Insect pollinators: linking research and policy

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Workshop Report

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EXECUTIVE SUMMARY

- Pollinators interact with plants to underpin wider biodiversity, ecosystem function, ecosystem services to agricultural crops and ultimately human nutrition. The conservation of pollinators is thus an important goal.

- Pollinators and pollination represent a tractable example of how biodiversity can be linked to an ecosystem service. This represents a case study for exploring the impacts of various policy instruments aiming to halt/reverse the loss of ecosystem services.

- There is a need to understand how multiple pressures (e.g. habitat loss, fragmentation and degradation, climate change, pests and diseases, invasive species and environmental chemicals) can combine or interact to affect diversity, abundance and health of different pollinator groups.

- Decision makers need to balance consideration of the effects of single pressures on pollinators against the suite of other pressures on pollinators. For instance, the threat from pesticide use (with its high public and media profile) also needs to be considered in the context of the other threats facing pollinators and balanced against the need for food security. An independent review of the balance of risks across pollinator groups from pesticide use would help synthesise current knowledge into an accessible form for decision makers.

- To manage or lessen these threats to pollinators (wild and managed) and pollination requires improved knowledge about their basic ecology. We still need to know where and in what numbers different pollinator species occur, how they use different environments, how they interact with each other through shared plants and diseases and how wild pollinator abundance is changing.

- Decision makers need clear factual evidence for i) the relative contribution of different managed and wild pollinator groups to wildflower and crop pollination and ii) how this varies across different land-uses, ecosystems and regions.

- Addressing these basic and applied questions will improve our ability to forecast impacts on pollination service delivery to agricultural crops arising from current and future environmental changes, pesticide use and emerging diseases.

- The development of a long-term, multi-scale monitoring scheme to monitor trends in pollinator (wild and managed) population size and delivery of pollination services (ideally tied to data collection on land-use, pesticide applications and disease incidence at relevant spatial scales) would provide the evidence base for developing the effectiveness of policy and management interventions over time.

- Such a monitoring scheme would benefit from including research council organisations (e.g. CEH), governmental departments (e.g. Fera), universities, museums and NGOs (e.g. BBKA,SBA, Bumblebee Conservation Trust etc)

- In the context of agricultural intensification and conservation we need to establish what type, quality and quantity of interventions (e.g. agri-environment schemes, protected areas) are needed, where to place them and how they can sustain different pollinator populations and effective pollination services.

- Current monitoring of the risks from diseases and pesticides requires broadening to consider other insects aside from honey bees, unless we can demonstrate that honey bees are good surrogates for all other pollinators.

- There is a need to increase confidence in regulatory risk assessments pertaining to pathogens and pesticides by incorporating other pollinator species, investigating chronic exposure to multiple chemicals and using field relevant dosages (specific to regions, not using other data sources as surrogates).

- At present the effects of spatial, social and temporal scales on the benefits stakeholders receive from pollination services are only beginning to be understood.

- Economic valuation of pollination services can help optimise the cost-effectiveness of service management measures and offer new opportunities to incentivise action or raise awareness among stakeholders.

- Novel tools and instruments (e.g. education and training) are needed to translate broad international (e.g. CBD, EU Biodiversity Strategy) and national (e.g. England's Biodiversity Strategy) policies into local actor (e.g. beekeeper, farmer, citizen scientist) contributions to meet biodiversity commitments

- Refocusing some public funding to link basic science to development of practical solutions (e.g. better crop protection products, improved disease resistance or treatment) could help science deliver better-targeted evidence for pollinator protection.

- Scientists need to make more use of opportunities (e.g. POSTnotes[1]; practitioner guides) to transfer knowledge to a broad audience in order to better influence decision maker and practitioner behaviours.

- Improved knowledge exchange between scientists and decision makers is important to combating threats to pollination. Central to this is improved understanding of the respective positions of policy makers and scientists. For instance, policy-makers usually need to be presented with a range of options to balance against other areas of policy. Science does not always arrive at a consensus due to uncertainties in data or models. Policy-makers need to understand that scientists are communicating the "*best available knowledge at present*" and that consequently it is not always possible to give a definitive answer.

[1] http://www.parliament.uk/mps-lords-and-offices/offices/bicameral/post/

2. BACKGROUND AND RELEVANCE

The growth and industrial development of the global human population is increasing the consumption of natural resources. These processes produce multiple environmental pressures that threaten biodiversity and endanger the provision of ecosystem services, such as insect pollination. Insect pollinators of crops and wild plants are threatened worldwide by, land-use intensification (including habitat destruction and pesticide use), climate change, invasive species and the spread of diseases and parasites [1, 2]. These different pressures on insect pollination may seriously affect food security, human health and ecosystem function [1].

2.1 Are Insect Pollinators Declining?

Evidence from the northern hemisphere suggests widespread reductions in the diversity and abundance of many wild and managed pollinators. The UK and the Netherlands are seeing declines in bee [3] and hoverfly [4] diversity. The extinction, lower numbers and reduced distribution of bumblebee [5-7] and butterfly [8, 9] species are reported across Europe, North America and Asia. Despite a global increase in the uptake of managed honey bee (*Apis mellifera*) colonies [10] there have been extensive declines in wild, feral and managed honey bees in Europe and North America over several decades [11-13].

A lack of systematic monitoring means that evidence of pollinator losses is mostly indirect, coming from studies of specific environmental impacts on particular pollinator groups. Together with the multitude of biological interactions that produce winners (mostly generalist species) and losers (often specialists) [5, 7, 9] this monitoring gap makes detection and prediction of pollinator responses to environmental change difficult. What is clear is that much of the evidence for pollinator declines comes from developed countries where extensive anthropogenic environmental change has already happened. Similar pressures (e.g. land-use change) are predicted to increase in developing regions [14] and it is likely that pollinator diversity and abundance will be affected in similar ways to that seen in the northern hemisphere.

2.2 Pollination as an Ecosystem Service to Agriculture

Many insects including social and solitary bees, flies, wasps, beetles, butterflies and moths provide an ecosystem service by pollinating crops worldwide. Insect pollination has been shown to increase or stabilize yields of fruit, vegetable, oil, seed and nut crops [15, 16]. Global cultivation of insect-pollinated crops has expanded since the 1960s, leading to about a 300% increase in demand for pollination services [10]. The global economic value of this pollination service was estimated (in 2005 US$) to be $215 billion or 9.5% of global food production value [17]. Similarly, the U.K. National Ecosystem Assessment estimated the production value of insect pollination (in 2007 GB£) to be at $430 million or about 8% of the total market value [18].

While honey bees are managed for both crop pollination services and honey production [10], honey bee pollination by itself is often unable to deliver sufficient pollen to crops where they are most needed [19]. A diversity of pollinators, however, can contribute to sustainable crop pollination. Natural habitats support a range of wild pollinators that can increase crop yield through provision of a resilient and complementary pollination service [19, 20]. Given the multiple threats facing pollinators, any dependence on individual species for agricultural crop pollination is risky [21, 22]. Regional losses of pollinators that alter delivery of crop pollination services to valued commodities (e.g. coffee, certain fruits or nuts) may decrease their availability or increase economic costs of production. If demand for insect-pollinated crops rises and pollinator numbers/diversity fall then – without technical or economic responses – shortages of insect-pollinated crops may follow [10, 17]. In a global economy, changes in pollination services are likely to have ramifications for geographically distant markets and human responses, such as developing new suppliers, may simply transfer the environmental impacts elsewhere in the globe. Aside from the monetary impacts, and the possible consequences for the socio-economics of human societies, loss of pollination may also affect human nutrition.

2.3 Pollination and Human Nutrition

Although wind-pollinated or largely self-pollinated crops (e.g. grains) provide the largest volume of staple human (and livestock) foods worldwide, insect-pollinated crops are crucial to good human nutrition worldwide [23]. Insect-pollinated crops provide dietary variety and nutrients (e.g. lipids, vitamins, folic acid, and minerals) important for human health [15, 23]. For example, vitamin A deficiency is a major human health concern worldwide. Insect-pollinated crops provide about 70% of this vitamin and pollination increases yields of these crops by about 43% [23]. Loss of pollinators and the service they provide will thus produce problems for human nutrition, although the magnitude of the problem will often depend on geographical location and degree of societal development. For instance, the human health consequences will be greater in developing countries where poorer people are often more locally reliant on insect-pollinated crops, such as beans, for essential subsistence calories and nutrients [23]. In the richer developed countries, the impact of pollinator losses on human health will be less profound but has the potential to erode the quality of human nutrition, or increase the reliance on synthetic micronutrients (e.g., vitamin supplements).

2.4 Wild Flower Pollination and Wider Ecosystem Impacts

Pollinator declines could also have very serious ecological consequences because insect pollination of wild plants [24] is a key supporting mechanism for many other organisms. The dependence of flowering plants on animal (mostly insect) pollination is estimated to range from 78% in temperate regions to 94% in the tropics [24]. Pollination processes are relatively resilient to loss of species because certain ecological characteristics (e.g. behavioural flexibility, species redundancy) confer robustness to networks of plant-pollinator interactions. However, simulation models indicate that if pollinator extinctions continue unabated then sudden crashes in plant diversity may arise when those species that interact frequently with many others in a network are eliminated [25]. Plants underpin terrestrial ecosystems by forming the base of many food webs. Consequently, reduced abundance and loss of pollinators would have serious ecological implications not only for individual plant species but also the wider community of organisms associated with plant and pollinator, and ultimately ecosystem function. These ecological consequences might be particularly felt in tropical regions where plant dependence on animal pollination is high [24], however, recent work showed that plant-pollinator networks are less specialised in the tropics and thus likely to be more resilient in the face of pollinator extinctions than temperate pollinator communities [26]. However, if pollination deficits do arise in tropical regions it is conceivable that such ecological change might impact further on human health as tropical plants are the source of many commercial nutritional supplements and, as yet undiscovered, medicinal properties [23], and also on the availability of non-timber forest products, and other ecosystem services.

2.5 Need for Workshop

The role of insects in pollination, the decline in their numbers and speculation as to how this might affect global food production has been the subject of many media articles over the last few years. Headlines such as "*Disastrous decline in honey bees is unlikely to stop due to a perfect storm of threats, UN warns*" and **"***Bee decline threatens our dinner and the countryside*" suggest imminent catastrophe, while others such as "*Mobile phones responsible for disappearance of honey bee*" are based on questionable research. UK policy-makers such as Defra (Department for Environment Food and Rural Affairs), the Scottish Government and Members of Parliament have to sift fact from fiction if they are to develop sensible policies relating to insect pollination. This is not always straightforward, and organisations lobbying for particular actions in support of their own aims can confuse the situation.

The UK Science and Innovation Network recognised the need to improve the translation of robust scientific evidence on insect pollination into policy-making. To this end an international workshop was organised building on international expertise and best practice to identify the current state of knowledge in insect pollination and the key messages that policy-makers need to assist them in their work.

Researchers throughout Europe, and worldwide, are engaged in a variety of projects to understand the biology and behaviour of different pollinator species, as well as the reasons why their populations may be declining. In the UK, the recent Insect Pollinators Initiative (jointly funded by the Biotechnology and Biological Sciences Research Council, the Natural Environment Research Council, Defra, the Scottish Government and the Wellcome Trust and under the auspices of the Living with Environmental Change (LWEC) partnership) boosted the research portfolio by funding nine projects aimed at understanding and alleviating pollinator decline. However, more research will be needed to understand fully the problems facing pollinators and to develop strategies and interventions.

Research in this area is, by nature, multidisciplinary, requiring expertise in areas including insect physiology and behaviour, ecology, epidemiology, microbiology, molecular biology and agricultural economics [1]. In addition, there are many organisations with an interest in this area, from beekeepers to wildlife conservation charities, and it is beneficial for researchers to engage with these groups [27]. Researchers are able to communicate their goals to these organisations, provide them with expert advice, and promote the benefits of scientific research. The organisations can help frame priority research challenges, and may have knowledge or data, which may be useful to the researchers, or be able to support the project in other ways.

The outputs of the workshop are intended to advise the development of the European Commission's post-2014 Horizon 2020 work programme, and other research initiatives. This does not guarantee that insect pollination will become a key theme of the programme, but it is intended that this information could be provided to those involved in planning the calls. We also intend using the outputs of the policy session to develop better ways of providing policy-makers with relevant and accessible information about insect pollination as a basis for developing effective policy in the future.

3. WORKSHOP METHOD

3.1 Preparation for the Workshop

The Science and Innovation Network (with advice from UK funders) invited a variety of researchers with expertise in key areas of pollinator research, representatives of relevant stakeholder groups and representatives of key policy-forming organisations. Attendance was by invitation only, and selection aimed to provide a balance of expertise within and across academia and the public and private sectors. Prior to the workshop participants were requested to complete a pro-forma summarising their research and/or policy interests and experience. This information was circulated among the participants and was used to help assign participants to breakout groups. Participants were asked to come prepared to talk about their research discipline, both their own and more widely, and to cite recent advances in the area and identify key research topics. They were also asked to write a response to the questions in Table 1. The responses were collated and used by working group chairs to help guide those discussions.

Table 1: Questions put to participants prior to workshop
1. What do you think are the major research challenges in your field and what are the major knowledge gaps in that area?
2. If you work at the policy–research interface, how do you ensure that this is effective and that you connect with the right people in this area?
3. What examples can you give of best practice on translating research into policy in your field?
4. What barriers have you experienced in achieving impact in this area?
5. Where (in your experience) do policy/decision makers go for evidence to help support their work?
6. The workshop conclusions will serve to inform development of the proposed food security and sustainable agriculture and the bio-economy theme under the European Commission's post-2013 research and innovation programme, Horizon 2020. Are there any specific points that you think should be included?

3.2 Workshop Structure

The workshop commenced with short presentations from Prof. Charles Godfray[2] and Dr Peter Costigan[3] to set the science and policy scenes, respectively. Thereafter the participants separated into four thematic working groups: **Pollinator Diversity**: (*Chair* Prof. Simon Potts, *Rapporteur* Dr Adam Vanbergen); **Pollinator Health** (*Chair* Prof. Robert Paxton, *Rapporteur* Dr Belinda Phillipson); **Pesticides and Pollinators**: (*Chair* Dr Jeff Pettis, *Rapporteur* Ms Debbie Harding); **Economics of Pollination** (*Chair* Dr Bernard Vaissière, *Rapporteur* Mr Brian Harris).

During the morning session, these working groups used their collective expert judgement to consider the current state of pollinator research, the key evidence from recent research and the critical knowledge gaps where further research is required to improve understanding of the impacts of pollinator declines and the effectiveness of policy and management interventions. While the UK research funders are not planning a new funding initiative (aside

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from applications to appropriate and current UK Research Council schemes), it was intended that the outputs from this workshop would feed into the planning of Horizon 2020 and other initiatives.

During the afternoon session, the working groups focussed on policy-makers and the information they require. The groups were asked to identify the range of stakeholders involved in policy development, the type of information required to develop future policy, and the key intelligence that policy-makers need about insect pollination on which they can act. The working groups were asked to consider how stories circulating in the media can affect policy and how this in turn can affect research. Groups were also asked to consider how to communicate results more effectively and how different interested parties (e.g. public, media and policy-makers) may interpret, and be influenced by, them.

3.3 Identifying and Ranking Research and Policy Priorities

The aim of each working group was to attain a consensus on a shortlist of science and policy priorities through a chaired group discussion. This was followed by a democratic vote (1 vote per group member) to rank the shortlist of priorities according to relative importance. The feasibility (easy, moderate, difficult) of each priority was decided upon by group discussion and a vote, but where time was limited subsequently by group Chairs. The final list was agreed upon via comments on the circulated report submitted to the lead author.

4. WORKSHOP RESULTS

4.1 Pollinator Diversity

Globally there are 19,500 described species of bee, with 2,000 species in Europe and 267 in the UK. In addition there are many other pollinating insects such as hoverflies and other flies, beetles, butterflies, moths and beetles. We have evidence that the diversity of insect pollinators - encompassing the variety of different pollinator species, their abundance and their interactions with plants and other organisms - is sensitive to many different anthropogenic environmental changes. Land-use change, agricultural intensification and urbanization often destroy and fragment the natural habitats that many pollinators rely on for food and nesting resources [28, 29]. Climate change is expected to alter the synchrony between plant flowering and pollinator flight periods thereby contributing to pollinator losses that subsequently disrupt the pollination of other plants flowering later in the season [30, 31]. Migration of pollinators in the face of climate change may halt as habitat destruction or degradation reduces the availability of suitable sites. Invasive plants are another feature of environmental change that can dominate plant-pollinator interactions [28]. Whether the invasive competes for or boosts pollination of native plants appears unpredictable but it can depend on the overlap in timing of flowering between native and invasive plants [32, 33].

The outcome of environmental changes for pollinators often depends on how specialized they are on particular habitats or plants [3, 6, 34] and their ability to locate and move between fragmented and widely dispersed resources [35, 36]. However, even pollinators that are habitat or flower generalists may be affected negatively, for example, by a reduction in the breadth of available foods or curtailment of the length of the foraging season [9, 31, 37]. However, it is important to recognize that in addition to those species that lose out, evolutionary histories have produced robust or flexible species (mostly generalist species) that may persist, or even benefit from, the new environmental situation [5, 7, 9].

4.1.1 Pollinator Diversity: Main Gaps and Priorities in Policy-Relevant Research

This working group through the general discussion reached a consensus on a short-list of four science priorities of relevance to policy. **These key research priorities are summarised in Table 2**. It should be noted that there is a degree of interdependence and overlap among them. For instance, targeting interventions effectively [38] (priority 1) requires that we need to know which taxa in which locations (priority 2) are the focus. Similarly, to understand the contribution of various drivers (priority 3) to shifts in pollinator communities requires an ability to measure those shifts (priority 2). In addition to the priorities summarised in (Table 2), this working group recognised the potential risks to pollinators from pathogens spread by movement of non-native [sub-] species and fresh pollen across international frontiers by commercial businesses. This threat was partly encompassed by priority 3 ***'Drivers and pressures'*** but it was felt that it fell under the umbrella of the 'Pollinator Health' group.

4.1.2 Pollinator Diversity: Main Gaps and Priorities for Evidence-Based Policy Making

The key points of relevance to evidence-based policy making are summarised in Table 3. This working group felt that there might be good opportunities to deliver benefits to pollinators and pollination through integration of policy across sectors (e.g. Water Framework, Habitat and Birds, and Nitrates Directives) but that these are yet to be explored. Moreover it was felt that it was very important that this integration would increase policy effectiveness by, for instance, ensuring that policy developed under one directive does not clash with policies developed under other directives. Further, there are opportunities for pollinator science to inform current (e.g. CAP) and novel (e.g. woodlands) policy developments. These policy areas touched upon were very broad, addressing general biodiversity or ecosystem service objectives and rarely specifically referred to pollinators. It proved difficult within the limited time to explore all these sectors thoroughly.

Table 2 Pollinator Diversity: Science Priorities

Key priorities (ranked)	Why is it important?
1. Interventions: *What are the impacts of interventions on pollinator population dynamics and pollination services?* *What quantity, quality and locations of interventions are needed to protect/restore pollinators and services?* *How can interventions be most effectively delivered?* ***Feasibility:*** *Easy/moderate*	• There is a body of evidence on how different interventions affect pollinator diversity [e.g. 38]. However, we lack knowledge on how these interventions (e.g. agri-environment schemes, Nature Improvement Areas (NIA), protected areas) affect pollinator abundance, population dynamics and particularly pollination services • While some associations between interventions and pollinator diversity have been established, we do not know how much, of what type, and in which locations interventions are needed to achieve desired pollinator conservation/management targets. The challenge is to answer questions such as *"how much is enough?"* • A number of different routes exist for delivering pollinator-targeted interventions (e.g. agri-environment schemes, BAP, protected areas). It is unclear, however, which are the best delivery routes • Furthermore, human factors, (e.g. farmer motivation and knowledge) need to be better understood to deliver more effective pollinator interventions (e.g. agri-environment schemes, NIAs) • Together the above challenges need to be met if the UK and Europe are to successfully conserve pollinator biodiversity and manage pollination services for both wildflowers and crops. This is part of the wider challenge of sustainable intensification and the need to increase food security, and is subject to the questions of whether land sparing or land sharing is the best route
2. Systematic Monitoring: *Develop [inter]national schemes to monitor pollinator diversity, abundance and delivery of pollination services using appropriate indicators and tools.* ***Feasibility:*** *Easy*	• Currently, direct evidence for shifts in pollinator diversity and species ranges are patchy (e.g. certain geographic regions) due to a lack of species occurrence data • Moreover, where such data exist the overall picture is complicated by 'winning' and 'losing' species. Importantly from an ecosystem service perspective, we do not know about trends in pollinator abundance and service delivery • We need to monitor both rare species of conservation concern (e.g. to meet conservation obligations e.g. CBD) as well as species that are numerically or functionally important for delivery of pollination services • To understand trends in pollinator populations and pollination services a multi-scale monitoring scheme is needed so that policy and management interventions can be appropriately targeted. Such a scheme would need to be of a long-term nature to deliver useful data. From these data, we should capture information to identify a suitable set of indicators for sustained long-term monitoring

Key priorities (ranked)	Why is it important?
3. Drivers and pressures: What are the relative contributions of various pressures on pollinators, on their own and in combination? ***Feasibility:*** *Difficult*	• To date, several drivers of pollinator loss have been identified including habitat loss, fragmentation and degradation, climate change, pests and diseases, invasive species and industrial chemicals in the environment • In the real world, these threats tend to co-occur. However, the relative importance of each, their potential interactive effects, and the sensitivity of different pollinator groups to individual and combined effects are poorly understood • The relative importance of different drivers of pollinator loss under environmental change will shift, but we have little idea of how • We do not know how resilient whole pollinator communities, and the species interactions therein, are to single and multiple environmental pressures.
4. Linking pollinator diversity or abundance to ecosystem service delivery ***Feasibility:*** *Moderate*	• The relationships between biodiversity, ecosystem functions and service provision is poorly characterised for most components of biodiversity, and pollinators are no exception • Some evidence is available linking pollinator diversity and pollination services (e.g. certain crops), but generally we do not understand these relationships for most pollinators, ecosystems and geographic locations • In particular, we need to quantify the relative contribution of different pollinators and species interactions to pollination of wildflower species, crop types and cultivars across different ecosystems and regions

Table 3 Pollinator Diversity: Policy Priorities

Key priorities (unranked)	Why is it important?
Evidence for the relative contribution of different pollinator taxa to wildflower and crop pollination ***Feasibility:*** *Easy*	• If pollination services are to be safeguarded and managed then it is a fundamental requirement to know which organisms underpin the service • Whilst there is some evidence to date, there remains a need for much greater certainty. Policy makers need clear factual evidence, because the arena is full of lobbyist messages that may or may not have a scientific basis • The differentiation should not be made simply as honey bees vs. wild bees, but be broader and measure the contributions of managed honey bees, other managed species (e.g. some bumblebee, Osmia and other emerging species), and wild pollinators (social and solitary bees, hoverflies and other wild insects) • The contributions of these different pollinators are likely to vary with context. For example, honey bees may be the main pollinators in 'simple' landscapes (e.g. intensively farmed areas with little semi-natural habitat) but wild bumblebees may be the main pollinator in 'complex' landscapes (e.g. extensively farmed areas with an abundance of semi-natural features). It is important to note, however, that these may well both be sub-optimal situations and pollination service delivery could be enhanced by sympathetic land management schemes. • Different taxa will be influenced by different policies, for instance promoting honey bees may require more socio-economic instruments while wild bees may require more conservation-oriented actions
Facilitate local actor contributions to (inter-) national biodiversity commitments ***Feasibility:*** *Difficult*	• We need to find tools and instruments to translate broad international (e.g. CBD Nagoya, EU Biodiversity Strategy) and national (e.g. England's Biodiversity Strategy) policies into local activities and actions. • Two key (inter-)national biodiversity targets are to: (i) stop human-induced extinctions, and (ii) halt the loss of ecosystem services. • Pollinators and pollination represent a tractable element of biodiversity linked to an ecosystem service that could provide a testing ground for the success of various biodiversity initiatives and policy objectives. Pollination as one of the better understood services could be used for monitoring ecosystem service trends within the context of the EU 2015 target of halting the loss of ecosystem services. • Policy needs to find ways to facilitate local actors (e.g. conservationists, planners, land managers and the public) to contribute to both local and national targets so as to reconcile the Localism Bill and Big Society agenda with international commitments. • Two important work areas were identified: (i) find novel ways of educating and training the public, farmers, and taxonomists; (ii) examining the role of, and facilitate the contribution of, citizen scientists to surveying and monitoring (e.g. BAP pollinator species).

Key priorities (unranked)	Why is it important?
Evidence of the success of new and existing policy instruments ***Feasibility:*** *Moderate*	• Agri-environment schemes represent a substantial governmental investment in biodiversity conservation. They can be a tool for alleviating the pressures on pollinator health and diversity but along with better information on their biological efficacy (see above) we need to know how to improve the implementation of such schemes (e.g. spatial connectivity of patches across multiple owner landscapes) • There are major policy commitments to establishing new wildlife supporting sites and/or improving the management of existing sites, but we need to know how the context (e.g. connectivity, surrounding land-use) of such areas influences their efficacy • Data and tools using pollinators as indicators of progress could be very informative in assessing the success of new management practices and overall monitoring of the programmes • An example is the use of Nature Improvement Areas (NIA). Evidence of success within and between NIA and controls sites, would provide information on the effectiveness of this policy
Use long-term data for underpinning policy development ***Feasibility:*** *Moderate*	• Long-term data series (e.g. Countryside Survey) may be costly to collect but provides a unique platform for understanding how land cover and biodiversity (at least of plants) is changing over time • Inclusion of pollinators in the Countryside Survey (or other initiatives) would add the additional dimension of another biodiversity component and one responsible for a key ecosystem service • Pollinator monitoring could build on existing schemes (e.g. bird surveys) to provide policy relevant data (indicators, trends) in the same way butterflies have through the Butterfly Conservation monitoring scheme.

4.2 Pollinator Health

Invertebrate pests and pathogens (viruses, bacteria, and microsporidian fungi) are a major source of mortality for pollinators and have been best studied in the honey bee. The *Varroa* mite is the vector of many viruses that are implicated in loss of honey bee colonies. *Varroa* suppresses host immunity and increases host virus load by feeding on the bee's blood (haemolymph) [39, 40]. The difficulty in identifying a single disease agent causing honey bee losses seems to be because: i) bees are commonly infected with multiple pests and pathogens and ii) the particular pests or pathogens associated with colony mortality vary both in space (e.g. geographically) and time (e.g. seasonally) [40-42]. While a single causative agent behind honey bee colony losses cannot be ruled out, it seems more likely that complex infections of multiple disease agents may interact over time and space to drive many of the observed honey bee losses [43].

Moreover, it is becoming clear that many pests and pathogens can spread within and between populations of wild and managed bee species and potentially other pollinating insects [5, 44, 45]. North American declines of bumblebee species have been associated with pathogens [5]. Losses of generalist species, like many bumblebee species, from disease may increase the chance for the collapse of pollination networks and the negative effects that would have for the wider ecosystem [25].

4.2.1 Pollinator Health: Main Knowledge Gaps and Priorities in Policy-Relevant Research

The key science priorities are summarised in Table 4. This working group initially debated what research should be considered: pure basic research, use-inspired basic research or pure applied research. Pollinator health actually encompasses the health of individuals or colonies, the resistance and/or resilience of the population or the abundance of a species across its range. It is important that when for a given priority it is clearly defined what is meant be health. There is a great deal of anecdotal information about pollinator health, but the group agreed this should be ignored as it has no clear scientific basis. This working group also thought it important to stress that managed and wild pollinators may face quite different 'disease environments' but may share disease organisms and that these relationships are likely to be important and need to be understood. Finally, monitoring insect population densities or diversity can be costly and not always a high priority for policy makers, for example those more focussed on pollinator health issues.

Table 4 **Pollinator Health Science priorities** (*note: the first four priorities attained equal ranking by vote)*

Key priorities (ranked)	Why is it important?
1. What does a normal healthy pollinator look like? **Feasibility:** Moderate	• Pollinators routinely encounter a community of microorganisms. We need to improve our understanding of the levels of pathogen 'infection' that an insect pollinator can support without adverse ill effects (e.g. latent infections) • This would provide a baseline from which to evaluate the impacts of single and multiple pathogen infections in individual insects, populations and communities and any effect on pollination service delivery • Molecular 'omics' approaches will be a important tool in assessing pathogen infections
2. How do we define the health status of pollinator populations? **Feasibility:** Moderate	• The health status of a pollinator population requires the setting of a baseline (see above) and monitoring changes in i) species abundance and ii) resilience of the remaining pollinator stock. • Needs additional research on pollinators other than social bees (honey bees and bumble bees)
3. Understand the role of different habitats and species in the dynamics of pollinator diseases **Feasibility:** Moderate	• Disease burdens are likely to be shared between pollinator species. Understanding this community epidemiology will enable a more accurate prediction of disease impacts on different pollinators and pollination services.
4. How do emerging stressors and diseases combine to impact fragmented pollinator populations? **Feasibility** Moderate	• Pollinators encounter multiple pressures in the real world (e.g. climate change, invasive species). To reduce this threat to pollinator populations, we must understand how different pressures interact to affect pollinators.
5. Who pollinates what, and how much pollination do we need? **Feasibility** Easy	• We need to understand through field-based research the providers of pollination to ensure future pollination needs are met and to target natural resource management effectively (note agreement with Diversity group table 3 first bullet point)

4.2.2 Pollinator Health: Main Gaps and Priorities for Evidence-Based Policy Making

The key policy priorities are summarised in [Table 5](#). The group thought it important that policy focus on pollinator health should be expanded to encompass all pollinators not just those that are managed (e.g. honey bees). It was suggested that considering a broad range of pollinator species would be a way to achieve this. Although there was support for this idea, it was felt that it would not be possible to develop policy in such a way in time for the current CAP negotiations. However, it was felt that co-ordinated groups with (single) focused messages already had scope to influence CAP negotiations through connections with policy makers.

Table 5 Pollinator Health Policy priorities

Key priorities (ranked)	Why is it important?
1. Appropriate legislation and implementation of policy aimed at limiting and managing pollinator diseases **Feasibility:** Moderate (but division in group between those who thought it was easy and those who thought it was difficult)	• A proper understanding of disease biology and the risks to the resilience of pollinator populations and ecosystem service provision must underpin policy development to contribute to its effectiveness
2. Develop effective and practical solutions to the challenge of pollinator diseases **Feasibility:** Moderate	• We need to develop additional tools to help beekeepers and land managers to directly lessen, or avoid, the impact of bee diseases
3. Transfer knowledge from scientists to stakeholders to influence practitioner behaviour **Feasibility:** Easy	• Shared responsibility and engagement between scientists and stakeholders (e.g. bee keepers, bee farmers, land mangers etc) is the best way to combat effectively the threat from current and emerging diseases to pollinators and pollination

4.3 Pesticide Impacts on Pollinators

Chemical insecticides targeting pests are often employed as part of intensive crop management strategies but these chemicals can also be harmful to beneficial insects such as pollinators [46]. For example there is some evidence that wild bee and butterfly species richness tend to be lower where pesticide loads and cumulative exposure risk are higher [47]. Used widely in the developed world, systemic pesticides (e.g. neonicotinoids) act via root uptake and so over time may accumulate in nectar and pollen, this raised concerns over potential sub-lethal negative effects on pollinator performance and behaviour [46]. Recent experiments have shown that sub-lethal neonicotinoid exposure impaired the ability of foraging honey bees to re-locate the hive [48] and reduced the foraging performance, growth rate [49] and queen production [50] of bumblebee *Bombus terrestris* colonies. Furthermore combined field-level exposure to a neonicotinoid and a pyrethoid insecticide increased the propensity for bumblebee colony failure [49]. While these studies are important, some uncertainties remain around how pollinator behaviour under un-manipulated field conditions may not equate to the neonicotinoid exposure contained in these experiments. While not invalidating these studies such uncertainties mean that these findings are difficult to generalise and so they should be replicated and extended to establish bee responses under an array of situations. Nonetheless, social bees, because they collectively forage, process and store nectar and pollen, can also accumulate agricultural pesticides in the nest; in addition managed honey bees are exposed to acaricides used by beekeepers to combat Varroa mites [51, 52]. Social bees, and managed honey bees in particular, can thus become chronically exposed to a suite of interacting chemicals that may affect survival, learning and navigation behaviours negatively [46, 49, 52].

4.3.1 Pesticide Impacts on Pollinators: Main Knowledge Gaps and Priorities in Policy-Relevant Research

This group had detailed discussions on the major research issues relative to pesticides and pollinator health and then identified obstacles that exist in relating information and ideas to policy makers. **The key research priorities are summarised in Table 6**. Pesticides were a rather polarising subject and consensus was difficult to achieve on most of the subjects discussed. The group also felt it was important to stress that the role of pesticides in pollinator declines must be considered both as a sole factor but also in concert with other pressures (e.g. land-use and climate change, landscape intensification, disease, invasive species) on pollinator diversity and health. There were some additional issues not captured in Table 6. Firstly, mathematical models (dose-dependent population models) exist at the population level for honey bees, but these cannot be extrapolated to other pollinators. Further, such honey bee population models often focus on the role of Varroa, and not other disease organisms, in population dynamics. Such dose-dependent population models thus need to be used carefully and not in isolation from experimental evidence. Secondly, there was a sense that we need to apply the knowledge being obtained to develop a new generation of pesticides that may have a different modes of action or be less toxic to non-target species. The main point of agreement was that a systematic review of pesticide research would provide a much-needed synthesis of current information (Table 6). There was little consensus about other issues.

4.3.2 Pesticide Impacts on Pollinators: Main Gaps and Priorities for Evidence-Based Policy Making

The key policy priorities are summarised in Table 7. In the discussions a number of points arose that were not identified as being key policy needs but warrant mention. Policy-makers and the media tend to ask questions such as - should we ban neonicotinoids? This is illustrated by Early Day Motion 2664 in January 2012 at the UK parliament[4]. The issues involved are often more complex than the question suggests and scientists need to find better ways of conveying uncertainties and complexities. One idea was to try to develop a “what if we ban neonicotinoids” scenario such that the alternatives are made clear and the impact on the environment, food production and wider society in terms of other replacement chemicals, is spelled out. A risk assessment exercise of this type may help to identify what could happen if such a ban were to be put in place.

Members of this group recognised that scientists must be more pro-active and take the initiative in engaging with policy-makers. Scientists can be rather conservative and focus on their specific area of research rather than the wider context. NGOs are often good at lobbying policy-makers at high levels, sometimes with biased, misleading or ill-informed messages. Publicly funded scientists therefore have a responsibility to balance lobbying with informed opinions.

Finally, there was an acknowledgment that too narrow a focus on government policy-makers (e.g. government departments and executive agencies) fails to account for decision-makers elsewhere (e.g. supermarkets, agro-chemical companies, farmers, NGOs) who make policy for their own organisations but also influence government. Scientists need to embrace this broader policy area.

[4] http://www.parliament.uk/edm/2010-12/2664

Table 6 Pesticide Impacts on Pollinators: Science Priorities

Key priorities (ranked)	Why is it important?
1. ***Identify risks and benefits of pesticide use*** **Feasibility:** Difficult	• Banning neonicotinoid insecticides is not without risk as other, more toxic pesticides would need to be used instead to achieve the same level of food production. Such a move might have a more detrimental effect on non-target insects such as pollinators • Banning pesticides completely would result in a drastic decrease in food production, not an option with current food security concerns • There may be scope for restricting their use to food production and avoiding their use in gardens • Neonicotinoid use could move away from a routine precautionary (prophylactic) approach towards as and when required • A risk/benefit analysis is needed to understand the relative importance of pesticides in food production • There are unhelpful perceptions about pesticides in the media and public. • Regulatory research has focussed on the use of honey bees as a model for non-target effects. Toxicity in other species is largely ignored and whether honey bees are a good proxy for the diversity of pollinating insects is not proven. • Compounds are usually tested in isolation whereas they may act in combination in the field or hive. • Combinations of pesticides with varroacides and antibiotics also need to be considered. • Realistically, there are too many combinations of compounds at both chronic and acute levels to assess in the laboratory. We need to prioritize the combinations that are likely to be encountered by insects. • Current safety regulations are more stringent for pesticides than for varroacides.
2. Review of existing information to provide evidence base **Feasibility:** Moderate	• The evidence base for pesticide impacts on pollinators is not clear at present • A systematic review of pesticide information would properly assemble and consider the evidence to avoid knee jerk reactions to issues involving pesticides. This would need to be done by someone outside the pollination field (e.g. epidemiology) and from a non-governmental organisation (e.g. University or Research Council) to give it independence and credibility and to minimise the perception of vested interests being at play

Key priorities (ranked)	Why is it important?
	• Since the workshop, the European Food Safety Authority (EFSA) and Defra[5] have published reviews of the threats from pesticides (particularly neonicotinoids) to the health of pollinators. EFSA's Panel on Plant Protection Products and their Residues published a Scientific Opinion[6] on the science behind the development of a pesticide risk assessment for honey bees, bumble bees and solitary bees on 23 May 2012. This is a very substantial and significant review and analysis of the state of the science. • The Opinion will be the basis for a Guidance Document for applicant companies and regulatory authorities in the context of the review of Plant Protection Products (PPPs) and their active substances under EU law. This guidance is due to be drawn up by the end of December 2012. • EFSA are reviewing the bees risk assessment for the three neonicotinoid active substances that have high acute toxicity to bees; this work is due to be completed by the end of 2012. The first stage is for the Member States that carried out the initial assessments when the active substances were last evaluated to consider - by July 2012 - all the new data relating to key areas of concern • Much unpublished commercial data about pesticides exists which could inform the wider research agenda. Much of this data is proprietary and while it is given to regulatory bodies, as part of the pesticide registration process, it is not available more widely. • Such commercial data are available in some countries but not in the UK. Anonymisation of land management data so that individuals, organisations or businesses cannot be identified is a complicating issue. A public data base would increase transparency of the system and could increase confidence that the regulatory process is working to protect pollinators.
3. Quantifying pesticide impacts on pollinators *-Linking laboratory and field studies to understand better the impact of pesticides* **Feasibility:** Moderate/Difficult	• The effects of specific chemicals needs to be tested under controlled laboratory conditions to reveal the mode and efficacy of action. Laboratory studies, however, are often criticised for not representing ‘real world’ situations. It is important to set against this critique that laboratory studies are good enough (indeed are absolutely required) for therapeutic drugs for human use in complex environments. • Field studies do not allow for the same level of control and thus they can be more difficult to interpret. However, field studies are essential to simulate realistic exposure, understand the effects on real pollinator populations and identify causal effects. • Fieldwork is essential to guide and expand upon laboratory studies. Integrated studies would improve prediction of pesticide impacts.

[5] http://www.defra.gov.uk/environment/quality/chemicals/pesticides/insecticides-bees/
[6] http://www.efsa.europa.eu/en/efsajournal/pub/2668.htm

Key priorities (ranked)	**Why is it important?**
-Standardisation of methods between different studies **Feasibility:** Easy	• There is a set of well-standardized study design available for regulatory testing purposes. However, further standardisation of methods that are not currently part of regulatory testing protocols would enable comparison of results between different studies. At present the differences in conditions in non-regulatory studies mean that it is difficult to draw overall conclusions.
4. Understanding basic ecology underpinning exposure of different species to pesticides **Feasibility:** Moderate	• Improved knowledge of pollinator ecology would help the implementation of measures to limit exposure of non-target insects to pesticides. • We need to know where different pollinator species occur, in what numbers, how they interact with each other and how they use different environments • We need to understand how habitat destruction affects a variety of pollinators, which pollinators are most affected, and how loss of nesting and floral resources affects pollinator-pesticide interactions. • We need to know which pollinators are most closely associated with different agricultural crops and thus are most likely to be exposed if pesticides are used.
5. Are honey bees good surrogates for other pollinators? **Feasibility:** Easy	• Honey bees are the pollinator of choice for pesticide testing because their biology is well understood and their availability worldwide • There is little information as to whether this good understanding of the biochemical and enzymatic mechanisms involved in honey bee responses to pesticides is applicable to other pollinators. • If honey bees are not adequate surrogates then we should develop our understanding of pesticide toxicology in other pollinators (e.g. bumblebees, *Osmia* and *Megachile*) • Discussing the relative importance of honey bees and other pollinators in agricultural systems is not always helpful. It has to be recognised that we need a variety of insect pollinators for sustained pollination. The importance of one pollinator over another may vary with ecosystem or crop and key issues for one pollinator may be less relevant for another.

Table 7 Pesticide Impacts on Pollinators: Policy Priorities

Key priorities (ranked)	Why is it important?
1. Synthesis of existing information into a simple summary for decision makers **Feasibility:** Easy	• As noted in the above research section, a systematic review would bring all available information together. It would need to be independent, i.e. be done by someone with no vested interests • The review would need a simple summary drawing out key points, so that policy-makers could understand its results. It should not attempt to draw out conclusions but just state the facts that are known. Such a succinct summary of the current state of knowledge would be very valuable
2. Transparency in the route of policy-making and better communication **Feasibility:** Moderate/Difficult	• Information about neonicotinoids and other pesticides needs to be presented to policy-makers (and others) in a more sensible way and in ways that policy-makers can understand easily • The underlying science frequently does not come to a consensus so it is not always possible to give a definitive answer. Policy-makers need to understand that this is an acceptable, and normal, situation and that lack of consensus indicates the degree of uncertainty in the evidence to date
3. Better mechanisms for communication with policy-makers, including POST and European equivalents **Feasibility:** Moderate	• In the UK, the Parliamentary Office of Science and Technology provide a four-page POSTnote[7] summarising information for Members of Parliament and other policy-makers on particular subjects. The US has something similar, the Congressional Research Service, which produces evidence on a particular subject but does not attempt to draw conclusions • Scientists could make more use of this opportunity to put their science across to a wide range of people, possibly by suggesting topics to POST (and similar bodies) and offering to help by providing information • Policy practise notes could be another form of output for scientists, although the fact that they have been published does not mean that they will necessarily be read • It is important to note that policy-makers usually need a range of options rather than being presented with a single scenario, in order to reflect their need to balance or trade-off different policy issues

[7] http://www.parliament.uk/mps-lords-and offices/offices/bicameral/post/publications/

Key priorities (ranked)	**Why is it important?**
4. Funding of research from basic science through to development of crop protection products **Feasibility:** Difficult	• Funding for near-market research is difficult to obtain • Research councils have a remit to fund basic through to applied research but do not fund commercialisation of products arising from research • The UK's Technology Strategy Board covers the commercial arena but does not have a background in agricultural or ecological research • Funding from basic research through to development of crop protection product is needed requires a refocused research pipeline
5. More confidence in regulatory risk assessments (can be done by addressing the research gaps) **Feasibility:** Moderate/Difficult	• It is not clear whether the existing risk assessments underpinning the regulation of pesticides are fit for purpose (e.g. only considering honey bees, only looking at one chemical at a time in isolation) • Veterinary medicines (e.g. antibiotics) need to be considered as well as pesticides when looking for unintended consequences
6. ***Encourage publication of negative results*** **Feasibility:** Easy/Moderate	• There is a great deal of useful information contained within negative results, but these tend not to be published. Often negative results in pesticide studies mean that there was no measurable effect. This needs to be published in order to provide the full evidence base for policy • The trend is reversing but not fast enough, and tends not be applied retrospectively. If negative results could be made available for a systematic review (see above) it would be help produce a more balanced picture. A US journal exists that publishes details of pesticide trials

4.4 Economics of Pollination

Pollination services are a significant input in many agricultural economies across the world [53], improving and stabilizing market yield and quality in ~75% of globally important crop species [15]. This added market output has been valued at €153bn annually and are thought to save consumers €153bn-€422bn by maintaining present supplies relative to demands [17]. Globally, the area of insect-pollinated crops has expanded rapidly [10] and insect-pollinated crops are the primary sources of several important micronutrients in the human diet [23], rising concerns about the economic and social impacts of pollination service losses. In addition to these market benefits, pollination services also underpin the reproduction of many wild and forage flowering plants important to people for their aesthetic value as part of the wider landscape [54] or which provide other ecosystem services such as nitrogen fixing clovers that improve grassland productivity [16, 55].

Economic valuation ecosystem services is regarded as a key tool in sustainable development strategies, facilitating the development of management strategies and policy to optimise service delivery [56], particularly to areas which are highly dependent upon pollination services [17, 53]. Valuation can also justify greater investment in conservation efforts (e.g. *Varroa* prevention in Australia [57]) or new management strategies (e.g. allowing undersown weeds in crop fields [58]) where the costs outweigh the benefits and form part of green accounting metrics to assess overall natural capital between years [59].

4.4.1 Economics of Pollination: Main Knowledge Gaps and Priorities in Policy-Relevant Research

Within early discussions, a consensus emerged that future valuation and pollination economics should be driven by better agronomic and ecological information on pollination services, such as which taxa pollinate which crops in different regions. These gaps were widely recognised as limiting both effective valuation, identification of risks such as potential pollination limitation and the development of effective management measures which are the focus of cost:benefit analysis. Presently, studies into the economics of pollination consider the benefits in isolation which the group felt was limiting effective valuation, recognising the need to consider pollination as part of a broader suite of managed and natural inputs (i.e. ecosystem services such as pest regulation) which affect crop productivity. Similarly, the group considered it equally important to recognise the impacts that pollination service management may have upon other ecosystem services, although these are likely to be positive in some cases (e.g. biodiversity conservation through the pollination of wild flowers) , in some cases it could be negative (e.g. pollination of pernicious weeds).

There was also a widely recognised need to expand beyond assessing the benefits of crops alone and explore the value of non-market pollination service benefits received by a broader range of stakeholders. Later discussion focused upon research needed to translate understanding of services into effective mitigation and natural capital building measures. In particular, the group recognised a need to include process based ecological economic models (e.g. life-cycle analysis) to identify how and to what extent different stakeholders benefit from pollination services, which bear the greatest risks and where potential free riding can occur. Such models should assist in developing more comprehensive cost:benefit analysis of pollination service management. **Based on these discussions, the group developed a series of research recommendations summarised in Table 8.**

4.4.2 Economics of Pollination: Main Gaps and Priorities for Evidence-Based Policy Making

Discussion on evidence-based policy-making focused heavily upon how to utilise ecological economics to translate conservation research into effective pollination service management measures. The importance of effective incentives for policies aimed at different stakeholder groups throughout supply chains was considered especially important as uptake of beneficial options by farmers remains low (see e.g. Nectar flower mixes in England's Entry Level Stewardship; [60]) due to low financial and social incentives.

The group also felt that other stakeholders should be encouraged to "buy in" to conservation, for instance encouraging suburban residents to plant wildflowers in their gardens that benefit pollinators and which may improve pollination services in nearby agriculture [61]. Ecological-economics research was considered an appropriate means of incentivising this support by highlighting the relative costs and benefits of action or inaction to different stakeholders. The group also felt that the relative importance of pollination compared with other ecosystem services should be accounted for within food security and sustainable development policies and an appropriate funding mechanism established. Based on this, it was again acknowledged that pollination should not be considered alone within policy and, similarly, that all land use and agriculture policies should at least consider impacts upon pollination. Issues of policy scale and coherence when concerning pollinators were also discussed, including the need to incentivise stakeholder co-operation. **Table 9 summarises the main evidence-based policy priorities identified on the basis of these discussions**

Table 8 Economics of Pollination: Science Priorities

Key priorities (ranked)	Why is it important?
1.Quantifying the contribution of pollination services to several model crops using a holistic approach **Feasibility:** Easy (methods exist [62])	• The economic benefits (yield and quality) of pollination services to modern crop cultivars of almost all crops and production systems are largely unknown • The extent to which the role of pollinator diversity in pollination services to crops provides insurance against fluctuating economic benefits is unknown • Past studies used to inform benefits analysis are often dated, non-standardised and do not account for the relative impact of pollination in relation to other ecosystem and artificial inputs (e.g. fertilizer, water, agrochemicals) • The main pollination service providers of many major crops and the relative contribution of wild and managed pollinating species are highly speculative • Understanding these factors allows the development of optimal service management strategies at field and landscape scale
2. Cost-benefit analyses for maintaining or restoring sustainable natural capital for pollination **Feasibility:** Easy/Moderate	• Although many measures to enhance pollinator populations are known, the effects of these measures on pollination services are less often assessed • The costs of strategies and relative benefits of changes to agricultural policies that may improve or maintain the quality of this capital (e.g. pesticide reduction) are presently unclear • Economic incentives to uptake beneficial measures, such as planting flower mixes, are often limited or not understood by stakeholders (e.g. hardly known if flower mixes promote pest species, spill-over of diseases to crops etc). • Understanding the variations in these costs and benefits can allow for more targeted and sustainable pollination management regimes • Analysis of costs and benefits may provide strong incentives for stakeholders to undertake or participate in pollination management at farm and landscape scales

Key priorities (ranked)	Why is it important?
3. Identify which economic instruments should be used to pay for the maintenance or restoration of this capital. **Feasibility: Easy**	• Pollination services benefit many stakeholders (farmers, crop consumers, supermarkets, the public etc.) in different, often un-quantified ways • Different policy instruments (taxes, payments for ecosystem services subsidies etc.) are required to engage different stakeholders • Engaging multiple stakeholders can propagate awareness and changes in behaviour towards sustainability • If the costs for restoring pollination services are born by only a single group then issues of free-riding can arise
4. Identify means to manage the risks of pollination deficits for society at large. **Feasibility: Difficult**	• The agricultural GDP and, in some countries, national GDP of many nations are often highly dependent upon the productivity of insect-pollinated crops • Pollination service deficits can result in lower yields, resulting in higher prices for consumers and greater reliance upon imports with an associated higher carbon footprint • A number of modern agricultural practices are likely to exacerbate the pressures on pollinators and consequently the risks of service loss, however removing these factors may have detrimental impacts on food security • Efforts to manage risks to pollinators may have additional costs to production or benefits to ecosystem services (e.g. reducing pesticide applications) • Different stakeholders may experience different degrees of risk, which may act as an incentive or disincentive to contribute • Co-operation between stakeholders, such as developing habitat corridors or sympathetic management of shared habitat, can potentially reduce risks and increase cost-effectiveness if correctly incentivised

Table 9 Economics of Pollination: Policy Priorities

Key priorities (ranked)	Why is it important?
1.Ascertain the risk of doing nothing to alleviate the pressures on pollinators **Feasibility: Easy**	• Past agriculture and development policy has not accounted for the impacts of intensification and development upon the stability of ecosystem services, resulting in many of the observed pressures on pollinators • Policy should always be assessed against a status quo of inaction to better illustrate the long-term benefits of any agriculture or land-use decisions • Policy to promote food security or alter agricultural production should be informed by any available evidence on the effects this will have on demand for pollination service relative to other artificial or ecosystem inputs
2. Identify the most effective policy instruments to address pollination service insecurity or loss at different scales **Feasibility: Moderate**	• Demands for pollination services and the nature of their socio-economic benefits can change substantially over different spatial, temporal and social scales (i.e. stakeholders) • Policy to secure pollination services should therefore utilise a range of instruments that consider long-term changes in value and demand for pollination and other related ecosystem services • Research should aim to inform policy about cost and benefit uncertainties across different scales, systems and regions and highlight areas of particular concern
3. Increase cost-effectiveness of policies aimed at pollination service management **Feasibility: Easy/ Moderate**	• Policy should incorporate information on how to optimise the cost-effectiveness of instruments over a landscape scale, allocating more resources to areas identified as being most dependent upon pollination • Stakeholders should have access to greater information regarding the benefits of pollination services to better affect awareness of instability and encourage a change in behaviour towards more sustainable consumption • Policies may become more cost effective if individual stakeholders or groups are encouraged to co-operate (e.g. landscape scale farming across several producers) • Both policymakers and researchers should endeavour to inform producers of the full economic costs and benefits of pollination service management to better incentivise uptake

Key priorities (ranked)	Why is it important?
4. Understand why policies may not work as well as planned- **Feasibility: Easy**	• Many present policy actions that benefit insect pollinators suffer from poor uptake because the social and economic incentives to undertake these actions are weak or technical limitations (difficulty in management etc.) are not accounted for • Efforts should focus upon the most cost-effective leverage points (consumers, supermarkets etc.) for encouraging uptake, propagating awareness and changing behaviour throughout the supply chain
5. Develop coherent national and EU policy targeting conservation of pollination (and other ecosystem services) **Feasibility: Moderate/Difficult**	• Policy to preserve ecosystem services across the EU should have defined objectives and quantifiable targets and funds targeted at areas with the greatest risks in pollination service losses

5. CONCLUSIONS

Pollinators are threatened by multiple pressures many of which are a consequence of human activities. Pollinators provide a key ecosystem service to agriculture and their loss will have ramifications for the stability and quality of food supply, although the level of impact will vary with geographic locality and degree of economic development. Loss of pollination would also have hard to predict consequences for ecosystem function due to knock-on effects on associated biodiversity across complex above- and belowground food webs.

The workshop provided an opportunity to distil some key messages to be transmitted to policy makers, practitioners and scientists at the national and international level. In brief these were:

- The threat to pollinators and pollination, like many environmental challenges, comes from multiple drivers. We need to study the relative importance of drivers and how they interact if we are to understand and mitigate pollinator losses.
- We need systematic monitoring of: i) wild pollinator densities and ii) pathogens in wild populations over time and at different spatial scales if we are to provide the necessary evidence base to decision makers.
- We must establish the effectiveness of current and future interventions in influencing pollinator diversity, abundance, populations and pollination delivery to wild and crop plants.
- We must identify regions and stakeholders at greater risk of pollination service losses and develop appropriate incentives to ensure that all stakeholders engage in conservation.
- Risk assessment in relation to disease, pesticide and economic impacts necessitates that we consider an array of wild pollinator species, in addition to managed bees, and greater real world complexity (e.g. multiple chemicals).
- Scientists need to make more use of opportunities to transmit their knowledge to the wider public, business and policy audiences in a simple and understandable form and develop novel practical solutions to specific problems.
- There is a need for mutual recognition and respect between the science and policy arenas: scientists must recognise that decision makers have to balance many, often competing, priorities while policy makers need to understand that a simple answer from scientists is not always available due to sources of uncertainty.

With biodiversity and ecosystem services being increasingly mainstreamed into national and international policy it is essential that inter- and transdisciplinary basic and applied science is able to provide a sound evidence base which is accessible to decision makers. Reciprocally, policy makers must facilitate and help direct scientific investigations by providing clear priorities and resources to allow the research community to build appropriate knowledge bases for policy support. A key element of this process is regular and sustained science-policy dialogues [e.g. 27], which will enable both groups to understand better the aims, principles, processes and barriers to overcome. This is crucial to developing effective and robust policy instruments to conserve biodiversity and manage ecosystem services better, both now and under future environmental change.

Pollinators and pollination represents a tractable flagship example of how biodiversity supports the ecosystem services and functions on which humanity relies and is understandable by wider society. Establishing policy tools to conserve and restore pollination will also promote the biodiversity of many organisms and multiple ecosystem services. It is within the capacity of scientists, decision makers and other stakeholders to understand the threats to pollination, to lessen anthropogenic impacts through evidence-based policy and ultimately to restore and maintain this ecosystem service into the future.

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