Identifying key knowledge needs for evidence-based conservation of wild insect pollinators: a collaborative cross-sectoral exercise

Lynn V. Dicks, Andrew Abrahams, John Atkinson, Jacobus Biesmeijer [et al.]

Insect Conservation and Diversity

Insect Conservation and Diversity (2013) **6,** 435–446 doi: 10.1111/j.1752-4598.2012.00221.x

POLICY

Identifying key knowledge needs for evidence-based conservation of wild insect pollinators: a collaborative cross-sectoral exercise

LYNN V. DICKS,[1]* ANDREW ABRAHAMS,[2] JOHN ATKINSON,[3] JACOBUS BIESMEIJER,[4,5] NIGEL BOURN,[6] CHRIS BROWN,[7] MARK J.F. BROWN,[8] CLAIRE CARVELL,[9] CHRIS CONNOLLY,[10] JAMES E. CRESSWELL,[11] PAT CROFT,[12] BEN DARVILL,[13] PAUL DE ZYLVA,[14] PHILIP EFFINGHAM,[15] MICHELLE FOUNTAIN,[16] ANTHONY GOGGIN,[17] DEBBIE HARDING,[18] TONY HARDING,[19] CHRIS HARTFIELD,[20] MATTHEW S. HEARD,[9] RICHARD HEATHCOTE,[21] DAVID HEAVER,[22] JOHN HOLLAND,[23] MIKE HOWE,[24] BRIN HUGHES,[25] THERESA HUXLEY,[26] WILLIAM E. KUNIN,[4] JULIAN LITTLE,[27] CAROLINE MASON,[28] JANE MEMMOTT,[29] JULIET OSBORNE,[30] TIM PANKHURST,[31] ROBERT J. PAXTON,[32,33] MICHAEL J.O. POCOCK,[9] SIMON G. POTTS,[34] EILEEN F. POWER,[35] NIGEL E. RAINE,[8] ELIZABETH RANELAGH,[36] STUART ROBERTS,[37] ROB SAUNDERS,[38] KATIE SMITH,[39] RICHARD M. SMITH,[40] PETER SUTTON,[41] LUKE A.N. TILLEY,[12] ANDREW TINSLEY,[42] ATHAYDE TONHASCA,[43] ADAM J. VANBERGEN,[44] SARAH WEBSTER,[45] ALAN WILSON[28] and WILLIAM J. SUTHERLAND[1] [1]Conservation Science Group, Department of Zoology, University of Cambridge, Cambridge, UK, [2]Poll Gorm, Argyll, UK, [3]The Co-operative, Corporate Affairs Department, Manchester, UK, [4]Institute of Integrative and Comparative Biology, University of Leeds, Leeds, UK, [5]Naturalis Biodiversity Center, Leiden, The Netherlands, [6]Butterfly Conservation, Wareham, UK, [7]Asda, Leeds, UK, [8]School of Biological Sciences, Royal Holloway, University of London, Egham, UK, [9]NERC Centre for Ecology and Hydrology, Wallingford, UK, [10]Centre for Neuroscience, Medical Research Institute, Ninewells Medical School, University of Dundee, Dundee, UK, [11]College of Life & Environmental Sciences, University of Exeter, Exeter, UK, [12]Stockbridge Technology Centre, Selby, UK, [13]Bumblebee Conservation Trust, University of Stirling, Stirling, UK, [14]Friends of the Earth, London, UK, [15]Greentech Consultancy, Boston, UK, [16]East Malling Research, Kent, UK, [17]Linking Environment and Farming (LEAF), Warwickshire, UK, [18]BBSRC, Swindon, UK, [19]World Wide Fruit, Spalding, UK, [20]National Farmers Union, Warwickshire, UK, [21]Heineken UK Ltd, Hereford, UK, [22]Natural England, Worcester, UK, [23]Game and Wildlife Conservation Trust, Fordingbridge, UK, [24]Countryside Council for Wales, Maes-y-ffynnon, Bangor, UK, [25]Conservation Grade, Biggleswade, UK, [26]Sainsbury's Supermarkets Ltd, London, UK, [27]Bayer CropScience Ltd, Cambridge, UK, [28]Waitrose, John Lewis plc, London, UK, [29]School of Biological Sciences, University of Bristol, Bristol, UK, [30]Environment & Sustainability Institute, College of Life & Environmental Sciences, University of Exeter, Exeter, UK, [31]Plantlife, Cambridge University Botanic Gardens, Cambridge, UK, [32]School of Biological Sciences, Queen's University, Belfast, UK, [33]Institute for Biology/General Zoology, Martin-Luther-Universität Halle-Wittenberg, Halle Saale, Germany, [34]School of Agriculture, Policy and Development, University of Reading, Reading, UK, [35]Institute of Neuroscience, Newcastle University, Newcastle upon Tyne, UK, [36]Campaign for the Farmed Environment, Cambridge, UK, [37]Bees, Wasps and Ants Recording Society, School of Agriculture, Policy and Development, University of Reading, Reading, UK, [38]Glaxo SmithKline, Brentford, UK, [39]The Co-operative Farms, Manchester, UK, [40]Buglife,

*Correspondence: Lynn V. Dicks, Conservation Science Group, Department of Zoology, University of Cambridge, Downing Street, Cambridge CB2 3EJ, UK. E-mail: lvd22@cam.ac.uk

The Invertebrate Conservation Trust, Peterborough, UK, [41]Syngenta, Bracknell, UK, [42]Horticultural Development Company, East Malling Enterprise Centre, East Malling, UK, [43]Scottish Natural Heritage, Perth, UK, [44]NERC Centre for Ecology and Hydrology, Edinburgh, UK and [45]Department for Environment, Food and Rural Affairs, Bristol, UK

Abstract. 1. In response to evidence of insect pollinator declines, organisations in many sectors, including the food and farming industry, are investing in pollinator conservation. They are keen to ensure that their efforts use the best available science.

2. We convened a group of 32 'conservation practitioners' with an active interest in pollinators and 16 insect pollinator scientists. The conservation practitioners include representatives from UK industry (including retail), environmental non-government organisations and nature conservation agencies.

3. We collaboratively developed a long list of 246 knowledge needs relating to conservation of wild insect pollinators in the UK. We refined and selected the most important knowledge needs, through a three-stage process of voting and scoring, including discussions of each need at a workshop.

4. We present the top 35 knowledge needs as scored by conservation practitioners or scientists. We find general agreement in priorities identified by these two groups. The priority knowledge needs will structure ongoing work to make science accessible to practitioners, and help to guide future science policy and funding.

5. Understanding the economic benefits of crop pollination, basic pollinator ecology and impacts of pesticides on wild pollinators emerge strongly as priorities, as well as a need to monitor floral resources in the landscape.

Key words. Bees, ecosystem services, food security, hoverflies, pesticide, policy, pollination, pollinator.

Introduction

Insect pollinators are key components of biodiversity and provide the crucial ecosystem service of pollination to many crops and wild plants. There is evidence of recent declines in both wild and managed pollinators (e.g. Potts *et al*., 2010), and indications of parallel declines in wild plants dependent on pollination (Biesmeijer *et al*., 2006). Globally, an estimated 88% of wild plants (Ollerton *et al*., 2011) and 65% of crop production by volume (Klein *et al*., 2007) depend on insect pollination to some extent. While there is no evidence of global declines in insect-pollinated crop yields, reliance on insect pollination in food production is increasing (Aizen & Harder, 2009).

The implications of pollinator decline, particularly for food production, have led to substantial attention and resources being directed towards pollinator research, conservation and public understanding from the public, private and third sectors. For example, the International Pollinator Initiative of the UN Food and Agricultural Organization (Food & Agriculture Organization of the United Nations, 2012), the recently established IUCN Bumblebee Specialist Group, the UK's £9.6 million Insect Pollinators Initiative (IPI), several high profile campaigns (such as Friends of the Earth's Bee Cause, the Co-operative's Plan Bee, the Sainsbury's Bee Happy campaign, Neal's Yard's Bee Lovely campaign, Syngenta's Operation Pollinator and the Xerces Society's Pollinator Conservation work in the United States), and entire non-governmental organisations (NGOs such as the Bumblebee Conservation Trust and the Bee Guardian Foundation), are all focussed on conserving or mitigating threats to insect pollinators. In addition, broader activities relating to wildlife or ecosystem conservation, such as on farmland, are increasingly identifying pollinators as conservation targets. Sowing nectar flower mix for flower-visiting insects is an option under the Entry Level Stewardship agri-environment scheme in England, for example. Many organisations, including the Royal Society for the Protection of Birds, now provide advice on establishing and managing nectar flower mix (RSPB, 2012).

Most groups investing in pollinator conservation are keen to ensure their efforts are based on the best available evidence. Current scientific opinion is that pollinator decline is likely to be caused by multiple interacting pressures lowering pollinator health, abundance, and diversity, rather than any single threat (Potts *et al*., 2010). This makes the problem complex and difficult to tackle. As the science itself is developing rapidly, now is a good time to identify the most pressing knowledge needs, from both scientist and practitioner perspectives.

Two of the authors (LVD and WJS) have been involved in several previous exercises to identify questions of importance to policymakers and practitioners (Sutherland *et al*., 2011a). These have generated substantial interest and have been used to shape science policy. For example, in the UK Government's Marine Science Strategy (Defra, 2010), the research questions in each of the three sections were acknowledged as being based on the UK 100 questions exercise (Sutherland *et al*., 2006). The exercise to identify the top questions in agriculture (Pretty *et al*., 2010) was subsequently used as the basis for a workshop that informed the initial priorities of the UK's Global Food Security Research Programme.

A critical objective of these exercises is to ensure that policymakers and practitioners are an integral part of the process. We are seeking to identify their knowledge needs, so their perspectives and experience, which could be called 'experiential knowledge' (Nutley *et al*., 2007), are as important to the process as the theoretical and empirical knowledge that experts bring. Where the scientific evidence is complex and difficult to interpret, as is arguably the case for insect pollinator conservation, a process of open discussion between stakeholder groups and scientists is a particularly important element of the exercise.

Practitioner involvement can also bring benefits to researchers. For example, Phillipson *et al*. (2012) surveyed 21 research projects and showed that 'stakeholder engagement was perceived as bringing significant benefits to the process of knowledge production'.

Here we report on an exercise to identify the priority knowledge needs for wild insect pollinator conservation in the UK. Such knowledge needs can be used to structure ongoing work to make existing knowledge accessible to research users, and will help to guide future science policy and funding towards the areas where research is likely to have real impacts in practice.

In this article, we follow previous authors (Kuldna *et al*., 2009; Potts *et al*., 2010) in distinguishing wild from managed pollinators. We only consider wild pollinators native to the UK. Following the UK National Ecosystem Assessment (Smith *et al*., 2011), we count as wild pollinators all flower-visiting insect groups that have the potential to pollinate crops or wild flowers, including butterflies and moths. Managed pollinators in the UK are primarily the honeybee *Apis mellifera*, captive-reared bumblebees (always *Bombus terrestris* in the UK) and, to a much lesser extent, solitary bees (including species of *Osmia* and *Megachile*) sold as glasshouse or orchard pollinators. There is evidence that honeybee populations across Europe are mainly composed of managed hives (Jaffe *et al*., 2010) and in the UK the majority of these managed colonies consist of various hybrids with exotic subspecies (Carreck, 2008).

Wild insect pollinators currently provide pollination at no direct cost to farmers or land managers. Managed pollinators can be used to supplement this free ecosystem service and their management is directly controlled by farmers or beekeepers. Protecting managed pollinators poses different challenges from those linked to pollinator conservation in the wider environment, being largely concerned with husbandry and disease management in a small number of species or subspecies (see, e.g. Morse, 1998; Bosch & Kemp, 2002). We excluded managed pollinators from this exercise to allow a clear focus on management of natural ecosystems. We did not exclude knowledge needs that would relate to the conservation of wild-living native honeybees (*Apis mellifera mellifera*), or to interactions between wild and managed pollinators.

Much of the evidence for wild pollinator decline is inferred from changes in the recorded occurrence of species of bee, fly, beetle, or wasp (e.g. Biesmeijer *et al*., 2006; Cameron *et al*., 2011). These records are generally collected by volunteer participants without following a defined survey protocol. The primary aim of such recording is to produce distribution atlases (e.g. Collins & Roy, 2012), although methods to extract trends in geographic range and frequency from these data are developing (Biesmeijer *et al*., 2006; Morris, 2010; Hill, 2011).

The direct evidence we have of declines in wild pollinator abundance over time (as opposed to declines in diversity or range) comes largely from long-term data on butterflies (and, to a lesser extent, moths), collected through participatory monitoring schemes with defined survey protocols involving standardised observations repeated regularly over space and time (e.g. Warren *et al*., 2001; Conrad *et al*., 2006; Fox *et al*., 2011). There is now also some direct evidence for changes in the relative abundance of long-tongued bumblebee species in Europe (Bommarco *et al*., 2012).

Our process to identify knowledge needs was designed to be as open as possible, to accommodate the full range of possible objectives in wild pollinator conservation. These objectives include understanding and reversing reported declines in pollinator numbers, pollinator diversity, ranges of rare pollinating species, and pollination services to wild plants or crops, as well as raising awareness about wild pollinators.

Methods

All 48 participants in this exercise are authors. They comprise five people from governments and agencies, 14 from businesses involved in food production or retail, two from agrochemical companies, 11 involved directly in insect or plant conservation, and 16 research scientists. The scientists included representatives from the seven IPI research projects relevant to wild pollinator conservation. We use the term 'conservation practitioners' for all the non-academics, or end-users of research in the process. This encompasses people engaged in pollinator conservation at a wide range of levels, from corporate sustainability strategy to detailed collation of data collected by volunteers.

Our methods involved collaborative development of an initial long list, followed by three stages of voting or scoring. Online surveys were designed and conducted using the online survey tool Qualtrics (Qualtrics, 2012).

Table 1 shows how the initial long list of knowledge needs was structured and drawn up. An online survey of all authors was used to construct the status and response sections of the list, because we did not consider the existing sources for these sections (listed in the final row of Table 1) provided comprehensive coverage of possible knowledge needs in these areas. The survey presented participants with a small number (eight) of existing sources of data on wild insect pollinators, and a small number of possible science questions (five, drawn from the sources listed in the final row of Table 1). Participants were asked to suggest other data sources and associated knowledge needs or new questions.

In the first voting stage, all members of the group anonymously voted on the long list of knowledge needs, using another online survey. They were asked to select between 5 and 20 items from each part of the list (status, response, environmental change, and underlying science) that represented the most pressing knowledge needs for wild pollinator conservation. The status section of the list was accompanied by a brief explanation of the extent and characteristics of each existing data source, and live links to websites with more information where possible. Items in the response part of the list that were previously identified as research priorities for wild bee conservation (Sutherland *et al.*, 2011b) were identified with an asterisk. Those for which certainty of knowledge about beneficial effects was scored 50% or higher by an expert panel in the same exercise (Sutherland *et al.*, 2011b) based on evidence described in Dicks *et al.* (2010) were marked with a '#'. Items in the environmental change part of the list were marked with an asterisk if they related to one of three threats judged by a panel of experts to pose the greatest threats to unmanaged pollinators in Kuldna *et al.* (2009). These three threats were: loss of habitat and ecological resources (such as flowers); application of pesticides and introduction of GM crops. Participants were also given a chance to comment or suggest amendments to each item on the list.

The final prioritisation of knowledge needs took place at a one-day workshop held in Cambridge on the 29th May 2012. In the second stage, each item on the long list was discussed during a 90–120 min session dedicated to

Table 1. Structure of the initial long list of knowledge needs for wild pollinator conservation. Different parts of the list were constructed differently. Sources listed in the final row ('Entire list') provided material for all sections of the list.

Section	Sources used to generate list	Number of knowledge needs
Status: Actions to help understand the status of wild pollinators and pollination	Actions suggested by full group of authors using an online survey (see text for details)	74
Response: Actions that directly benefit wild pollinators	List of interventions for wild bee conservation (Dicks *et al.*, 2010) List of interventions to enhance regulating ecosystem services (which include pollination). This is currently under development Additional actions suggested elsewhere in the scientific literature (e.g. by Meeus *et al.*, 2011)	92
Environmental change: Questions or knowledge needs about the effects of environmental change or drivers of change (threats) on wild pollinators	List of threats identified by academics (Kuldna *et al.*, 2009)	53
Underlying science Questions about the science of pollinators and pollination	Questions suggested by full group of authors using an online survey (see text for details)	27
Entire list	Knowledge gaps for science and policy identified at an International Pollinators Workshop organised by the Science and Innovation network of the UK Foreign and Commonwealth Office in February 2012 Recommendations to Government listed in a Friends of the Earth report (Breeze *et al.*, 2012)	246

each section of the list (status, response, environmental change, and underlying science; see Table 1). The full group was split in half and two sessions ran in parallel, so each person was involved in discussing two sections of the list. Participants were assigned to discussion groups before the meeting. Initially, this was done systematically by alternate allocation down an alphabetical list. Then each person was assigned one or more of the following areas of interest: retail, conservation, food production, agrichemical production, knowledge exchange, scientist (pollinator health), scientist (pollination), scientist (pesticide impacts), scientist (pollinator ecology), and the groups were re-balanced without reference to individual names to give equal representation of each interest area in each group. For the second session, half of each group was moved to the other group, and the groups were re-balanced according to interest as before. This process was designed to create groups small enough to encourage discussion and allow consensus, but with the full range of interests and expertise represented in each group. Including as wide a range of interests as possible in the group has been demonstrated by social psychologists to be important for eliciting expert judgement effectively (Yaniv, 2011; Bolger & Wright, 2011; Hussler *et al*., 2011).

During the discussion sessions, all participants could see the anonymous comments others had made during the first voting stage, and the number of votes for each knowledge need. In general, knowledge needs with more votes were given more discussion time, but there was ample opportunity to speak up for needs that had no votes, or few votes. Some knowledge needs were re-worded or amalgamated with others at this stage, by consensus. Voting by show of hands during each session was used to produce a shorter list of knowledge needs under each section. We aimed to emerge from each of the status and response sessions with 16 knowledge needs, and from the environmental change and underlying science sessions with eight needs each.

In a final plenary session, the 48 knowledge needs drawn from all sections of the long list were each briefly discussed by the whole group (largely for the benefit of those who had not been in the relevant sessions). Then all participants privately scored each knowledge need between 0 and 10 using another online survey, with 10 being of highest importance. The workshop facilitators (WJS and LVD) did not vote or score the questions at any stage. The final list of priority knowledge needs comprised the top 20 knowledge needs according to the scoring by conservation practitioners, along with any ranked in the top 20 by scientists. We used a Friedman test to identify whether any of the knowledge needs were scored significantly differently from others. We used a Multiple Factor Analysis, using the R Package FactomineR (Husson *et al*., 2012), to look for differences in scoring patterns between scorers. We also used a Spearman rank correlation test to assess the correlation between conservation practitioner and scientist scores. All statistical analyses were carried out using R (R Development Core Team, 2010).

Results

Our initial list comprised 246 potential knowledge needs (Table 1). All 32 conservation practitioners were engaged in at least one stage of the process. The one-day workshop was attended by 16 scientists and 26 conservation practitioners. Ten practitioners were unable to attend either the workshop itself, or the final voting session.

Table 2 shows the 35 top ranked knowledge needs, presented in order of selection by the 22 conservation practitioners who submitted final scores. The median scores of conservation practitioners and scientists are given separately in Table 2.

The knowledge needs in Table 2 are assigned to sections of the initial long list. In most cases, these are the sections in which the knowledge need originated. In three cases, discussions and re-phrasing during the meeting led to the knowledge need becoming more relevant to a different section of the list. Knowledge need nine in Table 2 began in the status section, as an action to monitor floral resources at a landscape scale. Its emphasis changed to a focus on how floral resources are changing, and so it has become more relevant to environmental change. Knowledge need 11 in Table 2 began in the environmental change section, where it was considered to be about the effects of loss of habitat. It is now focussed on measures to create habitat and belongs in the response section. Knowledge need 21 in Table 1 also began in the environmental change section of the list as the question: How does loss and fragmentation of habitats affect wild pollinators? It became a question of underlying science about the effects of habitat structure and spatial arrangement on pollinators. Here, participants felt we could not understand the effects of change without first understanding the basic ecology.

Of the 35 priority knowledge needs, seven are about the status of pollinators, 13 about responses, six about environmental change and nine about underlying science.

A Friedman test found that there were significant differences between the scores of the different knowledge needs (Friedman test statistic M = 211.82, $P = 2.2 \times 10^{-16}$). We do not present the results of post-hoc tests to identify where these significant differences lie, because the high number of pairwise tests required with 48 knowledge needs makes it difficult to assign significance to any differences.

The results of our Multiple Factor Analysis of scorers are shown in Fig. 1. Scorers are plotted according to the first two dimensions generated by the analysis (top panel). It is clear that conservation practitioners (closed circles) and scientists (open circles) do not separate in the multivariate space. The groups of knowledge needs (bottom panel, corresponding to the four sections of the list in Table 1) are relatively equal in their importance to the classification. Environment and response knowledge needs are most important in the first dimension, while status and underlying science are most important in the second dimension. This analysis shows there were not strong differences between scientists and conservation practitioners

Table 2. The thirty-five highest scoring knowledge needs, according to median score (1 = low priority, 10 = high priority) from conservation practitioners (*n* = 22). The median scores according to scientists (*n* = 16) are also given and the overall median from scores across both groups. This list includes the knowledge needs ranked in the top 20 by both conservation practitioners and scientists. As a result of frequent ties, ranking by median produced 28 top knowledge needs for conservation practitioners and 29 for scientists, with a median of 7.0 the lower limit for both groups. When practitioner medians were equal, knowledge needs are ordered according to overall rank.

	Knowledge need	List section	Median conservation practitioner score	Median scientist score	Overall median (interquar-tile range)
1	How important is the diversity of pollinator species to the resilience and reliability of the pollination service?	U	8.0	9.5	9.0 (2.75)
2	What are the relative contributions of wild and managed pollinators to crop yield (for a few crop models)?	U	8.0	9.0	8.0 (2.75)
3	What are the costs and benefits of maintaining and restoring the pollination service in farmland and how are they linked to farmers' evaluation of pollinators?	U	8.0	8.0	8.0 (2.0)
4	What are the sub-lethal effects of chemicals (pesticides and other environmental pollutants) on wild pollinators?	E	8.0	8.0	8.0 (3.0)
5	How much does insect pollination contribute to economic output (yield and quality) for a few crop models such as a fruit tree, a vegetable and an oil seed? What are the uncertainties?	U	8.0	7.5	8.0 (2.75)
6	Training for conservationists, agronomists and land managers on pollinator ecology and conservation	R	8.0	7.0	8.0 (4.0)
7	How can current and potential future agri-environment options for pollinators be bundled together and spatially targeted to maximise benefits?	R	8.0	6.0	8.0 (4.0)
8	How can we actively encourage the uptake of agri-environment options that benefit pollinators (such as nectar and pollen mix)?	R	8.0	7.0	7.0 (5.0)
9	What floral resources are currently available to pollinators at a landscape scale, and are these resources changing?	E	7.5	8.0	8.0 (3.0)
10	What are the implications of various sustainable agricultural intensification methods for pollinators?	E	7.5	8.0	8.0 (4.0)
11	What habitat creation measures can most help restore pollinator populations in rural and urban scenarios (taking their full life cycle into account)?	R	7.5	7.5	7.5 (3.75)
12	What naturally limits pollinator populations and at what stage in their life cycles is the greatest mortality?	U	7.0	9.0	8.0 (3.75)
13	Do interventions to mitigate threats increase pollinator populations or just change pollinator behaviour/local distribution?	R	7.0	8.5	8.0 (3.0)
14	How do different threats interact to affect wild pollinators?	E	7.0	8.5	8.0 (2.75)
15	Evidence to inform amendment of pesticide accreditation to include risk assessment for wild and managed pollinators in laboratory and field conditions	R	7.0	8.0	8.0 (4.75)
16	How far do different pollinator species move, especially in patchy or fragmented habitats, including for dispersal, foraging, mating?	U	7.0	8.5	7.0 (3.0)
17	How will pollinator populations and the services they provide respond to climate change (is evidence from butterflies representative of other groups)?	E	7.0	8.0	7.0 (3.75)
18	Data on flower resources in the landscape collected alongside pollinator monitoring (including timing of flower bloom)	S	7.0	7.5	7.0 (2.0)
19	Extension of the Wider Countryside Butterfly Survey's coverage of hoverflies and bumblebees	S	7.0	7.0	7.0 (3.0)
20	How resilient are pollinator communities to environmental change and how does this affect pollination?	E	7.0	7.0	7.0 (3.5)
21	What is the relationship between habitat (patch size, quality, type, connectivity) and pollinators?	U	7.0	7.0	7.0 (2.75)

Table 2. Continued

	Knowledge need	List section	Median conservation practitioner score	Median scientist score	Overall median (interquar-tile range)
22	Long-term objectives for agri-environment schemes that enhance their scale and effectiveness for pollinators	R	7.0	7.0	7.0 (3.75)
23	How can we optimise pesticide use to minimise damage and maximise foraging resources for pollinators?	R	7.0	7.0	7.0 (4.0)
24	Evidence to inform the uptake of alternative pest management methods on farms, such as the use of natural enemies	R	7.0	6.5	7.0 (3.75)
25	Improved access to data on aspects of land use (crop rotation, field size) alongside pollinator monitoring	S	7.0	6.0	7.0 (3.0)
26	Evidence to inform increased protection of existing natural or semi-natural habitats of importance to pollinators (such as species-rich grassland)	R	7.0	5.5	6.5 (3.75)
27	Improved access to existing information on pollinator habitat or forage resources nationally	S	7.0	5.0	6.5 (3.75)
28	Evidence to inform revision of the Bees Act 1980 and its associated orders, to include provisions for maintaining the health of all bees in addition to honeybees	R	7.0	3.0	5.0 (6.75)
29	Which insects pollinate which wild plants and how much do wild flower species (or some key species) in the UK rely on insect pollination?	U	6.5	9.0	7.5 (4.0)
30	Standardised, cost-effective methods for monitoring pollinators to be used by all (on farms or in any landscape)	S	6.0	8.0	7.5 (3.0)
31	An integrated system for identifying pollinator species, including keys (online and books) & automated methods (DNA, barcoding, wing venation recognition)	S	6.0	8.0	7.0 (4.0)
32	New agri-environment options that provide nesting resources for bees	R	6.0	7.5	7.0 (3.75)
33	Assessment of the positive and negative effects of restoring pollinator habitat on road verges	R	6.0	7.0	7.0 (2.75)
34	A UK-wide commercially viable monitoring scheme for crop pollination deficit	S	6.0	7.0	6.5 (3.0)
35	What factors increase or reduce pollinator movements through landscapes?	U	6.0	7.0	6.5 (3.0)

The sections of the list to which each knowledge need belongs are described in Table 1: S, status; R, response; E, environmental change; U, underlying science.

in the way they scored. If scientists had favoured questions of underlying science, and conservation practitioners had favoured responses in their scoring of knowledge needs, such a pattern would be visible in Fig. 1.

Figure 2 shows how the conservation practitioner and scientist median scores for all 48 scored knowledge needs were positively correlated (Spearman rank correlation test: $r_s = 0.53$, $P = 0.00011$). There are two outliers in Fig. 2, scored unusually low by scientists compared with conservation practitioners. The first is 'An exploration of the possibility of including flower usage in existing monitoring schemes, such as the Bees, Wasps, and Ants Recording Scheme and UK Butterfly Monitoring Scheme' (median practitioner score = 6.0, median scientist score = 2.5). This did not make it to the top 35 because it had a median score under 7.0 in both groups. The second is: 'Evidence to inform revision of the Bees Act 1980 and its associated orders, to include provisions for maintaining the health of all bees in addition to honeybees' (median practitioner score = 7.0, median scientist score = 3.0; knowledge need 28 in Table 1). This is a strongly policy-linked knowledge need.

Discussion

Whilst there were some differences in scoring between scientists and conservation practitioners, the general pattern was of consistent scoring across the two groups. This is true both for individual knowledge need scores and for scoring patterns across different sections of the list. Conservation practitioners and scientists generally agree on what is needed, despite coming from a wide variety of backgrounds.

A number of pure ecological questions emerge as important knowledge needs. For example, a longstanding

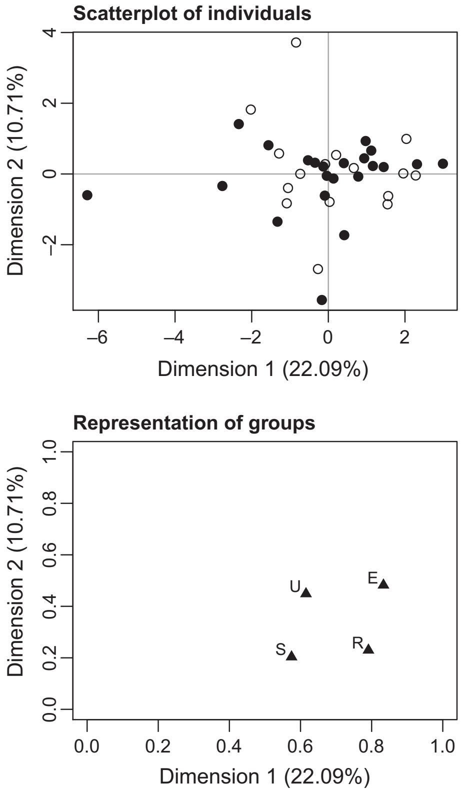

Fig. 1. Results of Multiple Factor Analysis. Upper panel: Individual scorers plotted in multivariate space according to the first two dimensions. The percentage of variance explained by each dimension is given in brackets. Closed circles (●) = conservation practitioners, open circles (○) = scientists. Lower panel: Groups of knowledge needs corresponding to relevant sections of the list (described in Table 1), each represented as a single point: S = status, R = response, E = environmental change, U = underlying science.

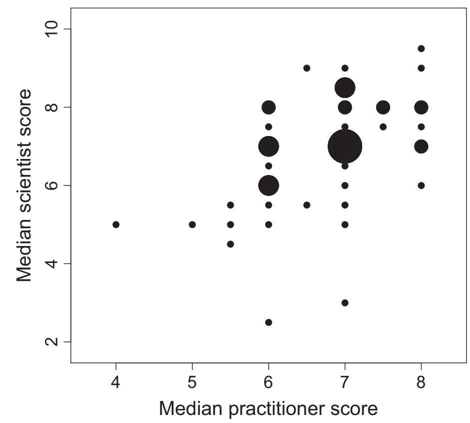

Fig. 2. Median scores for each of the 48 knowledge needs given by conservation practitioners (n = 22) and scientists (n = 16); 1 = low priority, 10 = high priority. Spearman rank correlation coefficient $r_s = 0.53$, $P = 0.00011$. Points are sized according to the number of knowledge needs with each combination of scores. The largest circle represents five knowledge needs where both groups scored a median of 7.0.

ecological question about the interaction between ecosystem function (the pollination service) and diversity (Hooper *et al.*, 2005; Mace *et al.*, 2012) achieved the highest overall rank. Knowledge needs 12, 16, 21, 29, and 35 in Table 2 are also questions of pure, rather than applied, pollinator ecology.

The economic benefits of wild pollinators for crop production are clearly seen by all as a very high priority, with three related questions in the top 10 (numbers 2, 3 and 5 in Table 2). In fact, four of the top five knowledge needs in Table 2 relate to the ecosystem service provided by pollinators (including number 1). This surely reflects the rapid shift of focus over the last five years in the policy and practice of wildlife conservation, towards understanding and maintaining ecosystem services (Eigenbrod *et al.*, 2009; European Commission, 2011; UK National Ecosystem Assessment, 2011). To some extent, the scientific knowledge base is still catching up with this change, which may be why these knowledge needs are the most urgent.

Our process was strongly framed as having the objective of wild pollinator conservation from the outset. Of the 32 practitioners involved, four came from national level Government nature conservation or environment agencies or departments, and nine came from non-government organisations with a focus on nature conservation (all the NGOs in the process apart from the Bees, Wasps and Ants Recording Society and the National Farmer's Union). Given this, the prominence of pollination, particularly crop pollination, is probably not because there was an over-representation of commercial food production interests. The top knowledge need – the importance of diversity for pollination – perhaps reflects a desire within the group to reconcile new ecosystem service objectives with more traditional objectives to conserve the diversity of species and habitats.

The results demonstrate that conservation practitioners in the group are focussed on existing agri-environment schemes as a mechanism for wild pollinator conservation (as described by Pywell *et al.*, 2011). Three knowledge needs that would help improve their effectiveness or uptake appear in the list (numbers 7, 8, and 22 in Table 2). Two of these were scored lower by scientists in the group. By contrast, scoring by scientists indicates a need for new agri-environment options that consider nesting resources for bees (number 32 in Table 2).

Pesticides are a high profile issue. Four priority knowledge needs relate to the impact of pesticides on wild pollinators. The highest priority amongst them (number 4) is to understand the sub-lethal effects of pesticides and other chemicals on wild pollinators. This is perhaps not surprising, given recent discoveries about sub-lethal effects of neonicotinoids on bumblebees (e.g. Whitehorn *et al.*, 2012). One knowledge need is strongly related to pesticide regulation (number 15) and two (23 and 24) are about minimising risks to wild pollinators from pesticides by changing land management practices.

Thirty-two of the 74 options in the status section of the initial long list were different ways to improve our knowledge about the status of wild insect pollinators through enhanced or new monitoring of the insects themselves, a need already identified by scientists (Potts *et al.*, 2011; LeBuhn *et al.*, 2013). These included directly funding, expanding, or enhancing a range of existing volunteer recording schemes for bumblebees, butterflies, moths and hoverflies, setting up a new comprehensive pollinator monitoring network (similar to that recommended by LeBuhn *et al.*, 2013), and engaging the public in a citizen science monitoring scheme, such as the Great Sunflower Project (USA) or Spipoll (France). Of these options, only one came through the process as a clear priority to both conservation practitioners and scientists. This is to extend the use of the Wider Countryside Butterfly Survey to monitor hoverflies and bumblebees, using methods that have already been tested for 12 easily identifiable wild pollinator species (Brereton *et al.*, 2011; number 19 in Table 2). This seems a very rational choice. It makes use of an existing scheme that generates good quality abundance data based on systematic site selection, rather than user-selected sites that may generate biased results. Three other options related to monitoring of pollinators (numbers 30 and 31 in Table 2) or pollination (number 34) were ranked in the top 20 by scientists but not scored so highly by conservation practitioners. One is to develop standard cost-effective monitoring methods to be used by everyone, including farmers (number 30). A possible approach to this has recently been piloted by the Centre for Ecology and Hydrology, Syngenta and Linking Environment and Farming (LEAF) as part of LEAF's Open Farm Sunday event (Biological Records Centre, 2012).

Three of the priority knowledge needs relate to the availability of floral resources for pollinators in the landscape. A variety of evidence suggests that floral resource availability is the primary direct factor influencing wild bee abundance (Roulston & Goodell, 2011). Forage plants important for bumblebees are known to have declined nationally since the 1930s in the UK (Carvell *et al.*, 2006), but there is a perceived need for regular monitoring and greater awareness of the status of these resources. The aspects highlighted are: access to existing information, including data captured by the Countryside Survey (Carey *et al.*, 2008), for example (number 27, ranked in the top 20 by conservation practitioners, but not scientists); assessment of current status and change in floral resource availability (number 9) and ongoing monitoring of flowers in the landscape linked directly to insect monitoring (number 18).

If conservation of managed pollinators had been included in the process, many of the same issues would probably have been prominent. For example, honeybees have also been shown to suffer adverse sub-lethal effects from pesticide exposure (Henry *et al.*, 2012) and may be threatened by reduced density of flowers in the landscape (Kuldna *et al.*, 2009). There might, however, have been some differences in the priority list. We would probably have seen a greater prevalence of pollinator health and disease management issues, both in the initial long list and the identified priorities, had conservation of managed pollinators been considered. There were several knowledge needs in the initial long list about wild pollinator health, such as 'What parasites and pathogens do normal healthy pollinator populations carry?' and 'What are the emergent problems for pollinator health?' None made it through to the top 35 priorities, despite several parasites being perceived by scientists as potential or emerging threats to wild pollinators (Evison *et al.*, 2012). We might also have identified a need to understand the extent of convergence or trade-off between conservation actions to benefit wild pollinators and those focussed on managed pollinators.

Next steps

In the next stage of this process, the same group of scientists and conservation practitioners will further analyse the priority knowledge needs we have identified. The list includes a range of different types of question and levels of information. Some are scientific questions that require large research programmes. These may need to be unpacked into smaller more manageable scientific questions. Aspects of many of the knowledge needs have already been tackled, or are in the process of being answered by existing projects in the UK (such as the projects within the IPI) or internationally. Here, the need is to review and synthesise existing and emerging knowledge, and make it accessible to an array of users. Other priority knowledge needs require new standardised data collection, or stakeholder-driven policy development.

We will continue to work collaboratively, with iterated discussions, to specify in detail what is already known in each area, where the relevant knowledge lies and what steps can be taken within or outside the group to meet the knowledge need cost-effectively. Our aim will be to ensure that knowledge and data from all sectors are taken into account. For example, to define which parameters are important to the economic output from insect-pollinated crops (knowledge need number 5), we may need to draw on the combined knowledge of retailers, suppliers, growers and scientists. Similarly, nature conservation agencies and NGOs amongst us are testing ways to encourage uptake of particular agri-environment options (see, e.g. Natural England, 2011). This experience, combined with emerging scientific understanding about the effectiveness of options such as sown nectar and pollen mix, will be important in defining the next steps towards meeting knowledge need number eight.

Clearly, the priorities that emerge from a process like this depend to an extent on the participants involved. As in previous similar exercises, we made every effort to be as inclusive as possible, and to involve representatives from all sectors, so we suggest that these results reflect a broad range of interests relevant to the implementation of wild insect pollinator conservation.

Acknowledgements

This work was funded by the Natural Environment Research Council as part of a Knowledge Exchange Fellowship. It was a knowledge exchange activity linked to the Insect Pollinators Initiative, a joint initiative from the Biotechnology and Biological Sciences Research Council, the Department for Environment, Food and Rural Affairs, the Natural Environment Research Council, the Scottish Government and the Wellcome Trust, under the auspices of the Living with Environmental Change programme. WJS is funded by Arcadia. We thank Stephanie Prior and Rebecca Smith for helping organise the meeting, Jessica Walsh and James Hutchison for collating results during and after the workshop, and David Roy for helpful comments on the manuscript. We also thank three anonymous reviewers for helping to improve the text.

Conflicts of interest

The following authors represented the interests of their organisations in this process. We do not interpret this as a conflict of interest because the process was designed to take account of a wide range of interests, including those of commercial and campaigning organisations. John Atkinson (Co-operative), Nigel Bourn (Butterfly Conservation), Chris Brown (Asda), Ben Darvill (Bumblebee Conservation Trust), Paul de Zylva (Friends of the Earth), Philip Effingham (Greentech Consultancy), Anthony Goggin (Linking Environment And Farming), Tony Harding (Worldwide Fruit), Chris Hartfield (National Farmers Union), Richard Heathcote (Heineken UK Ltd), David Heaver (Natural England), John Holland (Game and Wildlife Conservation Trust), Mike Howe (Countryside Council for Wales), Brin Hughes (Conservation Grade), Theresa Huxley (Sainsbury's Supermarkets Ltd), Julian Little (Bayer CropScience Ltd), Caroline Mason (Waitrose John Lewis plc), Tim Pankhurst (Plantlife), Elizabeth Ranelagh (Campaign for the Farmed Environment), Stuart Roberts (Bees Wasps and Ants Recording Society), Rob Saunders (Glaxo Smithkline), Katie Smith (The Co-operative Farms), Richard M. Smith (Buglife), Peter Sutton (Syngenta), Athayde Tonhasca (Scottish Natural Heritage), Sarah Webster (Defra), Alan Wilson (Waitrose John Lewis plc).

References

Aizen, M.A. & Harder, L.D. (2009) The global stock of domesticated honey bees is growing slower than agricultural demand for pollination. *Current Biology*, **19**, 915–918.

Biesmeijer, J.C., Roberts, S.P.M., Reemer, M., Ohlemuller, R., Edwards, M., Peeters, T., Schaffers, A.P., Potts, S.G., Kleukers, R., Thomas, C.D., Settele, J. & Kunin, W.E. (2006) Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science*, **313**, 351–354.

Biological Records Centre (2012) *Open Farm Sunday Pollinator Survey*. <http://www.brc.ac.uk/farmsunday/> 5th July 2012.

Bolger, F. & Wright, G. (2011) Improving the Delphi process: lessons from social psychological research. *Technological Forecasting and Social Change*, **78**, 1500–1513.

Bommarco, R., Lundin, O., Smith, H.G. & Rundlöf, M. (2012) Drastic historic shifts in bumble-bee community composition in Sweden. *Proceedings of the Royal Society B*, **279**, 309–315.

Bosch, J. & Kemp, W.P. (2002) Developing and establishing bee species as crop pollinators: the example of *Osmia* spp. (Hymenoptera: Megachilidae) and fruit trees. *Bulletin of Entomological Research*, **92**, 3–16.

Breeze, T.D., Roberts, S.P.M. & Potts, S.G. (2012) *The Decline of England's Bees: Policy Review and Recommendations*. Friends of the Earth, London, UK.

Brereton, T.M., Cruickshanks, K.L., Risely, K., Noble, D.G. & Roy, D.B. (2011) Developing and launching a wider countryside butterfly survey across the United Kingdom. *Journal of Insect Conservation*, **15**, 279–290.

Cameron, S.A., Lozier, J.D., Strange, J.P., Koch, J.B., Cordes, N., Solter, L.F. & Griswold, T.L. (2011) Patterns of widespread decline in North American bumble bees. *Proceedings of the National Academy of Sciences of the United States of America*, **108**, 662–667.

Carey, P.D., Wallis, S., Chamberlain, P.M., Cooper, A., Emmett, B.A., Maskell, L.C., McCann, T., Murphy, J., Norton, L.R., Reynolds, B., Scott, W.A., Simpson, I.C., Smart, S.M. & Ullyett, J.M. (2008) *Countryside Survey: UK Results from 2007*. Centre for Ecology and Hydrology. <http://www.countryside-survey.org.uk/> 26th August 2012.

Carreck, N.L. (2008) Are honey bees (*Apis mellifera* L.) native to the British Isles? *Journal of Apicultural Research*, **47**, 318–322.

Carvell, C., Roy, D.B., Smart, S.M., Pywell, R.F., Preston, C.D. & Goulson, D. (2006) Declines in forage availability for bumblebees at a national scale. *Biological Conservation*, **132**, 481–489.

Collins, G.A. & Roy, H.E. (2012) *Provisional Atlas of the Aculeate Hymenoptera of Britain and Ireland Part 8*. Centre for Ecology and Hydrology, Wallingford, UK.

Conrad, K.F., Warren, M.S., Fox, R., Parsons, M.S. & Woiwod, I.P. (2006) Rapid declines of common, widespread British moths provide evidence of an insect biodiversity crisis. *Biological Conservation*, **132**, 279–291.

Defra (2010) *UK Marine Science Strategy*. Department for Environment, Food and Rural Affairs, on behalf of the Marine Science Co-ordination Committee. <http://archive.defra.gov.uk/environment/marine/documents/science/mscc/mscc-strategy.pdf> 26th August 2012.

Dicks, L.V., Showler, D.A. & Sutherland, W.J. (2010) *Bee Conservation: Evidence for the Effects of Interventions*, 1st edn. Pelagic Publishing, Exeter, UK.

Eigenbrod, F., Anderson, B.J., Armsworth, P.R., Heinemeyer, A., Jackson, S.F., Parnell, M., Thomas, C.D. & Gaston, K.J. (2009) Ecosystem service benefits of contrasting conservation strategies in a human-dominated region. *Proceedings of the Royal Society B-Biological Sciences*, **276**, 2903–2911.

European Commission (2011) *Our Life Insurance, Our Natural Capital: An EU Biodiversity Strategy to 2020*. COM 244 final, European Commission. <http://ec.europa.eu/environment/nature/info/pubs/docs/brochures/2020%20Biod%20brochure%20final%20lowres.pdf> 26th August 2012.

Evison, S.E.F., Roberts, K.E., Laurenson, L., Pietravalle, S., Hui, J., Biesmeijer, J.C., Smith, J.E., Budge, G. & Hughes, W.O.H. (2012) Pervasiveness of parasites in pollinators. *PLoS ONE*, **7**, e30641.

Food and Agriculture Organization of the United Nations (2012) *International Pollinators Initiative*. <http://www.internationalpollinatorsinitiative.org/jsp/intpollinitiative.jsp> 20th June 2012.

Fox, R., Brereton, T., Asher, J., Botham, M.S., Middlebrook, I., Roy, D.B. & Warren, M.S. (2011) *The State of the UK's Butterflies 2011*. W. Butterfly Conservation and the Centre for Ecology and Hydrology, Wallingford, UK.

Henry, M., Beguin, M., Requier, F., Rollin, O., Odoux, J.F., Aupinel, P., Aptel, J., Tchamitchian, S. & Decourtye, A. (2012) A common pesticide decreases foraging success and survival in honey bees. *Science*, **336**, 348–350.

Hill, M.O. (2011) Local frequency as a key to interpreting species occurrence data when recording effort is not known. *Methods in Ecology and Evolution*, **3**, 195–205.

Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., Setala, H., Symstad, A.J., Vandermeer, J. & Wardle, D.A. (2005) Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs*, **75**, 3–35.

Hussler, C., Muller, P. & Rondé, P. (2011) Is diversity in Delphi panelist groups useful? Evidence from a French forecasting exercise on the future of nuclear energy. *Technological Forecasting and Social Change*, **78**, 1642–1653.

Husson, F., Josse, J., Le, S. & Mazet, J. (2012) *FactoMineR: Multivariate Exploratory Data Analysis and Data Mining with R*. <http://cran.r-project.org/web/packages/FactoMineR/index.html> 6th July 2012.

Jaffe, R., Dietemann, V., Allsopp, M.H., Costa, C., Crewe, R.M., Dall'olio, R., de la Rua, P., El-Niweiri, M.A.A., Fries, I., Kezic, N., Meusel, M.S., Paxton, R.J., Shaibi, T., Stolle, E. & Moritz, R.F.A. (2010) Estimating the density of honeybee colonies across their natural range to fill the gap in pollinator decline censuses. *Conservation Biology*, **24**, 583–593.

Klein, A.M., Vaissiere, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C. & Tscharntke, T. (2007) Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B-Biological Sciences*, **274**, 303–313.

Kuldna, P., Peterson, K., Poltimae, H. & Luig, J. (2009) An application of DPSIR framework to identify issues of pollinator loss. *Ecological Economics*, **69**, 32–42.

LeBuhn, G., Droege, S., Connor, E.F., Gemmill-Herren, B., Potts, S.G., Minckley, R.L., Griswold, T., Jean, R., Kula, E., Roubik, D.W., Cane, J., Wright, K.W., Frankie, G. & Parker, F. (2013) Detecting insect pollinator declines on regional and global scales, **27**, 113–120.

Mace, G.M., Norris, K. & Fitter, A.H. (2012) Biodiversity and ecosystem services: a multilayered relationship. *Trends in Ecology & Evolution*, **27**, 19–26.

Meeus, I., Brown, M.J.F., De Graaf, D.C. & Smagghe, G. (2011) Effects of invasive parasites on bumble bee declines. *Conservation Biology*, **25**, 662–671.

Morris, R. (2010) Web-based natural history recording. *British Wildlife*, **21**, 313–317.

Morse, R.A. (1998) *The Beekeeper's Handbook*. Cornell University Press, New York.

Natural England (2011) *Farming for Farm Wildlife*. Natural England. <http://publications.naturalengland.org.uk/publication/35037?category=49001> 26th August 2012.

Nutley, S.M., Walter, I. & Davies, H.T.O. (2007) *Using Evidence: How Research can Inform Public Services*. The Policy Press, Bristol, UK.

Ollerton, J., Winfree, R. & Tarrant, S. (2011) How many flowering plants are pollinated by animals? *Oikos*, **120**, 321–326.

Phillipson, J., Lowe, P., Proctor, A. & Ruto, E. (2012) Stakeholder engagement and knowledge exchange in environmental research. *Journal of Environmental Management*, **95**, 56–65.

Potts, S.G., Biesmeijer, J.C., Bommarco, R., Felicioli, A., Fischer, M., Jokinen, P., Kleijn, D., Klein, A.M., Kunin, W.E., Neumann, P., Penev, L.D., Petanidou, T., Rasmont, P., Roberts, S.P.M., Smith, H.G., Sorensen, P.B., Steffan-Dewenter, I., Vaissiere, B.E., Vila, M., Vujic, A., Woyciechowski, M., Zobel, M., Settele, J. & Schweiger, O. (2011) Developing European conservation and mitigation tools for pollination services: approaches of the STEP (Status and Trends of European Pollinators) project. *Journal of Apicultural Research*, **50**, 152–164.

Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O. & Kunin, W.E. (2010) Global pollinator declines: trends, impacts and drivers. *Trends in Ecology & Evolution*, **25**, 345–353.

Pretty, J., Sutherland, W.J., Ashby, J., Auburn, J., Baulcombe, D., Bell, M., Bentley, J., Bickersteth, S., Brown, K., Burke, J., Campbell, H., Chen, K., Crowley, E., Crute, I., Dobbelaere, D., Edwards-Jones, G., Funes-Monzote, F., Godfray, H.C.J., Griffon, M., Gypmantisiri, P., Haddad, L., Halavatau, S., Herren, H., Holderness, M., Izac, A.-M., Jones, M., Koohafkan, P., Lal, R., Lang, T., McNeely, J., Mueller, A., Nisbett, N., Noble, A., Pingali, P., Pinto, Y., Rabbinge, R., Ravindranath, N.H., Rola, A., Roling, N., Sage, C., Settle, W., Sha, J.M., Shiming, L., Simons, T., Smith, P., Strzepeck, K., Swaine, H., Terry, E., Tomich, T.P., Toulmin, C., Trigo, E., Twomlow, S., Vis, J.K., Wilson, J. & Pilgrim, S. (2010) The top 100 questions of importance to the future of global agriculture. *International Journal of Agricultural Sustainability*, **8**, 219–236.

Pywell, R.F., Meek, W.R., Hulmes, L., Hulmes, S., James, K.L., Nowakowski, M. & Carvell, C. (2011) Management to enhance pollen and nectar resources for bumblebees and butterflies within intensively farmed landscapes. *Journal of Insect Conservation*, **15**, 853–864.

Qualtrics (2012) Qualtrics Research Suite. <http://www.Qualtrics.com> 4th July 2012.

R Development Core Team (2010) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Roulston, T.H. & Goodell, K. (2011) The role of resources and risks in regulating wild bee populations. *Annual Review of Entomology*, **56**, 293–312.

RSPB (2012) *Advice for Farmers: Nectar Flower Mixtures*. <http://www.rspb.org.uk/ourwork/farming/advice/economics/nectar.aspx> 5th July 2012.

Smith, P., Ashmore, M., Black, H., Burgess, P., Evans, C., Hails, R., Simon, G.P., Quine, T., Thomson, A., Biesmeijer, K., Breeze, T., Broadmeadow, M., Ferrier, R., Freer, J., Hansom, J., Haygarth, P., Hesketh, H., Hicks, K., Johnson, A., Kay, D., Kunin, W., Lilly, A., May, L., Memmott, J., Orr, H., Pickup, R., Purse, B. & Squire, G. (2011) Chapter 14: regulating services. *The UK National Ecosystem Assessment Technical*

Report. UK National Ecosystem Assessment, UNEP-WCMC, Cambridge, UK. <http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=m%2bvhAV3c9uk%3d&tabid=82>

Sutherland, W.J., Armstrong-Brown, S., Armsworth, P.R., Brereton, T., Brickland, J., Campbell, C.D., Chamberlain, D.E., Cooke, A.I., Dulvy, N.K., Dusic, N.R., Fitton, M., Freckleton, R.P., Godfray, H.C.J., Grout, N., Harvey, H.J., Hedley, C., Hopkins, J.J., Kift, N.B., Kirby, J., Kunin, W.E., Macdonald, D.W., Marker, B., Naura, M., Neale, A.R., Oliver, T., Osborn, D., Pullin, A.S., Shardlow, M.E.A., Showler, D.A., Smith, P.L., Smithers, R.J., Solandt, J.L., Spencer, J., Spray, C.J., Thomas, C.D., Thompson, J., Webb, S.E., Yalden, D.W. & Watkinson, A.R. (2006) The identification of 100 ecological questions of high policy relevance in the UK. *Journal of Applied Ecology*, **43**, 617–627.

Sutherland, W.J., Fleishman, E., Mascia, M.B., Pretty, J. & Rudd, M.A. (2011a) Methods for collaboratively identifying research priorities and emerging issues in science and policy. *Methods in Ecology and Evolution*, **2**, 238–247.

Sutherland, W.J., Goulson, D., Potts, S.G. & Dicks, L.V. (2011b) Quantifying the impact and relevance of scientific research. *PLoS ONE*, **6**, e27537.

UK National Ecosystem Assessment (2011) *The UK National Ecosystem Assessment Technical Report*. UNEP-WCMC, Cambridge, UK.

Warren, M.S., Hill, J.K., Thomas, J.A., Asher, J., Fox, R., Huntley, B., Roy, D.B., Telfer, M.G., Jeffcoate, S., Harding, P., Jeffcoate, G., Willis, S.G., Greatorex-Davies, J.N., Moss, D. & Thomas, C.D. (2001) Rapid responses of British butterflies to opposing forces of climate and habitat change. *Nature*, **414**, 65–69.

Whitehorn, P.R., O'Connor, S., Wackers, F.L. & Goulson, D. (2012) Neonicotinoid pesticide reduces bumble bee colony growth and queen production. *Science*, **336**, 351–352.

Yaniv, I. (2011) Group diversity and decision quality: amplification and attenuation of the framing effect. *International Journal of Forecasting*, **27**, 41–49.

Accepted 26 July 2012
First published online 12 October 2012

Editor/associate editor: Simon R. Leather