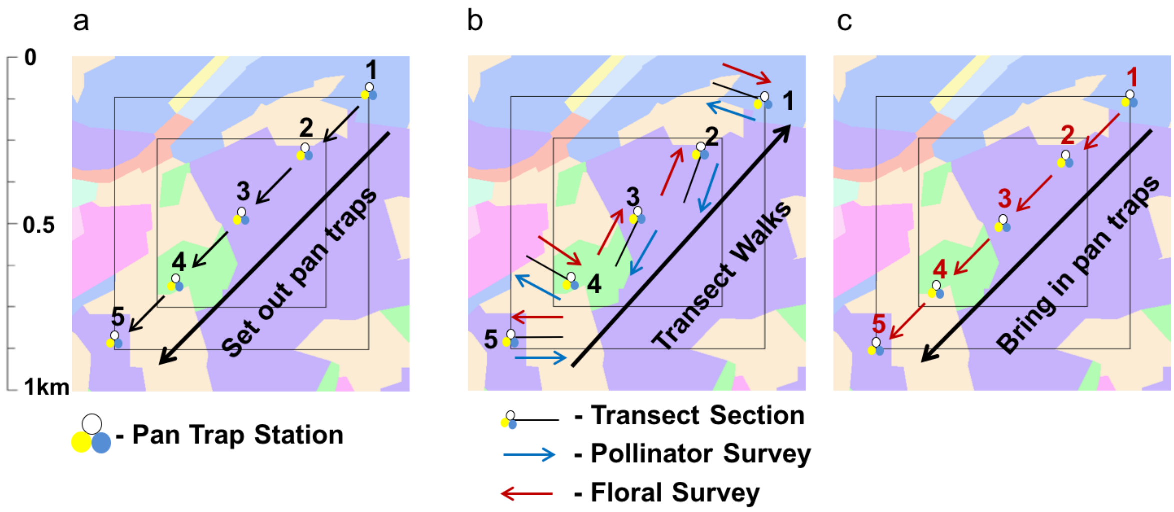


Figure 3.1. Schematic of the layout of pan traps and transects for a 'one day protocol' at a 1km^2 sampling site. a) Researchers and volunteers set out pan traps on arrival. For the consultants protocol this step is not carried out, but 1hr of 'free search' is conducted during the day. b) Pollinator and floral survey transects of 200m are walked in reverse order. Timed focal flower observations are conducted in between other tasks, at two 50x50cm patches of flowering plants chosen from a list and located anywhere within the 1km square. c) The day ends by bringing in pan traps in the same order in which they were set out, after approximately 6 hours.

Sample Size Achieved

The power analysis under Objective 1 indicated that a minimum annual sample size of 10 individuals of a given species or 'group' per site would be needed to detect changes of 30-50% over 10 years, or of 1 individual given a larger sample site network. Figure 3.2 summarises the dataset collected by the Research staff across the four sampling rounds. Our combined pilot protocol (including pan traps, transects and FFOs) provides large enough samples to assess trends in combined abundance of bees and hoverflies or at the broad taxonomic group level. Indeed, even taking pan traps or transects alone would provide sufficient samples at this resolution (except for solitary bees from transects). However, only a few individual species were sampled in sufficient numbers (21% of the

108 species identified from pan trapping and transect walks with a mean count of >1 per site, see Annex Table E3) to allow species-level monitoring at a local scale.

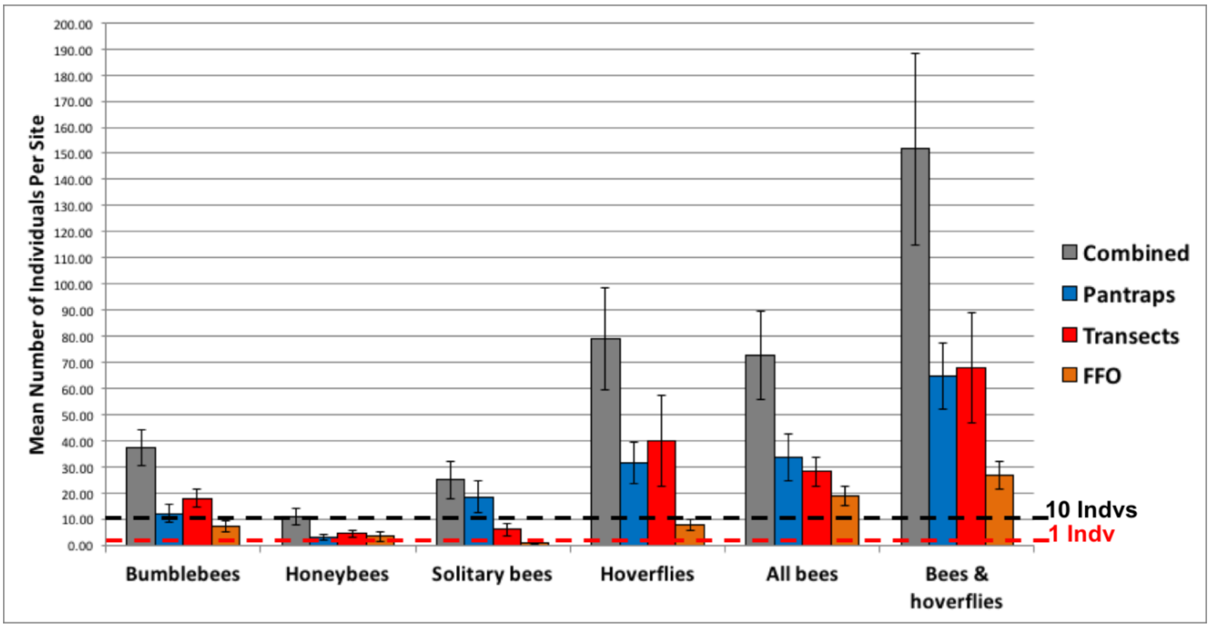


Figure 3.2. The mean number of individuals sampled per site (total annual count for 2015) by research staff using different sampling methods and all sampling methods combined for different taxonomic groupings, with threshold lines for 10 individuals (black) and 1 individual (red). FFO = Focal Floral Observations. Error bars show 1 standard error above and below the mean.

Method comparisons and complementarity

Comparisons of estimates of abundance and species richness provided by different sampling methods allow us to assess how similar a picture of the pollinator community is produced for a given site, and hence the degree of potential complementarity of survey methods (methods acting more effectively when in combination than when conducted in isolation). The objective of the sampling will also dictate, to some extent, the sample size needed to detect change. For example, sample sizes would need to be greater to detect changes in abundance or occurrence at the species level compared to those needed to detect change in broad taxonomic groupings (e.g. bees, hoverflies) (Section 1.3). In general, larger sample sizes are required for monitoring at finer taxonomic resolutions.

Across methods: A total of 2123 bees and hoverflies were recorded from the researcher dataset across pan traps, transects and focal floral observations. Pan traps and transects sampled 108 species in total, with 1634 of the 1858 insects recorded through these methods identified to species level. At the resolution of all bees and hoverflies and within broad taxonomic groups, estimates of abundance for focal floral observations (FFOs), transects and pan traps were significantly positively correlated (Fig. 3.3, shows the correlations between methods for summed counts of all bees and hoverflies)[7]. This link between the FFOs and transects is promising given that they were not spatially coincident at each site, suggesting that visitation rates to local flowering plant patches may be broadly representative of pollinator activity across a larger area (e.g. 1km square). However, the degree of correlation between methods was weak, and was reduced further at lower sample sizes (i.e. when including fewer than 5 pan trap or transect replicates). This suggests that larger sample sizes (i.e. more replicates) would be required if only a single method were to be adopted as part of a

[7] Results refer throughout to tests for statistical significance at the 95% level (p<0.05): full results given in Annex D

scheme, in order to ensure representative measures of overall abundance, but that deploying multiple methods is most likely to ensure more effective sampling of the pollinator community. Also notable across methods are the contrasts in trends in abundance over time (sampling rounds) for different taxonomic groups (Fig. 3.4, top row), emphasising the importance of multiple sampling rounds and utility of multiple sampling techniques to capture variability over time when monitoring such a diverse taxonomic group as pollinating insects.

Transects and pan traps: At comparable levels of sampling effort (over similar temporal and spatial scales), pan traps sampled more species than transects, particularly for solitary bees and hoverflies, and should therefore be a key component of a monitoring protocol. For bumblebees, considering the total catch derived for each site, estimates of abundance and species richness were similar (Fig. 3.4). However, for solitary bees much higher numbers of individuals and species were sampled via pan traps than transects, with pan traps proving effective in capturing some of the smaller, less conspicuous species such as within the genus *Lasioglossum* (Figs. 3.1 and 3.4). While estimates of abundance for hoverflies appear equitable between these methods, a higher number of species was sampled from pan traps (Figure 3.4). Outputs from both sampling methods varied over time, with pan traps performing particularly well early in the season and transects recording higher numbers in high summer, presumably because of more plants coming into flower and insects reaching peak levels of activity. Transects additionally provide an estimate of pollinator density (numbers per unit area), whereas the area sampled by a pan trap is hard to ascertain.

Focal floral observations: Relative to pan traps and transects, focal floral observations (FFOs) provided lower sample sizes in our trials (Fig. 3.2). However, this is intrinsically linked to the fact that there were fewer sampling units tested for FFOs (2 per sampling day versus 5 each for pan traps and transects) and increasing the number of observations would no doubt increase numbers recorded to levels comparable with the other two approaches. Similar to transects, FFOs performed poorly for solitary bees (Fig. 3.1). An additional issue is that the nature of the pollinator community detected through FFOs depends critically on the focal flower being observed, which in turn is constrained by the local species pool and phenology of flowering at the site. FFOs may prove the most promising of our methods for use in mass-participation citizen science approaches, and use of a defined list of common wild flowers could help to standardise across regions and habitats. If FFOs were to be employed in such a programme, it would make sense to incorporate them into a standardised site survey protocol (alongside pan traps and transects), as doing so would provide a means of calibrating citizen science data against standardised survey methods.

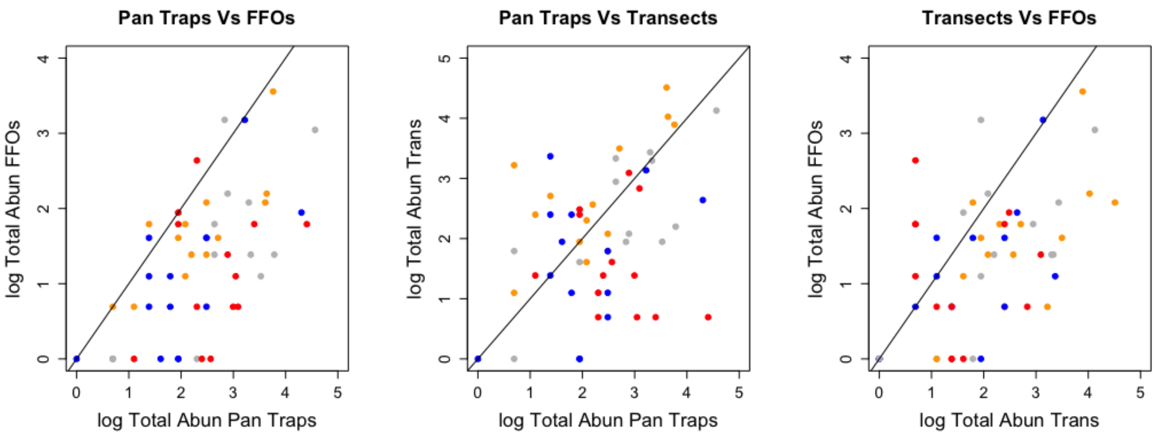


Figure 3.3. Correlations between estimates of abundance of all bees and hoverflies from pan traps, transects and focal floral observations for 54 site visits from the researchers' dataset. Numbers are the

sum of all individuals counted using a particular method on a sampling visit (e.g. all 5 transects/ pan traps or both FFOs). Points coloured according to sampling round; R1 = **red**, R2= **blue**, R3 = **orange**, R4 = **grey**. Data are log+1 transformed. The one to one line is shown on each plot to indicate whether there is a consistent tendency for one method to provide lower estimates than others.

Comparisons between recorder groups

Researchers and Consultants - Does expertise influence the data from transects?
No significant difference was found between the estimates of overall abundance or species richness from transects walked, when comparing data collected by the four taxonomic experts and six research staff carrying out surveys. However, there were notable differences in the community composition; consultants recorded 57% more individuals, and more than twice as many species of solitary bee than researchers. Conversely, hoverfly counts were substantially (3x) higher for researchers than they were for consultants, although consultants detected higher numbers of species (33 vs. 27). There were differences in the composition of these samples: consultants reported higher counts of the small black hoverflies in the genus *Cheilosia* (4.2 x as many individuals, and 3x as many species). For bumblebees, comparable numbers and species richness were sampled by the two groups. Taken together, the results suggest that observer expertise can influence transect samples, especially for inconspicuous, flighty or difficult to catch taxa.

The Addition of a Free Search
'Free searches' at high quality habitat patches are utilised by many taxonomic experts when collecting data on the species present at a site, and in the consultants' protocol these were carried out as well as fixed transect walks (Table 3.1). Abundance of individuals recorded on free searches was nearly double that recorded on transects, as would be expected from targeting flower-rich areas or nesting aggregations (Annex Table E10). Overall species richness estimates for sites were not significantly different for any of the taxonomic groupings (individually or combined) between transects and free searches (Annex Table E11), suggesting that the more standardised transects provided a reasonable estimate of richness at the site level. However, free searches tended to detect a higher average number of species per site and for hoverflies and solitary bees there were sometimes considerable differences in the component species sampled, with many species unique to a particular method.

Researchers and Volunteers - Transects and Focal Floral Observations
Researchers and volunteers conducted their sampling on the same day, with transect walks by each conducted in close succession and focal floral observations conducted at the same time. For transects the estimates of overall pollinator abundance, and of *pollinator abundance within the three broad groups* (solitary bees, bumblebees and hoverflies), were all strongly and significantly correlated between researchers and volunteers on the 17 paired site visits. For focal floral observations, where observations were conducted at the same time by researchers and volunteers, the records for all pollinators and three broad group estimates were closely matched. Overall this indicates that volunteers with limited taxonomic expertise, but with the aid of simple insect identification guides, can distinguish between insects (at least to broad group level) to collect data of similar quality to an experienced researcher.

Differences between GB Regions: Comparing England and Scotland
Distinct differences emerged when comparing patterns of abundance and species richness between Scotland and England. For bumblebees there were no significant differences between species richness or overall abundance estimates, although sites in England in general had higher overall abundance. Conversely, hoverfly abundance and species richness were higher in Scotland than in England, although again the differences were not statistically significant at the site level. The most striking contrast between regions emerged for solitary bees, where estimates of both species richness and abundance were significantly higher for England. Where 6 sites in England had on average 45.6 individuals of 10.5 species, Scottish sites had an average of 4 individuals and only 1.7

species. Only 2 sites were sampled in Wales, one of which (Mt. Snowdon) had very low abundances due to high elevation, making a valid comparison with the other regions impossible.

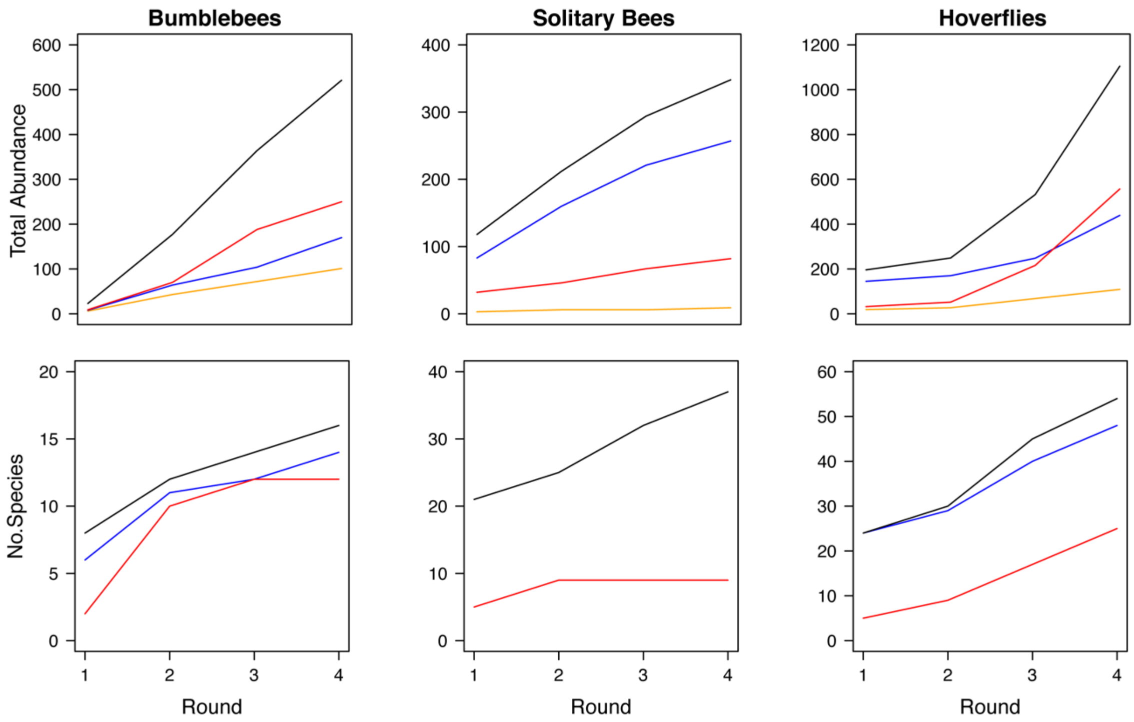


Figure 3.4. A summary of the accumulation over rounds of total number of individuals **(top row)** and the total number of species sampled **(bottom row)** for Bumblebees, Solitary bees and Hoverflies, for each method and for all methods combined. **Orange = FFOs**, **Red = Transects**, **Blue = Pan Traps** and **Black = All Methods** combined. For species richness there is no line for FFOs as data were not collected at the resolution of species. Only data from in the Researcher's protocol is used.

Feedback from recorders

The questionnaire was completed by all 6 researchers, 4 consultants and 12 non-expert volunteers who carried out survey protocols across the 14 sites. Three statements were proposed relating to each of the methods, with the final statement reading: "I would be willing to use this method as part of a wider monitoring scheme for pollinators or pollination services". Answers could range from 1 (strongly disagree) to 5 (strongly agree). See Annex E for summary tables of responses to questions by different recorder groups. All methods scored averages of above 3.5 within each recorder group (Fig. 3.5), with the exception of the consultants who tended to be less positive about use of transect walks and floral surveys than they were about focal observations and timed free searches. However, the responses of consultants in this small group varied, demonstrating the range of surveying styles and preferences among experts with specialist knowledge of different taxa, and the small sample of consultants precluded statistical analysis of these responses. It should also be noted that all volunteer recorders in this pilot study were known to the research teams in some capacity (eg. as friends, family or colleagues), which may have influenced levels of 'willingness' expressed in the feedback (and the same applies to the recorder groups in the crops pilot study, Section 3.1b).

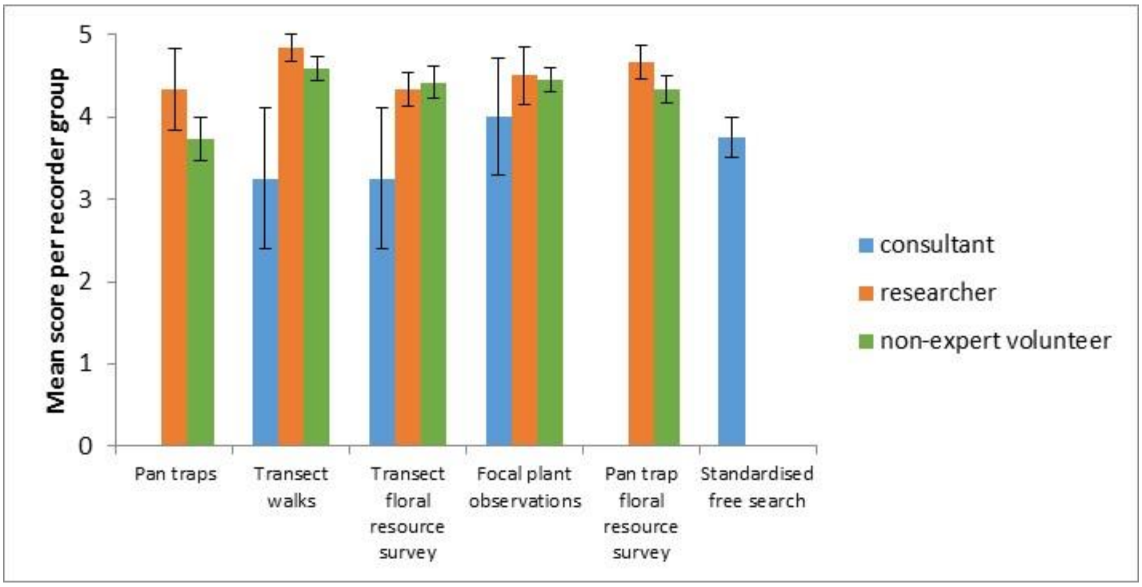


Figure 3.5. Average scores assigned by different recorder groups to the survey methods they implemented during the pilot study (Table 3.1) when asked "Would you be willing to use this method as part of a wider monitoring scheme"?

Overall, several themes were common throughout the detailed feedback received. For pan traps, six respondents felt that the equipment load required was excessive and four found that the protocol involving five sampling stations across a 1km square made for a long day in the field. When using three 1m quadrats to estimate floral abundance around each pan trap, recorders commented that these were often not representative of the whole transect.

For transect walks, six respondents had problems locating or following the 1m sections and some also reported challenges with recording different insect groups where high numbers were present. When estimating flower abundance on transects, seven respondents reported problems with identifying plants to species level. For the focal floral observations, several respondents found this an easy method to follow, though five suggested that the 10-minute observation period could be reduced ,especially if activity was low; as suggested by the earlier field trials (Annex D) and other studies[37] this poses a risk to data quality since shorter observation periods may generate lower counts. Of the four consultants carrying out standardized free searches, two reported potential issues with data quality or comparability between recorders since it is hard to standardize this sampling approach.

3.1b) Crop pollinators and measures of pollination service

This pilot study was run across 5 oilseed rape fields, 7 bean fields (each in Berkshire and Tayside, Scotland) and an apple orchard (in Kent) and was coordinated by the University of Reading and the James Hutton Institute. The study involved experienced research staff visiting study fields during crop flowering (three sampling rounds per crop type) along with novice volunteers, farmers and agronomists, and each recorder group implementing a number of crop pollination survey methods following simple protocols (Table 3.1). See Annex Fii for detailed protocols and Annex E for a full report of analyses and results.

Comparisons between recorder groups

For transect surveys, recorders were asked to walk a 50m tramline of flowering crop over 10 minutes and record all insects they saw visiting crop flowers, within 1m (for oilseed and beans) or along the tree row, to as high a taxonomic resolution as they could (including bumblebees to species level). Significant effects of recorder group on counts of different pollinator groups were found (Fig. 3.6). More bumblebees were recorded to species level by novice volunteers and researchers than by farmers and agronomists, and researchers recorded fewer solitary bees and honeybees than novices. These findings indicate that on transect surveys researchers and novices were more able and/or more willing to attempt to record bumblebees to species in the field than farmers and agronomists. The high counts of honeybees and other bees by novices could be a result of records made from outside the observational area, or misidentifications of other flower visitors such as large flies, because novice recorders were keener to record high numbers of pollinators. The strict observation areas necessary to collect accurate data could be made more explicit in future in order to reduce this variability.

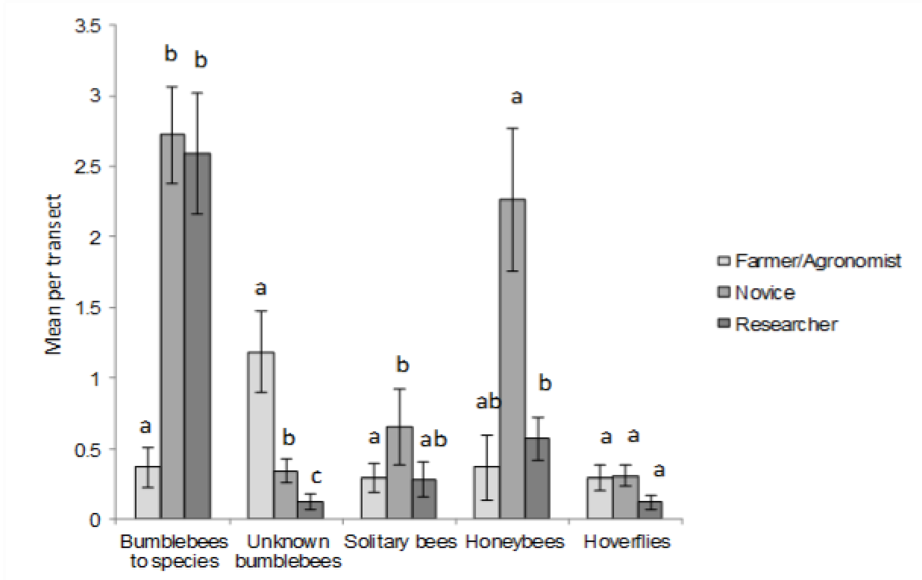


Figure 3.6. Average counts per transect observed by different recorders across fields of beans, oilseed and apple orchards. Bars within pollinator groups with different letters are significantly different ($P < 0.05$).

Pan trapping involved recorders placing out three coloured water trap arrays at 25m intervals along a tramline in flowering crop fields. At the end of a survey visit, recorders were asked to count what was caught in all pan trap arrays and record numbers to the highest taxonomic resolution possible on the data sheet. Data shows that records from the same pan traps varied between different recorders. In some cases, numbers of specimens were miss-counted and in other cases, specimens were missed altogether (See Annex E, Table E2). It was not possible to statistically compare counts made by different recorder groups because of the paucity of data. However, it is not possible to accurately record what is caught in pan traps in the field, making it necessary to return pan trap catches to the laboratory for sorting by trained technicians in order to generate data on their contents.

Feedback from recorders

A total of 42 recorder questionnaires were completed, nine by farmers and agronomists, 18 by novices (non-expert volunteers) and 16 by researchers covering the three different crops surveyed. Individual recorders who carried out surveys in more than one crop completed a questionnaire for each crop. See Annex E for summary tables of responses to questions by different recorder groups. Responses were broadly positive with regards to the enjoyment, practicality and willingness to implement pan trapping and transect surveys, but were more negative for hand pollination and bagging techniques. An important question to consider in the context of using different recorder groups to implement a wider survey is whether recorders would be ‘Willing to use a method as part of a wider scheme’. In this regard, responses for all recorder groups were positive for pan trapping and transect surveys (Table 3.2). Researchers, farmers and agronomists however had more reservations concerning carrying out bagging and hand pollination techniques more widely. Pending better understanding of their suitability as metrics for monitoring changes in pollination service delivery across different crops, the use of more simple measures such as seeds per pod or fruit set taken at crop harvest may provide more practical measures for novice recorders, farmers and agronomists in the future.

Table 3.2. Percent of responses to the question "Would you be willing to use this method as part of a wider scheme?" for three pollination service sampling methods, from Agronomists and farmers, Novice volunteers and researchers.

Method	Recorder	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
Hand pollination & plant bagging	**Agronomist/Farmer**	0	17	17	50	17
	Novice volunteer	0	100	0	0	0
	Researcher	0	22	44	33	0
Pan Traps	**Agronomist/Farmer**	22	56	22	0	0
	Novice volunteer	21	64	14	0	0
	Researcher	60	40	0	0	0
Transect walks	**Agronomist/Farmer**	44	33	0	22	0
	Novice volunteer	35	59	6	0	0
	Researcher	56	38	0	6	0

In conclusion, the data collected on crop pollinators by different recorders varies with some recorder groups more willing and able to record some pollinator taxa to species than others. The total number of observations is also much higher for some taxa than others when recorded by novices compared to researchers. With additional training perhaps this variation could be addressed and the confidence and ability to record particularly common bumblebees could be improved in all recorder groups. Most recorders would be willing to implement pan traps and transect surveys if required, which is encouraging, although if more direct pollination service and deficit measures were required then, according to feedback from the questionnaires, some form of incentive would be necessary to encourage participation. This could take the form of direct payments, or if farmers or agronomist were able to utilise the data collected to understand levels of pollination service in their fields this could inform the management of pollination services to reduce deficits and potentially enhance profitability.

Key findings (Section 3, Objective 4)

- We present a standardised protocol designed to be implemented by one person on one day (with four repeat site visits per year). A pilot study of this protocol, across 14 sites in England, Scotland and Wales (representing both agricultural and semi-natural habitats), identified the combination of sampling methods (water-based pan traps, fixed transect walks and timed floral observations) as providing a comprehensive toolkit for assessing pollinator diversity and wildflower visitation. This protocol would generate sample sizes required to assess long-term trends in abundance at broad group level (bumblebees, solitary bees, hoverflies) but probably only at species-level for a few common species (e.g. 21% of the 108 species sampled in the pilot).
- Sampling intensities required from a systematic approach to detect and monitor rare species are likely to be prohibitive, so these will require continued targeted recording effort. Collecting data on pollinators to species level is important given potential turnover in species and communities with continuing environmental change that could see dominant crop types or native plant communities and their key pollinators change in the future.
- For both *pollinators* and *pollination services* to crops, pilot studies over a limited number of sites provided an opportunity to compare the relative performance of different sampling methods when carried out by different recorder groups. With training, pan trapping,

transects, timed floral observations and some pollination service measures taken directly from the crop (e.g. using bagging experiments) could be implemented by all recorder groups, though the taxonomic difficulty associated with observational approaches must be considered (see below). Implementation on a larger scale is needed in order to understand how any biases towards particular taxonomic groups and potential effects of region, land-use or crop type may affect longer-term trends in pollinators and crop pollination metrics.

4. Framework and costed scenarios for future monitoring of pollinators and pollination services across GB (Objectives 3, 4 & 5).

The opportunity to run a single scheme that delivers robust measures of long-term change in pollinator populations and pollination services is currently limited, in part by a lack of resources but also by a lack of skilled surveyors and taxonomists. However, our increased understanding of the capacity of different recorder groups to generate *data of known quality*, together with a large potential pool of enthusiastic volunteers, offers opportunities for new pollinator monitoring activities (potentially in concert with existing NSS activities). We therefore present a framework that includes a set of core components (inputs) which are combined under different *scenarios* to deliver measures of change in specific response measures (outputs). The scenarios are not mutually exclusive and indeed may be complementary, offering overall cost savings if particular options are implemented in combination; Scenarios 1 – 4 represent *potential new activities* in order of increasing volunteer involvement and decreased likely cost and Scenario 5 represents existing biological recording activity with a simulated 10% increase in number of usable records.

Framework components are **broadly defined** and **colour-coded** in subsequent figures summarising scenarios as follows:

Recorders: Four generic groups with defined volunteer or professional and expert status.

Methods: A set of potential methods that may be applied on their own or in combination to deliver more robust or detailed outputs.

Sampling site networks: Site networks defined according to one of four types: ad-hoc opportunistic; self-selected; targeted (e.g. to specific crop types) or systematic random (nationally representative of habitats).

Support tools: Essential requirements to support a scheme, including data capture, validation, analysis, storage of samples, supporting materials, training, ID guides, website set-up, promotion and providing feedback to participants.

Outputs: A set of potential response measures representing *change* in *pollinator population status* (double green line), *pollination service* to crops or wild plants (dashed green line) or the capacity of the *landscape* to support pollinators (solid green line).

Definitions of each input and output measure are given in the Glossary. Five potential scenarios are presented schematically over the following pages to clearly demonstrate the outputs delivered, along with consideration of the necessary sampling design and assumptions, support requirements, costs (from low to high sensitivity options), likely land-use cover, benefits and limitations. ***Greyed*** **boxes indicate components that are 'turned off' for that scenario; dashed lines for arrows indicate indirect or incomplete delivery of a particular response measure.**

Each scenario ensures that the proposed methods are appropriate to the recorders or participants (based on our "methods matrix" exercise, Obj 2) and that the site network and sampling intensity provide at least 80% power to detect changes in the defined response measures of 30% over a 10-year period, equating to a *3.5% annual increase or decline*, with at least 5% statistical significance (based on our power analyses, section 1.3)[note8]. We also present indicative costs to detect 10-year changes of 30-50%, equating to a 3.5-7% annual change, which would meet or exceed the ideal sensitivity proposed by the experts in our survey (details in section 5 and Annex C). We focus in particular on power to detect changes in *relative abundance of bee and hoverfly species or groups* and *crop fruit or pod set* over time, based on counts sampled in our pilot study (Obj 4) and from the larger-scale IPI projects. This expands on previous studies that have considered detection of changes in only total abundance and/or species richness of bees[28,38]. Scenarios are not mutually exclusive, in that we assume current recording activity as outlined in Scenario 5 would continue.

All scenarios and costs *assume monitoring at the GB-level*. The suggested site networks would not deliver robust measures of change in all response measures at *country or regional levels*, but may allow for detection of change in grouped abundance or flower visitation rates, or could be applied at country level to deliver the same measures with equivalent statistical power. Finally, we have costed in most cases for a full-time *GB-level coordinator* with additional support at regional levels (from technicians and/or administrators). However, this would be a complex and challenging role probably requiring more than the equivalent of one full time person (FTE) and a specific job description depending on the scope of the scenario.

A note on the potential value of DNA barcoding for specimen identification and need for consideration of sample curation and storage facilities to support any long-term scheme

Specimen identification can be hampered by the limited number of skilled taxonomists, especially for many of the smaller pollinator taxa, but may be helped in future by 'DNA barcoding' (the sequencing of short, standardised gene regions for each specimen and its match to a taxonomically validated reference set of DNA sequences). For the UK bees such a reference set is >90% complete (A. Vogler pers. comm.). The technology provides a universal identification tool that reduces the reliance on multiple taxonomic experts who each specialise in a subgroup of species obtained in a sample. Advances in DNA technology, specifically the development of metabarcoding and metagenomics, also permit the identification of species directly from field-collected bulk samples[16,39]. In addition, DNA barcoding can potentially detect the internal and external parasites associated with a specimen and identify the flowers visited by an individual from minute amounts of pollen attached to the body. Here we provide a case study of indicative costs based on the pan trap samples generated in our pilot study (Section 3.1a) for DNA barcoding as an alternative to traditional taxonomy under Scenario 3b.

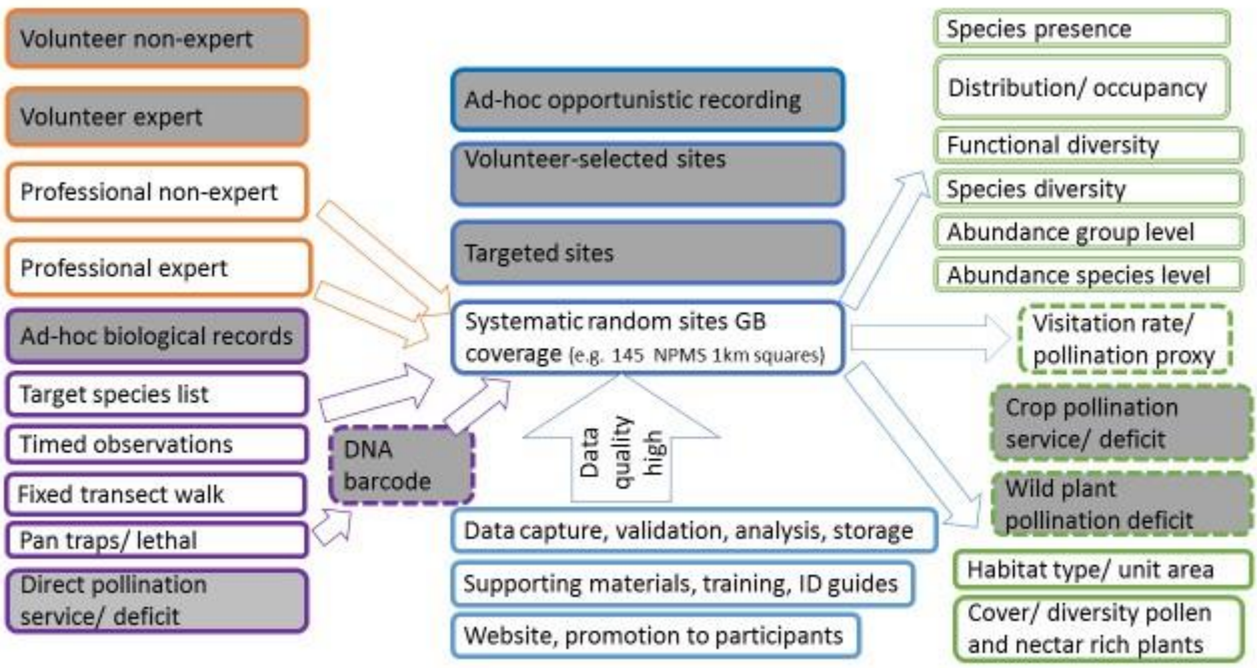
Choosing a facility for long-term storage and curation of specimens would likely depend on the funding source and ownership of collected material. However the potential added value from storing pollinator specimens appropriately for future research could be considerable (e.g. the opportunity to explore population genetic factors, parasites, chemical residues or pollens associated with individual insects). The Natural History Museum is the permanent home for an archive of 46,000 specimens from research projects funded under the recent UK Insect Pollinators Initiative for completion by October 2016. Formation of this archive required 1 person year of dealing with documentation and data issues and 1.5 person years of processing specimens for long term storage, with joint funding from the original IPI funders (BBSRC, NERC, Wellcome Trust, Defra and Scottish Government) (G. Stone pers. comm.). Production of this archive from individual project collections highlighted the

[8]These power analyses provide a *broad indication* of the likely sampling intensity and site network required to deliver a given % change over time. However, it is difficult to estimate the likely variability in pollinator numbers over a 10-year period with existing datasets which typically span up to 3 years and contain many zero values, hence estimates of likely power would be contingent on building up data over the initial 5-10 years of any future scenario.

need to consider specimen data management, storage and ownership issues in depth as part of project planning (see Annex C).

Further pollinator specimens could in principle be added to the IPI archive, especially if applying DNA barcoding approaches for identification (see Scenario 3). Alternatively, research institutes may be well placed to combine specimen identification with curation and storage, such as Rothamsted Research where the Rothamsted Insect Survey (RIS) has more than 50 years of experience in receiving, processing and storing samples. The RIS network of suction trap sites for monitoring aphid abundance sends in samples on a twice weekly basis, these samples are sorted, the aphid fraction removed and identified in order to produce a bulletin at the end of each week (e.g. http://www.rothamsted.ac.uk/insect-survey-bulletins/bulletin-no-25-21-september-27-september-2015) and the non-aphid fraction stored for research. The sample archive houses in the region of 150,000 samples containing an estimated 120,000,000 invertebrates between them. Current work is underway to improve storage techniques for use for molecular analysis however there have been promising results in utilising these samples, depending on techniques. In addition, associated metadata and datasets should be deposited within data centres allowing 'open access', such as the NERC Environmental Information Data Centre and the National Biodiversity Network Gateway.

SCENARIO 1: Professionally-led systematic repeated sampling



Sampling design and assumptions: Repeated surveying of a fixed set of environmentally and geographically stratified sites across GB, using standardised and tested methods performed by trained permanent staff. The network would be organised around a set of institutional bases: for example the four CEH sites (Edinburgh, Bangor, Lancaster and Wallingford) with up to 14 additional 'base stations' (e.g. long-term research facilities, Universities, ECN sites). Each station would be responsible for 5-8 survey sites (see Table 4.1), selected from the network of ca.2000 1km squares designated under the National Plant Monitoring Scheme (NPMS: http://www.npms.org.uk, see Glossary). Surveys would involve setting out five pan trap sets (three pans per set) at fixed sampling stations within each 1km square, undertaking transect walks from each pan trap set, and collecting the pan traps after a period of 6-7 hours (see Glossary and Annex E), thus requiring 1 person-day per site and a minimum of 4 sampling rounds between April and September. Timed observations of focal plant groups would be included IF being implemented as part of a wider citizen science activity (under Scenario 4) to calibrate data and increase sample sizes. Additional staff time would be required per sampling round to sort (to group level) and dispatch samples to consultant experts for species-level ID.

Support requirements: A full-time national (GB) coordinator at senior scientist level would be required; this role would involve compiling, managing and analysing data, distributing equipment and samples, training, maintaining the surveyor network and liaising with National Recording Schemes. Administrative costs would include a website or project-based Wiki to enable effective communication between partner institutions.

Costs: £1.2M - £3.3M over 10 years (£115K - £324K annual years 2-10).
A technician would be required at roughly 0.4 FTE per station, devoting 6-7 days of effort per sampling round (with 5 sites). Additional expenses would be required to cover travel (sites assumed at a maximum distance of 20 miles from base stations), equipment, sample postage, an initial day of training field staff, and ID costs (full details in Annex C). ID costs (identification to species for all bees and hoverflies only) could transfer from consultant taxonomists to DNA barcoding in future (see Scenario 3b), or be reduced over time with increased investment in training of institute staff who already have some of the required taxonomic skills. Costs of sample curation and storage have not been factored in here but would require consideration in advance of any large-scale sampling (see above).

Table 4.1. Samples sizes required to detect change in pollinator groups or species at different levels of sensitivity.

Change over 10 years	Annual change	Yr 1 mean count/ site*	Sites	Number of 'base stations'	Sites per station	Groups/ species monitored: pan traps + transects combined BB = bumblebee; SB = solitary bee; HF = hoverfly; HB = honeybee
30%	3.5%	1	145	18	8	BB, SB & HF grouped abundance & diversity; species abundance common pollinators (ca. 20% species*, incl. 6 *Bombus* species and HB) [(a)]
30%	3.5%	10	75	15	5	BB, SB & HF grouped abundance & diversity; species abundance ca. 2% very common species [(b)]
50%	7%	1	45	9	5	As (a) above with lower sensitivity
50%	7%	10	20	4	5	As (b) above with lower sensitivity

*21% and 2% of the 108 species sampled during our pilot test across 14 1km squares in agricultural and semi-natural habitats reached mean counts/site of 1+ and 10+ respectively (using pan traps and transect walks combined).

Land-use cover: Use of the network of ca.2000 NPMS squares would ensure sampling that is statistically representative of GB, with good geographic coverage, and potential to select subsets of the 1km NPMS squares to provide proportional representation of different land-uses at national or country level. Squares within the NPMS were selected using a weighted random selection based on presence of 18 LCM habitats (excluding coastal rock and built up areas) across all regions such that, for example, 22% of their area covers arable land as compared with the national average of 31% (O. Pescott pers. comm).

Benefits

This is the only scenario that ensures continuity of monitoring locations and techniques, providing the best method of monitoring long-term change in pollinator abundance and diversity.

Complementarity between methods allows measures of the full pollinator community over the season (i.e. some species groups may be missed if single methods are applied). Functional group diversity could be measured, even if species-level abundance shifts could only be assessed for the commonest species, depending on size of the sample network.

Pan traps provide the least biased sampling[40] of the full bee *and non-bee* community. Non-bee insects may be increasingly important crop pollinators and respond differently than bees to land-use change.

This approach includes measures of habitat quality (through flower counts) and of visitation rates to common native plant species, providing a standardised *proxy* for pollination service to wild plants.

The transect component builds on the 'BeeWalk' transect network run on volunteer-selected sites by BBCT, providing additional species-level bumblebee data that could complement BeeWalk transects.

In combination with continued ad-hoc recording and the application of dynamic occupancy models that bring opportunistic and standardised datasets together, this approach could significantly strengthen our understanding of changes in species *distribution and abundance*.

By focussing on shared survey sites, this scenario links with parallel monitoring of changes in plant species community composition under the NPMS.

Sampling network could be utilised to integrate crop-focussed measures of visitation or production.

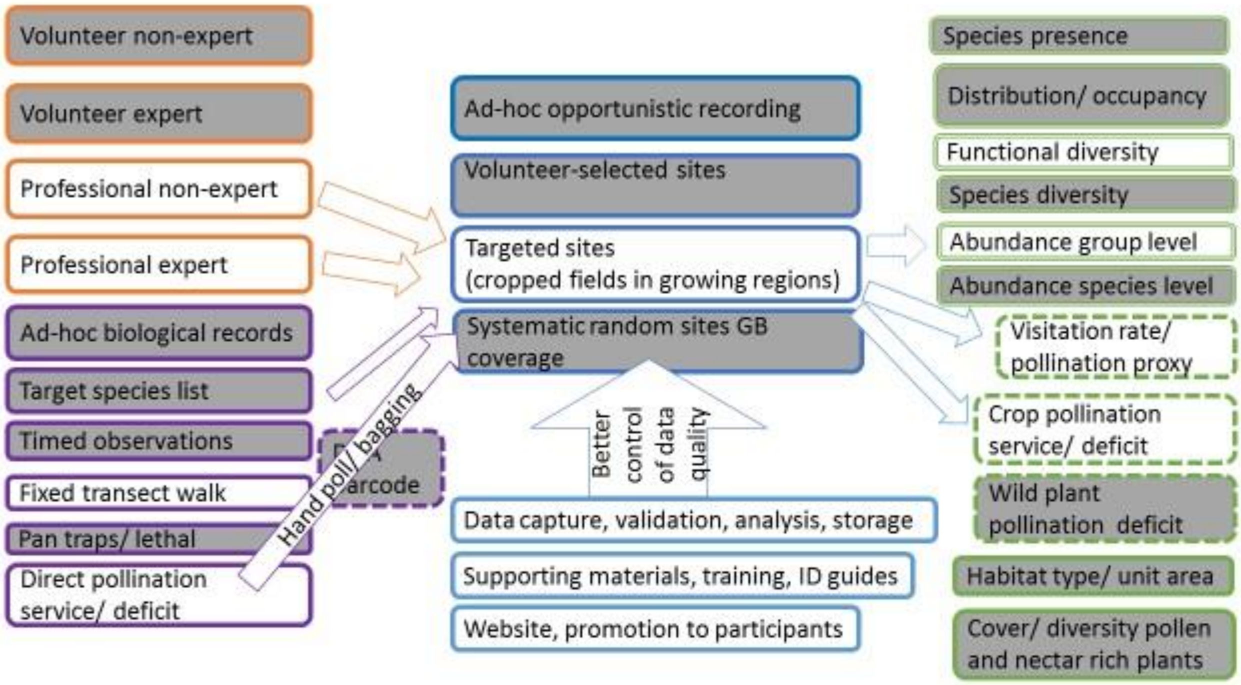
Limitations

Pan trapping is a lethal sampling approach, but studies suggest this has no detrimental effect on local populations over time[41]. This project has demonstrated that the use of small bowls and shorter trapping durations, minimises the numbers caught (typically on average 3-4 bees and hoverflies per set of three traps left out for one day, amounting to annual site totals of 65 individuals using the recommended protocol) whilst ensuring data of sufficient quality for quantitative analysis.

Abundance of individuals from standardised counts provides only a relative measure, or *proxy* for population size, especially for the social insects such as bumblebees, for which numbers of nests are the absolute measure of population size.

This approach is unlikely to adequately monitor rare species (S41, S42, Scottish biodiversity list) or the more specialised pollinators of some native plant species unless targeted to sites or specialist habitats (eg. using 'free search' approaches). However, the targeting of NPMS squares towards rarer habitats would increase chances of sampling in habitats with botanical interest, and pilot testing using this protocol did reveal examples of rare species (e.g. *Bombus ruderatus* and *Andrena fulvago* at single sites in England and *Lasioglossum fulvicorne* in Scotland – see front cover) in the 'wider countryside'.

The approach would be professionally-led and implemented and does not include scope for the involvement of volunteers. However, recruitment and training, as for BeeWalks, could be considered for increasing the sampling extent.



SCENARIO 2: Professionally-led repeated systematic sampling focussed on crop pollination

Sampling design and assumptions: Repeated surveying of insect pollinated crops (top fruit e.g. apples, soft fruit e.g. strawberries, and broad acre e.g. field beans) targeted to growing regions across GB, using standardised and tested methods performed by trained permanent staff and/or agronomists. The network could be organised around a set of institutional bases: e.g. Research institutions, CEH sites, University and Agricultural college farms). Each base would be responsible for coordinating the required number of fields/ sites in any given monitoring region (see Table 4.2 for necessary site numbers). Surveys would involve crop pollinator transects (Table 4.2 Scenario 2a and 2b) to provide data on changes in crop pollinator activity, or, in combination with direct pollination service and deficit measures (Table 4.2 Scenario 2c and 2d) could provide additional data on changes in pollination service to crops. The addition of any pollination service measures would require an additional visit to field sites to harvest crops (Annex E). These Scenarios do not involve identification or collection of species-level data given delivery of crop pollination services are driven by the abundance of key functional groups. If changes in individual crop pollinator species abundance or diversity (e.g. to understand the role of diversity in the resilience of pollination services) are required, then additional methods for specimen collection and identification would be necessary and site numbers required to detect changes would be greater.

Support requirements: See above, as for Scenario 1, although currently no specimen collection, identification or sample storage support would be needed unless methods were adapted in order to collect species-level data.

Costs: Scenario 2a = £0.9M-£1.4M over 10 years (£85K - £135K annual years 2-10);
Scenario 2b = £1.5M-£3.5M over 10 years (£139K - £341K annual years 2-10);
Scenario 2c = £2.2M-£2.7M over 10 years (£213K - £262K annual years 2-10);
Scenario 2d = £6.6M-£8.6M over 10 years (£655K - £851K annual years 2-10).

A technician would be required at 0.4 FTE per base station, devoting roughly 3 days of effort per crop site per year. Additional expenses would cover travel, equipment and training costs (see Annex C). Crops are typically in flower for only a short period (2 weeks apples, 4 weeks oilseed) so investment in staff would need to be sufficient to enable all necessary visits to monitoring sites during the period of crop flowering.

Table 4.2. Samples sizes required to detect change in crop pollinators or service measures at different levels of sensitivity and for differing numbers of crops types.

Scenario	Change over 10 years	Annual change	Yr 1 mean count/ site*	Sites	Transects per site	Service sampling stations per site	Crop types monitored	Response measures BB = bumblebee; SB = solitary bee; HF = hoverfly; HB = honeybee
2a	30%	3.5%	~10	75	6	0	1	BB, SB & HF grouped abundance, broad functional diversity for groups detected at ~10 records annually per site* (Annex B).
	50%	7%	~10	20	6	0	1	
2b	30%	3.5%	~10	300	6	0	4	
	50%	7%	~10	80	6	0	4	
2c	30%	3.5%	~10	200	6	10	1	As 2a and 2b with addition of crop pollination service and deficit
	50%	7%	~10	150	6	10	1	
2d	30%	3.5%	~10	800	6	10	4	
	50%	7%	~10	600	6	10	4	

*based on averages for typical oilseed, bean and apple crop data, see Annex B; some groups may not be sufficiently represented in particular crops (e.g. SB in oilseed and beans; HF in beans).

Land-use cover: A minimum number of sites (fields) is required to detect a change of 30 or 50% in crop pollinators or pollination service over 10 years (Table 4.2). These sites would have to be located in certain crops or in growing regions where changes in crop pollination were to be monitored. Therefore the number of different crops and separate growing areas involved in monitoring will dictate the number of sites and geographical area covered. The cost implications for single crop and multi-crop scenarios monitoring changes in crop pollinators or crop pollinator and crop pollination service are outlined under Objective 1.4 (Annex C).

Benefits

Continuity of monitoring locations (at least to crop types within regions, due to field rotation) and techniques, providing the best method of monitoring long-term change in crop pollination services.

Engagement of professional agronomists and agricultural colleges in monitoring a *commercially relevant measure of pollination service* would strengthen understanding of pollinator issues and increase likelihood of adopting management practices to enhance wild pollinators.

Sampling protocols could be applied to horticultural crops. The approach could potentially be extended to allotments and small holdings to allow participation by the general public, beekeepers and other groups[20], but would need to account for variation in size and crop types, and measurements made would not have any direct relevancy to commercial agriculture.

Limitations

On its own, this approach would not deliver *species-level* data on changes in abundance or diversity of crop pollinators, aside from a few key (abundant, easy-to-identify) species (unless additional support tools such as photographic verification of observations introduced, see Scenario 4 or pan trapping was carried out in addition to Transects).

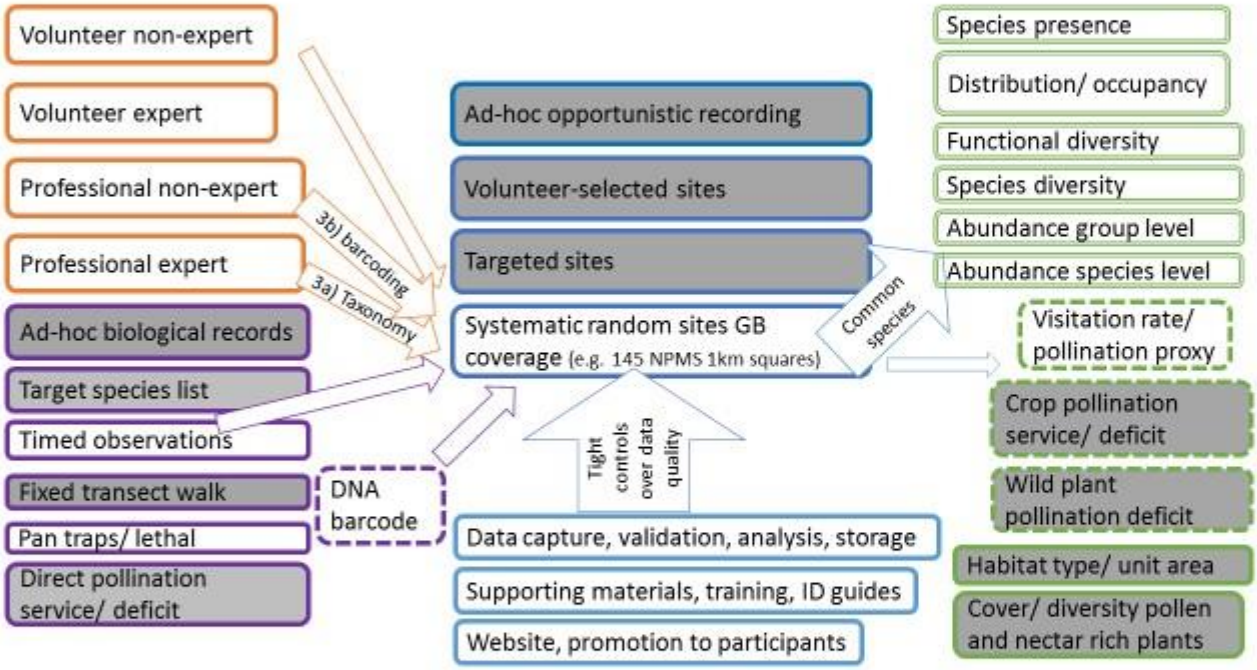
Professional agronomists will have limited time and willingness to undertake sampling unless protocols are easy to implement, or expenses paid through the scheme or by growers paying for "pollination service" assessment analogous to assessments for pest control. Training in direct service and deficit measures using hand pollination and bagging will be essential. More simple measures of seeds per pod, or fruit, could be undertaken in only a single visit, but ONLY for crops where this measure has been shown to reflect final crop production and is *independent of other agronomic factors*. Surveying crop pollinator communities using transects only would be more accessible and popular to the grower community but would only provide data on activity levels of crop pollinators and no direct measure of service.

Given that pollinator communities vary spatially across the UK, an understanding of any change in crop pollination service over time would only be relevant to the crops and the regions in which it was measured. Increasing the crops sampled and the regions involved would improve our overall understanding of crop pollination services in the UK.

The relationships between a pollinator community visiting a crop, resulting levels of crop pollination and subsequent crop yield need to be quantified for any crops involved in a monitoring scheme if real changes in production are to be detected or anticipated. These relationships have started to be developed for some crops (See Objective 2, Annex D). For this reason, measures of *total crop yield* as a potential proxy for pollination service have not been included in the proposed Scenarios.

SCENARIO 3: Volunteer-led pan trap network

(3a is based on using conventional taxonomy; 3b uses DNA barcoding when techniques developed)



Sampling design and assumptions: Repeated surveying of a set of environmentally and geographically stratified sites across GB, with volunteers using standardised and tested methods. Sites would be selected from the network of ca.2000 1km squares designated under the National Plant Monitoring Scheme (http://www.npms.org.uk). A network of 145 sites (or 45 sites at lower sensitivity) would deliver robust measures of change in species diversity, and abundance of pollinator groups (Table 4.1), but with only pan traps being deployed, species abundance trends could be measured only for key common species. Volunteers would use a 'Square near me' function (as with the NPMS) to match them with a square near their post code, and stratification by region could limit the number of volunteer applications in each area, with preference going to applicants with entomological skills where possible (gleaned through simple on-line tests). Surveys would involve the 6-7 hour pan trap protocol outlined under Scenario 1, and undertaking timed observations of focal plant groups (IF being implemented as part of a wider citizen science activity under Scenario 4). This could allow each volunteer to survey two sites in one day of good weather, provided acceptable travel distance between sites. A minimum of 4 sampling rounds would be required between April and September. Counts of trap contents to group level could be done by volunteers in the field, but samples will be sent to be sorted by a national coordinator and identified by experts.

Support requirements: A full-time national coordinator with scientific and volunteer-liaison experience would be required, this role including recruiting, training and maintaining the volunteer network; compiling, managing and analysing data; distributing equipment and samples. Training would need to be developed to ensure it met the needs of the scheme but might for example include on-line videos alongside regional face-to-face training days covering survey protocols and identification. Further work would be required to develop training methods and evaluate effectiveness. Volunteers would receive support in requesting necessary permissions from landowners (eg. an introductory letter). A website and discussion forum would be used to communicate with volunteers and share results. An annual meeting could also provide a mechanism for feedback and engagement. There could be a potential need to resource bilingual communications in Wales, although this was not costed here.

Costs: Scenario 3a = £0.9M-£1.6M over 10 years (£79K - £151K annual years 2-10);

Scenario 3b = £0.9M-£1.6M over 10 years (£80K - £149K annual years 2-10)

Surveyors would volunteer their time and travel. Expenses could potentially be offered for travel above a specific minimum distance to service remote sites. Project expenses would include materials (pan traps, stands, limited amounts of ethanol or preservative), postage and a large contribution to ID costs. ID costs could be transferred from taxonomists to DNA barcoding (depending on method development[42]), carried out at the Natural History Museum, in future under Scenario 3b. These barcoding costs scale with the number of expected specimens, but remain similar to conventional identification methods (based on current materials and salary estimates for a skilled molecular biologist with processing taking around 5 weeks per 1000 specimens, Annex C).

Land-use cover: As with Scenario 1, use of NPMS squares would ensure a network statistically representative of GB, and would help link pollinators to floral communities, but volunteer locations and travel constraints may lead to greater focus in some regions or habitats. For example, current take-up of NPMS squares by plant recorders suggests a bias towards lowland areas and away from the uplands (Pescott pers. comm.).

Benefits

Pan traps are an effective and standardised means of surveying pollinator abundance and species richness, and species-level dynamics of some common species.

Early examples of this approach have been established during 2014, eg. in the UK, members of the general public doing monthly trapping for 48hrs using three pan bowls in their garden (run by Sussex University http://thebuzzclub.uk/citizen-science-projects/pollinator-abundance-network) and a more intensive sampling approach in the US mid-Atlantic states run by a combination of volunteers, county and state employees (Droege pers. comm.).

Limiting participation to a relatively small number of geographically stratified volunteers would reduce excessive lethal sampling of pollinators and limit pressure on taxonomic resources, while conferring status to selected volunteers.

Undertaking counts to group level from both pan traps and flower patches allows participants to begin at a level appropriate to their experience but quickly progress to identification of target species should they wish.

Visitation rates to common native plant species provide a standardised *proxy* for pollination service to wild plants, collected at same sites as the pan trap samples.

Limitations

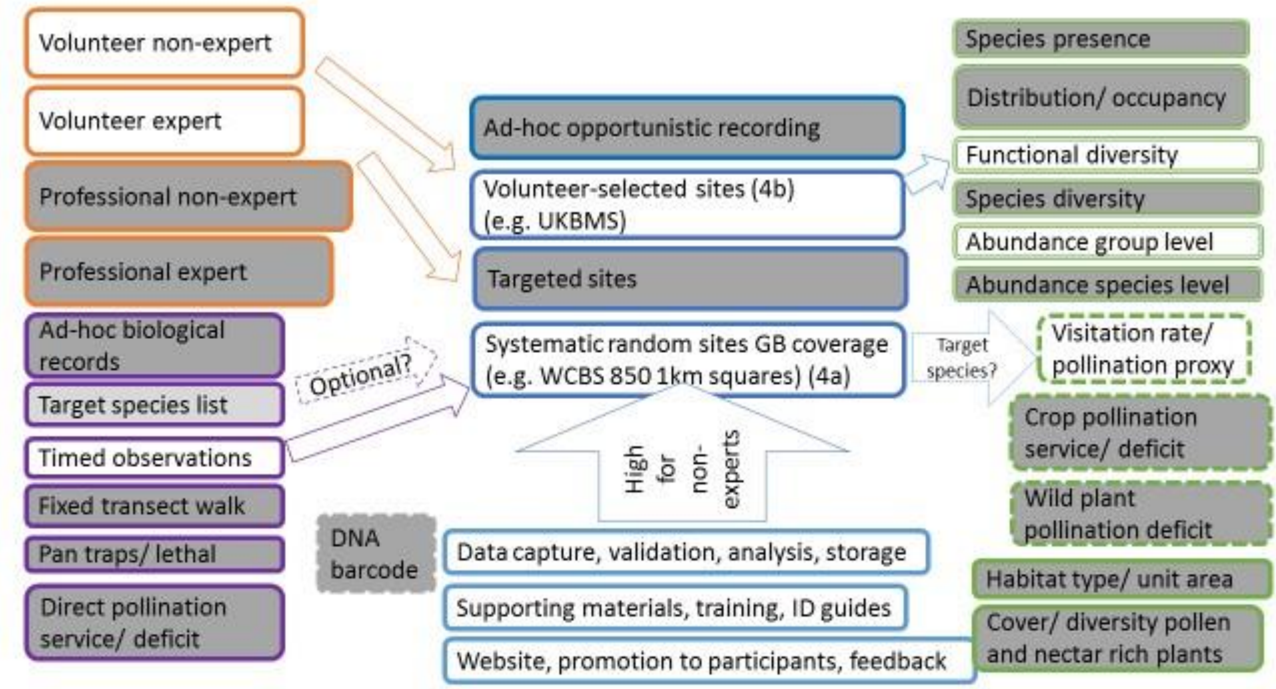
Retaining volunteer involvement to ensure continuity in sampling sites over time will require significant investment in time and resources. There is a need to increase *understanding of volunteer motivations* to inform strategies for recruitment and retention, which may need to build on the more appealing ‘timed observations’ element in this Scenario to retain interest alongside pan trapping. However, after an initial period (ca. 5 years) of flux, it may be possible to build up a core of long-term volunteers (potentially including BWARS members who have indicated a willingness to use pan traps at randomly allocated sites if given travel expenses, see questionnaire in Annex G), such that substantial levels of comparability across time are more likely.

Volunteers might be unwilling to carry out protocols involving lethal sampling, and requirements for preserving and chilling specimens for DNA barcoding may be prohibitive. Additionally, there is a risk that pan traps might be destroyed in the field under any scenario, though the short (1-day) sampling period should reduce this.

Risks to surveyors within livestock areas may limit sampling within intensive grassland or grazed systems: in practice this means that volunteers must be allowed to move sampling stations out of stocked fields when necessary.

SCENARIO 4: Timed floral observations on existing scheme sites or as wider citizen science activity

(4a extends monitoring activity on sites within WCBS/ UKBMS network using BC / BTO recorders and 4b extends to volunteer-selected locations added by wider public participation)



Sampling design and assumptions: This scenario uses a standardised approach to observing insect visitors to flowers of *defined 'focal' species* (see Annex E) over a fixed time period, and is seen as an attractive and tangible activity with potential for application by a range of 'recorder types' (Obj. 2 and 4). Our experience suggests that members of the general public cannot be relied upon to identify pollinators even to broad taxonomic group level without training[37]. Under 4a, volunteers with experience in butterfly recording on the UKBMS (over 1000 sites) and WCBS (ca 850 1km squares) would be asked to consider this protocol as an extension to their monthly or twice-a-year transect. Our pilot testing identified a quadrat of 0.5 x 0.5m as an appropriate size to encompass a typical single flowering plant or plants of the same species. It suggests that two quadrats observed for 10 minutes each are required to reach counts approaching 10 'pollinators' (*mean total bees + hoverflies* per site from four sampling rounds), though counts of other insect groups would likely be higher and this is highly dependent on choice and flower density of focal species. At this sampling intensity, at least 145 sites would be required to measure change in abundance at the group level and in any key species. Area and duration of observation could be modified, with the critical factor being a consistent measure of visitation rate per unit area, per unit of a defined floral resource and time across all participants. However, when insect activity is low it may be preferable to observe for longer than 10 minutes to avoid generating many 'zero' observations.

Scenario 4b extends the activity to volunteer-selected locations to encourage wider public participation. Web-based (or app-based) data and photo uploading, training and testing materials would be critical for quality control. Entry-level surveys could involve recording the number of flowers and insect visitors within a fixed patch, as well as some information about the location, date, weather and habitat context. Advanced-level would include guidance on distinguishing pollinators by group (ie. Hymenoptera from flies and other insect orders; honeybees, bumblebees, other ("solitary") bees and wasps; different bumblebee colour groups; 'functional' groupings of hoverflies (eg. size or feeding guild categories, or the 13 recognised 'tribes'); sets of easily recognised focal species), linked to a system for verification from photographs (see Support section). Higher skill levels could involve yet more demanding activities (eg. photographic surveys akin to the SPIPOLL[43] survey in France).

As a pilot test of approach 4b, as well as testing protocols on our 14 pilot squares, this project helped design an activity pack for use via the Bioblitz network http://www.bnhc.org.uk/bioblitz/count-pollinators-in-your-garden/.

Support requirements:

For 4a coordination could be provided through a part-time post (15%) within the organisations running the butterfly surveys (BC/ BTO/ CEH). This role would include promoting pollinator observations to butterfly recorders, distributing training materials, attending training days and compiling and analysing data alongside the butterfly schemes. For 4b, a full-time national (GB) coordinator would be required, this role including (targeted) recruiting, training and maintaining the volunteer network; compiling, databasing and analysing data; reporting outcomes to a range of audiences. Training materials would include online videos and printable guides to distinguish pollinators at different levels and recognise key focal plant species, with annual training days. For 4a, we have made a conservative assumption that all observations would be photographically verified (to at least group level) by a technician (not expert consultant) to ensure data quality. For such a system under 4b using photographs of insects on flowers, we have also scoped the costs to set up and run a function for *crowd-sourcing identifications* from photographs within iSpot as follows:

Option 1. Set up a pollinator-specific function within iSpot, for verification of IDs from photographs to *group level* (to one of 6 groups: bumblebees, solitary bees, honeybees, hoverflies, other flies, butterflies; include ability to check flower identifications). This would provide support to volunteers who have identification queries, but would *not* be used to gather data.

Option 2. Costs for Option 1 plus the addition of online data entry and downloading of resulting data, so that volunteers could enter all relevant data from their survey onto iSpot at the same time as asking for photo ID verification. Depending on the required sensitivity for detecting change, a minimum of between 870 to 4,500 verified photographs across all groups (based on numbers in Table 5.1) would be required (costs based on the higher end estimates).

Option 3. Costs for Options 1 + 2 with the addition of the use of quizzes/randomised tests that would allow assessment, tracking and development of volunteers' identification abilities.

Costs: Scenario 4a = £49K - £59K over 10 years (£4.5K - £5.1K annual years 2-10);
Scenario 4b with full Option 3 = £893K over 10 years (£71K annual years 2-10)

There would be substantial start-up expenses in developing online tools (eg. through the Indicia platform), and in the creation of training materials and publicity activities.

Land-use cover: Through 4a, use of WCBS squares could ensure a network that is statistically representative of GB, with a focus on the wider countryside, though willing recorders would need to be stratified by region in order to control for this. Use of UKBMS transect sites would increase representation of semi-natural habitats, although with no statistical sampling design in terms of location selection. Wider application through 4b would increase coverage in urban areas, parks, allotments.

Benefits

4a allows butterfly surveyors to build their skills and focus on pollinators more widely, generating additional data from already well-sampled sites (parallel butterfly monitoring gives added strength).

4b would provide a source of public engagement and education (as recently demonstrated by the 'Big Bumblebee Discovery' schools project [37]), allowing participants to begin at a level appropriate to their experience but quickly progress to ID of target species and others should they wish, and with a development pathway to participating in 4a and WCBS/ UKBMS surveys.

Training materials would be 'available to all' potentially engaging next generation of taxonomists.

Participants in our pilot surveys have found this an enjoyable activity that they would be prepared to undertake as part of a wider monitoring scheme, therefore may be possible to retain volunteer interest into the long-term.

Visitation rates to common native plant species provide a standardised *proxy* for pollination service to wild plants, with the method being applicable also to horticultural and field crops.

Selecting from a defined list of common plant species would help standardise observations across regions and habitats, though further development is required to understand trade-offs between the area, duration and number of observations required, data quality and the volunteer 'experience'.

With *clear aims and objectives*, this approach could generate large volumes of data at GB-scale, allowing better comparison of trends in broad metrics (ie. grouped abundance) between land-use types and/or regions.

Limitations

Recruitment and retention of volunteers would require an active and sustained campaign, but possibly less challenging than for pan trapping under Scenario 3.

There would be very *limited opportunities to measure change in abundance at species level*, and no potential to measure species richness or other aspects of pollinator diversity without a fully developed photographic ID system.

High support requirements: massive effort would be required from a limited pool of expert taxonomists to achieve species-level identification from photographs (eg. for *Colletes hederae*, the Ivy bee, 316 'records' were received following a feature on AutumnWatch 2014; only 18% of these could be accepted at a cost of ca £18 per verified record). Even identifying insects to broad group level is not a trivial task: the larger and more typical species can be learnt quickly, but the smaller species pose challenges (e.g. *Lasioglossum* solitary bees and *Neoascia* hoverflies are often misinterpreted by novices).

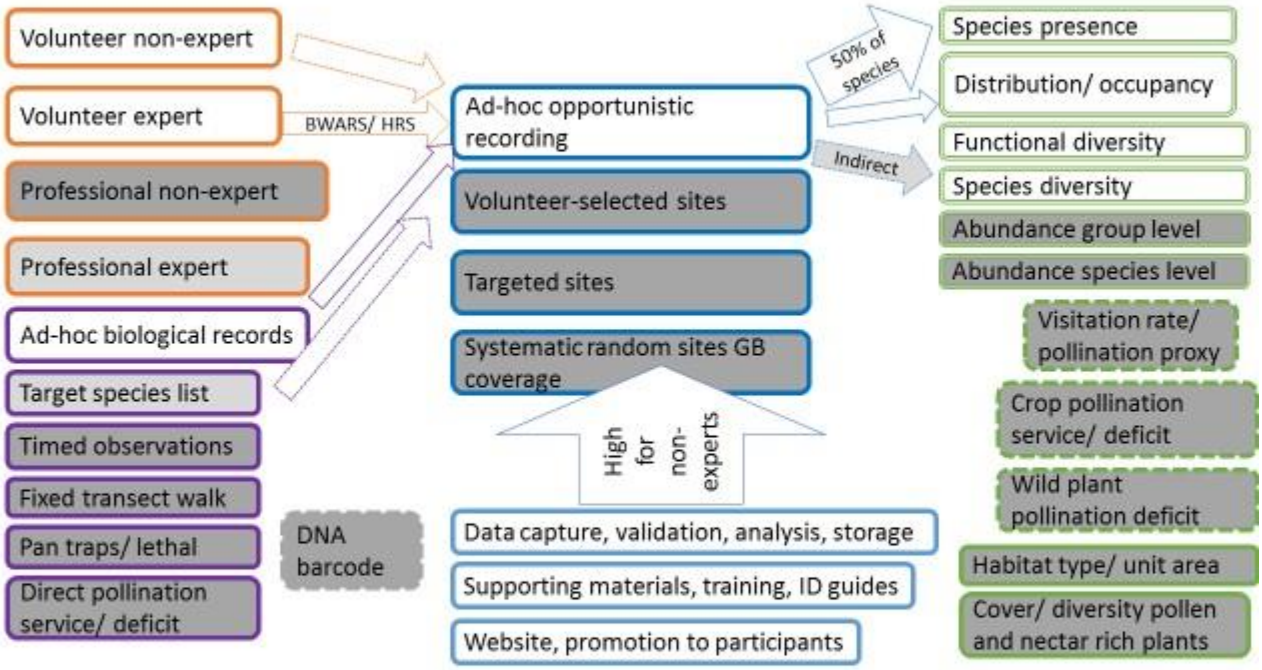
Identification of the focal plant species could also present a challenge, although we designed an easy-to-use guide to distinguish the 25 species on the list for Focal Floral Observations (see Annex Fi), and use of photographs for verification would also include the flower being visited.

Repeated sampling at the same sites would be required to detect change in visitation rates at the group level, this being harder to guarantee from a volunteer network. Even if sampling at the same sites year-on-year, it would be difficult to locate and observe flowers of the same focal plant. Modelling approaches could overcome this issue given sufficient sample sizes.

Option 4b alone would need to be statistically corrected for spatial biases, likely towards urban areas.

Additional approaches (e.g. Scenario 1 or 3, above) would be required to calibrate visitation rates to specific focal plants to more general metrics of pollinator abundance.

SCENARIO 5: National Recording Schemes and Societies (NSS)



Sampling design and assumptions: This scenario represents the current position that will continue to deliver invaluable records from across much of GB that can be used to generate estimates of broad trends in species occupancy and inform biodiversity policy[21,22]. BWARS has around 400 paying members of whom around *50 are 'active' recorders* contributing data on a yearly basis, in addition to receiving records from non-members. HRS is the Hoverfly Recording Scheme that operates within the wider Dipterists' Forum (network of fly recording Schemes). The HRS has seen a total of 5,600 recorders submitting records up to January 2015, with currently over 1,000 contributors each year. Critically 75% of these data have been submitted by about 155 people and 50% by *20 active and experienced* recorders able to recognise all taxa. In addition, submission of data resulting from academic research projects is encouraged, along with verified bumblebee records from the BBCT BeeWalk and BeeWatch schemes.

We have simulated the implications of increasing the number of records received by each Scheme by 10% over the 10-year projected timescale. Costs were based on the annual average number of verified records across both schemes between 2008-2012. BWARS now actively encourage members to provide extra information with their records (eg. survey methods used, numbers seen, flowers visited), though this cannot be guaranteed.

Support requirements: Volunteers submit data in standardised formats either digitally (in spreadsheet form) or on biological record cards, and increasing numbers of records are gleaned from online sources (e.g. iRecord, iSpot and Facebook pages). These require significant verification effort. Both HRS and BWARS have introduced Facebook pages since 2013/14, with HRS gleaning as many as 70% of 2015 records (at current estimate, approaching 21,000 records) through this route. Verification of these photographic records, and conversion to useable data, has required many voluntary hours from specialist HRS scheme organisers. Such effort is unsustainable and should not be presumed to continue under this Scenario. Training in hoverfly identification is provided to ca. 50-70 people per year through courses run by the HRS and with most costs met by scheme organisers, but only ca. 5% of these convert to active recorders, and BWARS run no such equivalents.

Both schemes also receive support through the Biological Records Centre (jointly funded by JNCC and CEH/NERC) which includes website hosting (BWARS), time and expertise for mapping and publishing atlases, plus modelling data to produce status and trend estimates (section 1.2). The recent publication of accessible identification guides to bees and hoverflies represent an excellent resource for volunteers to develop their skills. However, currently the number of people who can accurately identify pollinating insects to species level remains small, and those who already have these skills are often fully committed to recording already, and may not have much time to devote to new projects nor to mentoring novices. It is unlikely that robust monitoring of pollinators can be achieved without the involvement of a large number of volunteers/citizen scientists. While the high level of interest in pollinators suggests that there is a large pool of potential recruits, additional resources are required to develop the capacity for NSS to expand their pool of contributors, whilst maintaining high data quality and not over-burdening the small number of existing experts.

Costs: £491K over 10-years would be the 'unpaid replacement cost' of increasing capacity to accommodate a 10% increase in records. Scheme organisers and recorders operate on an entirely voluntary basis, though at current levels of involvement the total 'in kind' contribution is estimated at around £4.9M over 10 years.

Land-use cover: Records within both BWARS and the HRS show a strong bias in recording towards southern England and are also biased with respect to land cover, tending to under-represent agricultural areas in favour of semi-natural sites with greater entomological interest.

Benefits

Generates data on rare or less common species of interest to the Recording Schemes and critical for biodiversity policy and conservation reporting.

Provides a forum for interaction between experts and non-experts, critical for sustaining potential taxonomic capability and ecological understanding.

Modelling approaches have improved our ability to describe changes in occupancy or distribution of individual species by incorporating the 'data collection process' and accounting for detection probability.

Limitations

Records are 'unstructured' and generated from 'ad-hoc' sites, these often changing from year-to-year. They provide data on species occurrence but do not provide data on changes in abundance of species or insect groups over time.

Data contain biases in sampling effort and spatial coverage, caused by contrasting recorder behaviours (field techniques and preferences vary between experts), where they live or spend holiday time recording. Majority of records may represent only a subset of the total fauna (90% of hoverfly records relate to around 30 species), and statistically robust trend estimates are typically therefore achieved for ca. 50% of species. Additional information from recorders about sampling intensity at the point of data collection (eg. time spent, area searched) could significantly improve model accuracy, but is currently not recorded as standard practice.

Recorder activity is rarely constant. It tends to fluctuate in response to directed calls for species records. For example, those aimed at the production of Atlases of species distributions, publication of new keys/ guides, or new methods of data submission such as via Facebook or iSpot (note: images currently uploaded using this online approach are manually converted to records by scheme organisers (HRS) or require submission via iRecord (BWARS)).

The potential taxonomic breadth of recording through the NSS is high, but misidentifications may persist and a greater understanding of the effects of such 'taxonomic difficulty' across different bee and hoverfly species is required when interpreting distributions or trends.

Schemes rely heavily on the time and enthusiasm of a few dedicated volunteer organisers such that capacity for verification of larger numbers of species records or support for new recorders is limited (see Stakeholder Workshop report within Annex F). For example, BWARS and the HRS have no plans to expand membership substantially or to employ any staff.

5. Cost: Benefit analyses of proposed scenarios

Aims: To evaluate the costs of different monitoring scenarios and to assess their potential benefits in answering key research and policy questions on UK pollinators.

The costs of undertaking each monitoring scenario were estimated using data collected from the project (see Annex C , section C.ii, for full details) for sample networks capable of detecting 50% and 30% changes in pollinator populations (or pollination services in Scenarios 2c and 2d) over a 10 year period. For Scenarios 1 to 4, costs were broken down into elements relating to labour (real or replacement 'voluntary' cost), materials, identification, coordination, support and training. For scenario 5, no costs were estimated, instead only the additional voluntary hours required to generate a 10% increase in records was calculated, using data provided by BWARS and HRS and additional assumptions about the number of hours required to collect records from the field. The resulting range of costs (presented within section 4 and Annex C) compares with the average annual support of about £100K per project per year[44], for current monitoring schemes relying on volunteer contributions that provide data for UK headline indicators (e.g. the UKBMS or Breeding Bird Survey). The greater range of values for *pollinators* and *pollination services* reflects the greater complexity, in terms of species numbers and approaches, compared to other monitoring schemes.

A survey of 28 relevant European experts [note9] was conducted to estimate the site networks they believe would be required to answer eight key research questions (listed in Table 5.1) to a minimum and ideal standard. These questions were derived from a number of existing published studies[45] and in consultation with Defra. Each expert was asked to respond for a subset of three questions, one of which always concerned the development of a network to monitor pollinator status and trends. Full details of this survey can be found in Annex C, section C.iii.

Table 5.1. Questions used in the expert survey to calculate benefits of monitoring to wider research objectives

	Research Question
1	How does **climate change** influence changes in pollinator populations and pollination services?
2	How do **habitat based interventions** affect the status and trends of pollinator populations and pollination services in **agricultural** landscapes?
3	How do **habitat based interventions** affect the status and trends of pollinator populations and pollination services in **urban** landscapes?
4	How do changes in the **abundance and diversity** of pollinator populations affect **pollination services to crops** in the UK
5	How do changes in the **abundance and diversity** of pollinator populations affect **pollination services to**

[9] Experts were selected on the basis of either a published track record of large scale research on bees or pollinating insects or their expertise in conducting and analysing insect monitoring schemes.

	wildflowers in the UK
6	How does **changing landscape complexity** influence changes in pollinator populations and pollination services?
7	How does **agrochemical** use influence changes in pollinator populations and pollination services?
8	How is the **abundance and diversity of pollinator populations changing** within the UK?

Experts indicated a range of different sample network sizes and structures would be required to assess each research question (Annex C, Tables C.7a-g). The largest sample networks were generally those required to address issues of climate change and monitoring status and trends. For four of the eight research questions (Questions 1, 6, 7 and 8), a median ideal standard network would require over 100 sites. Typically, experts indicated that large scale, diverse sites would be required to address most research questions to even a minimum standard. Crucially, there was only one research question (Q4) for which expert's ideal standard network required an annual detection rate of ≤5% total pollinator abundance, indicating that the scenarios used in this study are all adequate to provide information to address these research questions and would meet the minimum standard for a scientifically robust monitoring network.

The median results from all experts were used to develop a series of minimum and ideal standard expert sampling networks (Annex C, tables C.7a-g). As they represent research projects, costs were assumed to follow a similar structure to Scenario 1 and were estimated for pan trap and insect transect methods. The overlap between the scenario networks and the minimum and ideal standard expert networks was then calculated by estimating the total sample power of each scenario network, assuming a degree of space-for-time substitution (Table C.8b).

Analysis of overlaps suggest that sample networks containing ≥75 sites (>150 sites for the less regularly sampled networks of Scenario 2), with a detection rate of ≤5% annual change, would be sufficient to answer each of the eight research questions to their minimum standard (Annex C, Tables C.10a and C.10b). In particular, the median expert response suggests that a network of 50 sites, sampled 3 times a year over an 8 year period would be sufficient as a monitoring network for evaluating changes in the status and trends of UK pollinators. In reality, only the largest site networks are likely to be sufficiently diverse to assess the majority of these research questions simultaneously. Nonetheless, these findings indicate that, although varying degrees of additional information are required, a monitoring network with carefully selected sites and sufficient long-term support, has the potential to supply a large amount of data for use in answering key research questions. In particular, the most comprehensive 145-site network in Scenario 1 has a monetary cost:benefit ratio of £1:£2.41, assuming that it can be designed to deliver the resolution of data required for all eight research questions.

Glossary of abbreviations and terms

Note terms in **bold** are components potentially included within the **framework scenarios** (p. XX); other terms are referred to elsewhere in the text or Annexes.

<u>Organisations, Schemes and Projects:</u>

BeeWalks: a network of volunteer-selected transects (roughly 1km in length) across the UK, visited monthly by volunteers to count bumblebees, run by the Bumblebee Conservation Trust (BBCT).

BeeWatch: a project run by the Bumblebee Conservation Trust, generating casual photographic records to map the distribution of bumblebees across the UK.

Big Bumblebee Discovery: a citizen science project run by CEH, involving UK school children counting bumblebee colour groups at lavender plants to assess diversity and abundance of bumblebees in relation to the surrounding landscape (in partnership with BSA and EDF Energy).

BWARS (Bees, Wasps and Ants Recording Society): National society dedicated to studying and recording bees, wasps and ants (aculeate Hymenoptera) in Britain and Ireland.

Dipterists Forum: National society aiming to promote the study, recording and conservation of Diptera. Provides an umbrella body to support the national recording schemes for Diptera families.

ECN (Environmental Change Network): the UK's long-term, multi-agency, environmental change monitoring programme, collecting and analysing long-term data from a network of sites (11 terrestrial and 45 freshwater) across the UK since 1992.

Great British Bee Count: a project run by Friends of the Earth, generating records of iconic bees across the UK during 2014 and 2015.

HRS (Hoverfly Recording Scheme): a National Recording Scheme to collate information about the ecology and distribution of hoverflies across Great Britain, linked more widely with the Dipterists' Forum.

IPI (UK Insect Pollinators Initiative): established in 2010 to research the causes and consequences of threats to insect pollinators, funded jointly by the BBSRC, Defra, NERC, Scottish Government and Wellcome Trust under the auspices of the Living with Environmental Change Partnership (www.insectpollinatorsinitiative.net).

IPI Agriland project: Systematic surveys sampling pollinators across 96 predominantly agricultural sites (64 in England and 32 in Scotland) conducted during 2012 and 2013 between April – September (3 survey visits per year). Data from pan traps (to species level) and fixed transects (to pollinator group level) were collected.

iSpot: an online community developed by The Open University that helps people learn about wildlife identification, by connecting beginners with experts and fellow enthusiasts. Users upload images of wildlife and a crowd-sourcing approach is taken to identification.

iRecord: a website and associated apps for collecting and sharing wildlife records, including photos. All wildlife sightings for non-sensitive species are shared with other users and are made available to National Recording Schemes, Local Record Centres and County Recorders. iRecord is developed and maintained by the Biological Records Centre at CEH, with the goal of making it easier for wildlife sightings to be collated, checked by experts and made available to support research and decision-making at local and national levels.

National Recording Schemes and Societies (NSS): National recording schemes (such as the HRS) and societies with a paying membership (BWARS) dedicated to the recording, conservation and exchange of information on different taxa.

NPMS (National Plant Monitoring Scheme): a new habitat-based plant monitoring scheme designed by BSBI, CEH, Plantlife and JNCC and launched in 2015. Aims to collect data from randomly chosen 1km squares to provide an annual indication of changes in plant abundance and diversity. The NPMS design is 'biased' towards sampling of rare habitats (i.e. semi-natural habitats), but with a second level of stratification of 100km grid cells to ensure that there are squares in all geographic areas of GB/UL

Open Farm Sunday Pollinator Survey: one-day citizen science activity held in June to generate an assessment of abundance of pollinating insects on farmland across the UK.

Rothamsted Insect Survey (RIS): networks across the UK with light traps monitoring moths (74 sites) and suction traps monitoring aphids (15 sites), returning samples to Rothamsted Research for processing and storing since 1964 (www.rothamsted.ac.uk/insect-survey).

Wider Countryside Butterfly Survey (WCBS): Monitors the changing abundance of widespread butterfly species within ca 850 randomly assigned 1km squares across the countryside (UK).

Recorder 'groups' are defined as follows:

Volunteer Non-expert: members of the public, 'citizen scientists' not covered under the expert category

Volunteer Expert: unpaid 'amateur' experts, primarily those submitting to National Recording Schemes or Societies

Professional Non-expert: paid non-experts in pollinator species ID but with training or experience in conducting field surveys, primarily technicians at research institutes, could include farmers/ agronomists

Professional Expert: paid experts with training in pollinator sampling and identification, primarily at research institutes but includes entomological consultants

Sampling/ monitoring Methods are defined as follows:

Opportunistic or ad-hoc records: data that are not collected using standardized methods. Often referred to as "ad-hoc" records, these describe data that are typically collected by volunteer 'citizen scientists' (whether expert or non-expert) and submitted to National recording Schemes and Societies or projects via online databases.

Target species list: species are recorded from a defined list, usually featuring highly detectable species that are easy to identify in the field.

Pan Traps: Trapping stations consisting of three bowls (Blue, White & Yellow UV reflective) containing water and drop of washing up liquid, in which insects land and drown; often raised to vegetation height; duration typically 24-48hrs but in our 2015 pilot study left out for 6hrs in dry weather (across the 'wider countryside' squares) or for the duration of crop pollination surveys (in cropped fields) (Annex E).

Fixed Transect Walks: linear transects of defined width and length (up to 1km) over which insects seen visiting flowers (or in flight) are recorded; can include netting for ID to species level; our 2015 pilot study tested 1m-wide transects running 200m from each pan trap station across the 'wider countryside' 1km squares defined as either following the nearest linear feature or taking a straight line across the landscape, and for crops 1m-wide transects running 50m down the tramline of a field crop or along a row of apple trees (Annex E).

Timed Focal Floral Resource Observations (FFOs): a standardised floral resource is observed over a set period of time (patch of wildflowers or crop, potted plant) to record all insects visiting flowers; our 2015 pilot involved 10-min observations of focal plants (abundant at the particular site but picked from a list of 25-30 'top' plants for pollinators, see Annex E) within a 0.5 x 0.5m quadrat, repeated twice per site visit and with flowers counted.

Timed 'free search': the approach typically used by entomologists on site surveys; 2015 pilot used targeted 30-min searches across two plots of roughly 1000m^2 (e.g. 100m x 10m or equivalent) selected by the consultant as providing high quality pollinator habitat (these areas can be altered between visits so as to track change in resources over the season).

Flight Intercept Traps: Traps which catch insects during flight e.g. Malaise Traps and Window Traps.

Trap Nests: Man-made tube nests that can be colonised by aerial nesting solitary bee and wasp species. Left out in a designated area, then can be collected in after the breeding season, reared through and identified. There is a non-destructive option of counting the number of occupied tubes and leaving in situ.

Passive Suction Traps (e.g. Rothamsted Suction Traps): Fixed air suction traps e.g. the Rothamsted network of 15 traps, designed to monitor distribution and abundance of pest aphids at a regional scale, but also sampling pollinating insects.

Portable Suction Transect: Transects over which, at regular intervals a portable suction trap is used to collect samples from within the vegetation.

Sweep Netting Transect: Transects over which, at regular intervals a set number of sweep net samples from within/above the sward is collected.

Camera Trap: Cameras set up to record insect visitation to a specific floral resource

Species Inventory Event: Bio blitz type : Volunteer based events at which over a set period of time (e.g. 24hrs) members of the public, with assistance from experts, collect data on the species found at a particular site.

Targeted Pollinator Survey Event: Targeted at pollinators and recording abundance: Volunteer based events where members of the public, with assistance from experts, are asked to record the number of individuals of specified pollinator groups seen visiting flowers, in a set period of time (run as part of Open Farm Sunday but could be applied over other land-uses).

Direct pollination service/deficit: Bagging and hand pollination methods to quantify insect contribution to crop pollination, independent of variation in agronomic factors. These involve field visits both during crop flowering and at harvest time.

Data Collection: the 'fieldwork' component of a survey, which may or may not involve identification to group or species level

Specimen Processing: the follow-up to fieldwork that leads (if necessary) to identification and creation of a valid 'record'; does NOT include data entry or data analysis.

Potential response measures were defined as follows:

Species presence: The presence of a given species at a given site, confirmed from a verified record. Lack of presence cannot be assumed to equate to absence without systematic surveys or assumptions within any modelling framework.

Distribution/ occupancy: The overall range size, distribution or frequency of occurrence of a species typically reported here at the 1km grid cell resolution.

Functional diversity: The diversity of species groups within a sampled community, defined by a set of ecological or *'functional' traits*, such as tongue length, body size, flight period or potential effectiveness as pollinators for a given crop. High functional diversity could indicate a healthy pollinator community represented by a variety of traits, able to pollinate different crop and wild plant species.

Species diversity: The diversity of species within a sampled community, reflecting their relative abundance as well as presence (which, on its own, would be termed 'species richness'). Often described using an index (eg. Simpson's) that is not sensitive to variations in sample size.

Abundance – group level: The total number of individuals recorded in defined broad taxonomic groups (here typically involving bumblebees, solitary bees, honeybees (one species), hoverflies, other flies, wasps, butterflies etc.). Further 'functional' groupings can be defined where relevant and with training, for example within the hoverflies aphid eaters can be distinguished from detritivores and plant eaters.

Abundance - species level: The total number of individuals of each species for a given group, which will also provide species richness estimates. Note such measures of abundance of *adult insects 'on the wing'* provide measures of relative abundance within a standardised unit of space/time, rather than *absolute population size* for which measures of *nest density* (of bees at least) would be required. (If data can be collected at this resolution then various diversity indices may also be calculated, which would allow estimates of spatial and temporal turnover to be made).

Visitation rate/ pollination proxy: The number of *visits per unit time* to a defined area or density of flowers. This is widely recognised as a good proxy for pollination but should not be extrapolated directly since it does not account for the *effectiveness of different species* in transferring viable pollen (see Obj 2.2).

Crop pollination service/ deficit: level of crop pollination by insects effecting fruit set or seed set. This reflects changing production in some crops (section 2.2), but in others the link between changing pollination and changing crop production needs to be better established.

Wild plant pollination deficit: Inadequate pollen receipt that limits seed production in wild plants.

Habitat type/ unit area: The % cover of different habitat or land-use types in a given area which may reflect the capacity of the *landscape* to support pollinators.

Cover/ diversity of pollen and nectar rich plants: Estimated cover of plant species or groups per unit area, measured here within quadrats or along 1m pollinator transects. Such data can now be combined with estimates of typical nectar or pollen quantity per flower to estimate how much food resource a given habitat or landscape supports[46].

Technical Annexes

A. Understanding status and trends from existing NSS and other datasets
B. Statistical power analyses using existing datasets to inform sampling design
C. Cost-benefit analysis of existing National Recording Schemes and Societies and datasets and proposed scenarios for monitoring pollinators and crop pollination services
D. Developing robust and realistic survey methods for monitoring pollinators and pollination services
E. Full analysis and results from pilot study of proposed best methods
F. Protocols for standardised monitoring of pollinators and pollination services to crops
G. Full reports from Stakeholder Workshops held in December 2014

Electronic Appendices

1. Catalogue of metadata for existing NSS, projects and datasets on pollinators and pollination services
2. Assessment scores for the capacity of different method – recorder combinations to generate data on pollinators and pollination services

Data availability

The principal datasets arising from this project will be deposited and made available through the NERC Environmental Information Data Centre (http://eidc.ceh.ac.uk/) and any arising scientific publications.

All records identified to species level will be submitted to the relevant Recording Schemes (BWARS and HRS) and the National Biodiversity Network Gateway (https://data.nbn.org.uk/).

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