ORIGINAL RESEARCH ARTICLE

Assessment of the response of pollinator abundance to environmental pressures using structured expert elicitation

Martine J Barons[*a] Anca M Hanea[d], Sophia K. Wright[a], Katherine C R Baldock[e], Lena Wilfert[f], David Chandler[g], Samik Datta[h,n], Jessica Fannon[g], Chris Hartfield[j], Andrew Lucas[k], Jeff Ollerton[l], Simon G. Potts[m] and Norman L Carreck[b,c]

[a] *Department of Statistics, University of Warwick, Coventry, CV4 7AL, UK*
[b] *Laboratory of Apiculture and Social Insects, School of Life Sciences, University of Sussex, Falmer, Brighton, East Sussex, BN1 9QG, UK.*
[c] *International Bee Research Association, 91 Brinsea Road, Congresbury, Bristol, BS49 5JJ, UK.*
[d] *Centre of excellence for Biosecurity Risk Ananlysis, University of Melbourne, Parkville VIC 3010, Australia*
[e] *School of Biological Sciences, Tyndall Avenue, Bristol, BS8 1TQ UK*
[f] *Centre for Ecology and Conservation, University of Exeter, Penryn, Cornwall, TR10 9FE, UK*
[g] *School of life sciences, University of Warwick, Coventry, CV4 7AL, UK*
[h] *Zeeman Institute: SBIDER, Warwick Mathematics Institute, University of Warwick, Coventry, CV4 7AL, UK*
[j] *Plant Health Unit , National Farmers' Union, Stonleigh, Warwickshire, CV8 2TZ, UK*
k Department of Biosciences, Swansea University, Singleton Park, Swansea, SA2 8PP, UK
[l] *Department of Environmental Science, University of Northampton, Avenue Campus, Northampton NN2 6JD, UK*
[m] *Centre for Agri-Environmental Research, School of Agriculture, Policy and Development, Reading University, Reading, RG6 6AR, UK.*
[n] *National Institute of Water and Atmospheric Research, Evans Bay Parade, Wellington 6021, New Zealand.*

[*]Corresponding author: Email: Martine.Barons@warwick.ac.uk

Summary

Policymakers often need to rely on experts with disparate fields of expertise when making policy choices in complex, multi-faceted, dynamic environments such as those dealing with ecosystem services. For policy-makers wishing to make evidence-based decisions which will best support pollinator abundance and pollination services, one of the problems faced is how to access the information and evidence they need, and how to combine it to formulate and evaluate candidate policies. This is even more complex when multiple factors provide influence in combination. The pressures affecting the survival and pollination capabilities of honey bees (*Apis mellifera*), wild bees and other pollinators is well documented, but incomplete. In order to estimate the potential effectiveness of various candidate policy choices, there is an urgent need to quantify the effect of various combinations of factors on the pollination ecosystem service. Using high quality experimental evidence is the most robust approach, but key aspects of the system may not be amenable to experimentation or may be prohibitive based on cost, time and effort. In such cases, it is possible to obtain the required evidence by using structured expert elicitation, a method for quantitatively characterizing the state of knowledge about an uncertain quantity. Here we report and discuss the outputs of the novel use of a structured expert elicitation, designed to quantify the probability of good pollinator abundance given a variety of weather, disease and habitat scenarios.

Key words: Structured expert elicitation, IDEA protocol, bees, hover flies, pollinators, conservation, ecosystem services

Introduction

The dynamics of pollinator populations and factors that impact upon these populations, are a focus of attention for policy-makers concerned with conservation and vital ecosystem services like pollination. There are substantial gaps in knowledge about the status of pollinators worldwide (e.g. abundance declines, distribution, species declines) and the effectiveness of measures to protect them (GM crop regulation, pesticide policy, pollution control, etc.) (L. V. Dicks et al., 2016; Godfray et al., 2014; Potts et al., 2016). In order to adequately protect and preserve pollinators, such as by means of England's National Pollinator Strategy (NPS) in the UK (Defra, 2014), it is vital to know what and how much effect various key factors have on the abundance of honey bees, wild bees and other pollinators (such as hover flies) and whether these effects act independently or in combination. A suitable monitoring framework to support the pollinator strategies is vital (Carvell et al., 2016).

It is estimated that over 70% of important food crops worldwide are dependent upon pollinators (Klein et al., 2007), and pollinator-dependent food products are important contributors to healthy human diets and nutrition (Potts et al., 2016). The status of bees and other pollinators is also of key concern in global food security (Bailes, Ollerton, Pattrick, & Glover, 2015; Blaauw & Isaacs, 2014; Lonsdorf, Kremen, Ricketts, Winfree, & Greenleaf, 2009; Lucas, 2017; Ollerton, 2012). Many agricultural businesses employ migratory bee services in order to ensure adequate pollination of crops (Bishop, Jones, Lukac, & Potts, 2016; Gordon, Bresolin-Schott, & East, 2014). However, the mere presence of bee colonies on site may not guarantee optimal pollination, if the colonies are weakened by disease or struggling for environmental or other reasons. Whilst honey bees are not the only pollinators (Breeze et al., 2014; Rader et al., 2016), they are distinctive as they are often managed by humans so can be described as livestock. As such, the direct impact of bee keepers on their survival and health, for example by controlling levels of parasites and disease, is a potential point of intervention for policymakers. In the UK, protected crops within polytunnels, like most of the UK soft fruit industry, use bought-in boxes of bumblebees, with the health of these bees assured by the supplier. This is another potential point for policy intervention.

There are two interrelated problems facing policy-makers wishing to make evidence-based decisions. The first is how to access the information and evidence they need, including quantitative statements about levels of uncertainty, for example probabilistic estimates of pollinator distributions (Elith, 2009; Fithian, Elith, Hastie, & Keith, 2014; Guillera-Arroita et al., 2015; Renner et al., 2015). The second problem is how to combine evidence in a transparent, defensible, coherent and statistically robust manner. This is especially difficult when the evidence is incomplete, and that which does exist is inherently uncertain (probabilistic) in nature, particularly with respect to estimates of future values. The latter point, how to integrate probabilistic data for policy decisions, is addressed by (Smith, Barons, & Leonelli, 2017), who developed a formal statistical methodology to draw on the expertise of a variety of disparate panels of experts and their diverse supporting probabilistic models and then integrate this network of information coherently in order to explore and compare the efficacy of different candidate policies. In this paper, we focus on the difficulty of accessing information that is required, but is prohibitively difficult or expensive to obtain in the form of a designed experiment, as is the case of combinations of interacting and interrelated factors affecting pollinator abundance on realistic spatio-temporal scales. For this, we harnessed the power of structured expert elicitation.

Expert elicitation

Using expert advice and opinion to support policy decision-making is commonplace. Indeed, the opinions and contributions of experts and stakeholders were integral to the development of England's NPS. Expert judgment elicitation seeks to elicit a subjective probability distribution for a quantity of interest from each of several experts and to summarize these distributions to provide insight about the quantities of interest, the extent of uncertainty, the sources of the uncertainty, the extent of agreement/disagreement and reasons for any disagreement among the group of experts consulted. Commonly, the way in which their contributions are synthesized and amalgamated to inform the eventual decision is not very transparent. Additionally, where informal elicitation and aggregation is employed, experts are subject to a number of well-documented biases: social biases deferring to the member with the most compelling personality or who is seen as the most senior, bias towards the most readily available information and misunderstandings due to semantic differences (Kahneman & Tversky, 1984; Slovic, 1999). As a result, unstructured elicitation of expert judgements can produce results that are not reproducible and can be unreliable and heavily biased. However, the difficulties that beset unstructured expert elicitation can be substantially reduced by using structured approaches designed to mitigate the most pervasive and debilitating psychological and contextual frailties of expert judgement (W. Aspinall, 2010; Burgman, 2016; R. Cooke & Goossens, 2008; Keeney & von Winterfeldt, 1991; O'Hagan et al., 2006).

Structured elicitation of expert opinion in pursuit of decision support is an increasingly important technique and the European Food Safety Authority recently composed a detailed guidance document on its use for food and feed safety risk assessment (EFSA, 2014). It has also been used to guide policy on safety from volcanic eruptions (W. a. C. Aspinall, Roger M. , 1998), assess health risks (R. M. Cooke et al., 2007), climate change (Granger Morgan, Pitelka, & Shevliakova, 2001) and to quantify uncertainty in the risks of herbicide-tolerant crops (Krayer von Krauss, Casman, & Small, 2004). Aggregation of experts' judgements can be behavioural (seeking consensus) or mathematical (combining individual estimates using a formula) or a mixture of the two. There are several well-established methodologies for structured expert elicitation protocols, each with its own strengths and limitations, described in detail in the EFSA guidance: namely Delphi, Cooke's and Sheffield protocols. For this elicitation, we used the IDEA protocol (Hanea et al., 2016), a recently-developed elicitation method which combines the strengths of these three methods (individual estimates, group discussion, and calibration) and ameliorates some of the limitations (a requirement for consensus).

The IDEA protocol

The acronym *IDEA* arises from the combination of the key features of the protocol that distinguish it from other structured elicitation procedures: it encourages experts to *Investigate* and estimate individual first round responses, *Discuss, Estimate* second round responses, following which judgements are combined using mathematical *Aggregation*.

In the pre-elicitation stage, the information sought needs to be expressed as precisely as possible to minimise any risk of semantic or other misunderstandings arising and to aid in the identification of the suitable experts. The elicitation stage consists of three phases: investigate, discuss and estimate. After investigating relevant background material, experts are asked to provide their private estimates for the quantities of interest in the order: lowest plausible, highest plausible and then best estimate to avoid anchoring around the central estimate. After a facilitated discussion of the anonymised results for each question in turn, experts are asked to give second private estimates for the quantities of interest. Calibration questions, which have `answers' that can be checked, are elicited using the same protocol. Finally, individual experts' estimates are aggregated into a single estimate for each question using information gained in the calibration stage. More details of the IDEA protocol are given in Appendix 1.

Materials and methods

The IDEA protocol was used to elicit from pollinator experts the conditional probabilities required to populate a Bayesian Network (BN) (Pearl, 1985) representation of the pollinator system. BNs are probabilistic graphical models in which nodes represent variables of interest and directed arrows represent (possibly causal) relationships between the variables. This BN is to be used to provide an overarching framework for combining the probabilistic elements of the pollinator system in order to produce a decision support system for policymakers (see methodology developed in (Smith et al., 2017)). After the quantities which needed to be elicited were identified, relevant experts were invited to take part in an expert elicitation exercise. Background evidence was sought through a literature search and sent out to experts and the quantities of interest refined into specific questions. These steps were followed by the face-to-face elicitation workshop.

The experts

The selection of suitable experts is key to a successful elicitation exercise. Eleven experts agreed to attend and a list of background materials circulated to them, given in Appendix 1. One of the experts attended for an additional working day prior to the elicitation workshop to lend domain knowledge to the refinement of the questions of interest in order to ensure that they were clear and fair.

Selection of the questions of interest

Selection of the questions of interest was based on the variables revealed as key drivers of pollinator abundance in a literature search. From these the system was represented by a BN developed with the aid of multiple experts in pollinating insects and pollination services in the UK and Australia. Whilst good evidence is available to quantify many aspects of the system, quantitative assessments of the effects of disease, habitat and weather on pollinator abundance were weak and so we elected to supplement these with a structured expert elicitation exercise. In the full model, variables identified in the literature and by the pollination experts as impacting the abundance of pollinating insects (Brown et al., 2016; Mayer et al., 2011), include:

- land use, its incentives & costs (K. Baldock et al., 2015; K. C. R. Baldock et al., 2015; Cranmer, McCollin, & Ollerton, 2012; Hall et al., 2016; Hicks et al., 2016; Matheson & Carreck, 2014; Meixner et al., 2014; Ollerton, Erenler, Edwards, & Crockett, 2014; Orford, Murray, Vaughan, & Memmott, 2016; Senapathi, Goddard, Kunin, & Baldock, 2016; Tarrant, Ollerton, Rahman, Tarrant, & McCollin, 2013),
- weather & climate, (Al-Ghamdi, Abou-Shaara, & Mohamed, 2014; Kerr et al., 2015; Settele, Bishop, & Potts, 2016)
- disease & pest pressure (Arundel, 2011; Bull et al., 2012; Capri, Higes, & Kasiotis, 2013; N. Carreck, 2011; N. L. Carreck, Ball, & Martin, 2010a, 2010b; Dave Chandler, Bailey, et al., 2011; D. Chandler, Davidson, Pell, Shaw, & Sunderland, 2000; Dave Chandler, Prince, & Pell, 2011; Datta, Bull, Budge, & Keeling, 2013; Fürst, McMahon, Osborne, Paxton, & Brown, 2014; Gordon et al., 2014; Manley, Boots, & Wilfert, 2015; Martin, Ball, & Carreck, 2010; Ryabov et al., 2014; Wilfert et al., 2016),
- pesticide, fungicide and herbicide use, (Botias et al., 2015; Dively, Embrey, Kamel, Hawthorne, & Pettis, 2015; Godfray et al., 2014; Pettis et al., 2013)
- habitat loss, degradation and fragmentation (Staley et al., 2013)
- social attitudes & incentives (Gill et al., 2015; Ollerton, Rouquette, & Breeze, 2016; Staley et al., 2012),
- standards of beekeeping and husbandry – this is a major pressure on honeybee colonies - and agricultural inputs (N. L. Carreck & Ratnieks, 2014; Godfray et al., 2014; Hartfield, 2017).

These all change over time, and are all linked directly or indirectly to the abundance of different classes of pollinator. Policies which may be adopted include incentives and regulations on various aspects of land use and agricultural inputs, policies to ameliorate the effects of extreme weather events, research investments on pests and diseases of pollinators, and social marketing and education related to societal and farming support for pollinators (L. V. Dicks et al., 2016). In order to evaluate these policies, it is necessary to agree upon suitable measures of pollinator abundance and to quantify the effects of various policies on this measure.

It is important, for a successful elicitation, to agree upon clear definitions of the variables to be quantified, depicted in Figure 1.

[FIGURE 1 HERE]

The overarching goal was to provide decision support for policymakers; given that disease burden is only amenable to direct human intervention – and thus to policy change – in managed honey bees, disease pressure was assumed to affect honey bees only. In order to avoid over-burdening the experts participating in the structured elicitation, the cumulative effects of weather, environment and disease pressure on pollinator abundance needed to be restricted to two levels for each as follows: abundance of various pollinators was considered to be good or poor; weather was either average, or unusual, disease pressure was high or low and the environment was supportive or unsupportive. We then needed to define precisely what we meant by these categories and how they would be measured.

Following careful discussion with the experts at the elicitation workshop, good abundance of honey bees was defined as overwinter losses of no more than 30% as defined by the honey bee research association, COLOSS (van der Zee et al., 2013), and poor abundance corresponded to overwinter losses greater than 30%. For wild bees, abundance was considered good if the number of observations recorded in the spring season by the Bees, Wasps and Ants Recording Society (BWARS) was within the range of averages for the spring season recorded in the last five years and poor if fewer. For other insect pollinators, hover flies were considered to be a representative taxon and so abundance was defined as good if the number of observations recorded in the spring season by the Hoverfly Recording Scheme (HRS) was within the range of averages for the spring season recorded in the last five years and poor if fewer. Some limitations of the BWARS and HRS recording methods were noted, particularly that recordings of rare species are more likely to be made than common varieties and that survey regions are likely to be limited to easily accessible areas.

The participating experts considered the parasitic mite Varroa (*Varroa destructor*) to be the key pest affecting honey bees. The UK National Bee Unit's BeeBase website provides a wide range of free beekeeping information for UK beekeepers and the threshold for Varroa treatment given on BeeBase was used to delineate between good and poor Varroa control and this was used as a proxy for overall disease pressure.

Following in depth discussion, environment was defined as supportive if it had at least 15% of semi natural land, and unsupportive if the percentage was below this threshold, following a study by (E. Benjamin, R. Reilly, & Winfree, 2014).

The weather was categorised as average or unusual based on figures obtained from the UK Meteorological Office: average if the number of days with more than 0.2mm of rain fell between 35-70, hours of sunshine fell between 240-480 and mean daily temperature fell between 3-10C; and unusual otherwise.

Following these clarifications, the experts each gave private, individual first round estimates for the probability of good pollinator abundance given the various combination of the influencing factors in each of the elicitation questions. It was assumed that the probability of poor pollinator abundance is: 1- the probability of good abundance. The experts' estimates were plotted in anonymised form on graphs (see Appendix 2 Figure A2.1) ready for the discussion phase. The elicitation questions are listed in Appendix 1
During the discussion of the anonymised results, experts shared their understanding of what precisely each question was asking, discussed how they had come to their estimates and the reasons for the width of the interval between their lowest and highest plausible estimates. In particular, it was important for the facilitators to understand whether a wide interval was indicative of the expert's perceived uncertainty in the system or a reflection of their own uncertainty, for example, where they had more expertise in honey bees than hover flies and so felt less well able to estimate quantities on the questions about hover flies. Following the discussion, the experts each gave private, individual second-round responses in line with the IDEA protocol.

After the workshop, the experts' first and second-round estimates were compared and whilst some responses were unchanged, others were changed considerably. Of particular note, many of the experts reduced the interval between highest plausible and lowest plausible values in their second-round estimates, suggesting that they were more certain about the interval within which a good estimate should lie following the discussion. For example, in Q1.7, expert 1 showed a lot of uncertainty in round one which is reduced after the discussion as seen in a reduced distance between upper and lower estimates in their round 2 estimates. Experts 4 and 5 showed a significant change of mind on the location of their estimates following discussion, but remaining experts did not change much. A similar plot was produced for each question. In Q1.6, expert 2 shows a great deal of confidence with narrow bands between the upper and lower estimates which do not change after the discussion. Expert 3, in contrast, completely relocates their estimate following the discussion, so that the upper and lower bounds do not overlap. Expert 9 shows enormous uncertainty before discussion and a greater certainty afterward, as shown by reduced bands between upper and lower values from a difference of 90% to a difference of 20% (see Appendix 2 Figure A2.2 and A2.3).

The calibration exercise

Following the main elicitation exercise, the experts kindly agreed to take part in a calibration exercise. Permission was generously granted by a number of authors of refereed papers (see acknowledgments) to base calibration questions on their papers after they had been accepted for publication in a journal, but ahead of their actual publication, so that these papers were unavailable to the experts at the time of giving estimates for the calibration questions. The wording of the questions and the papers on which they were based is given in Appendix 1.

First-round estimates were received from ten of the original eleven experts via email and these were plotted in an anonymised format on graphs, as before. The discussion phase was held by Skype, with experts who were unable to attend agreeing to read the anonymised written record of the discussion before making their own second-round estimates. During the discussion, it emerged that the experts present at the meeting felt they had insufficient expertise between them to answer calibration questions 9, 10 and 11 with any confidence, so the second-round estimates for these questions were assumed to be identical to the first and calibration scoring was done both with and without these questions as a sensitivity analysis. All ten experts subsequently provided second estimates by email by an agreed date. These were analysed using the following measures of performance (See Appendix 1 and (Hanea et al., 2016) for details):

- The Brier score (per question, per expert)

- The average Brier score (per expert)
- The length of the uncertainty interval (per question, per expert)
- The calibration term of the Brier score (per expert calculated from all questions)
- Relative informativeness (per expert calculated from all answers)

These analyses showed that the differences in calibration scores were not significant between experts. This means that the estimates of the quantities of interest from the original elicitation workshop can be combined using an equal-weighting scheme of the second-round estimates.

Results

Using an equally weighted combination average, the aggregated lowest plausible, highest plausible and best estimates for the probability of good abundance of honey bees, other bees and hover flies were calculated from the of the second-round estimates.

These are given in Table 1.

[TABLE 1 HERE]

Using these values in the Bayesian network, we can now perform "what-if" analysis for all possible scenarios. The first scenario is a baseline, populated with the best estimate probabilities from Table 1 with the baseline probabilities that weather is average 62% of the time and 20% of UK environment is supportive as defined previously and that there is a 50/50 chance of good Varroa control (Figure 2).

[FIGURE 2 HERE]

The following scenarios are produced by asserting that one or more aspects of weather, environment or Varroa control have been observed, by setting these to 100%, also called `adding evidence'.

With a supportive environment the probability of good abundance increases from baseline values, but with a smaller improvement for honey bees as these are still impacted by the quality of Varroa control. Similarly, with an unsupportive environment the probability of good pollinator abundance reduces from baseline values, but less so for honey bees (Figure 3).

[FIGURE 3 HERE]

With good Varroa control, the probability of good honey bee abundance increases significantly from baseline values whilst the probability of good abundance of other bees and hover flies is unaffected since only honey bees are affected by the quality of Varroa control and analogously for poor Varroa control (see Appendix 2 Figure A2.4).

A combination of good Varroa control and unusual weather captures the balance of the influencing factors on different classes of pollinators. The values for hover flies and other bees are the same as unusual weather alone. The effect on honey bees of the combination of good Varroa control with unusual weather, shows probability of good abundance higher than baseline values, reflecting the experts' assertion that Varroa control has a stronger influence on honey bee abundance than weather. Similarly, the effect on honey bees of the combination of poor Varroa control with unusual weather shows probability of good abundance much lower than baseline values, reflecting the strong effect of poor Varroa control exacerbated by unusual weather (Figure 4).

[FIGURE 4 HERE]

A combination of good Varroa control and supportive environment shows a probability of good abundance of all pollinator classes much higher than baseline values (Figure13), which persists even in the event of unusual weather (see Appendix 2, Figure A2.5).

Finally, using the BN we can determine what the probabilities of good Varroa control, average weather and supportive environment need to be in order to be certain of good pollinator abundance. For good abundance of all classes of pollinators, Varroa control would need to be good with 73% probability in combination with 82% probability of average weather and 82% probability of supportive environment (Figure 5).

[FIGURE 5 HERE]

For good honey bee abundance, this level Varroa control along with probabilities of supportive environment and average weather raised slightly from baseline values would be sufficient. Under these conditions, the probability of good abundance of hover flies and other bees is also slightly improved. For good other bee abundance, a further slight increase in the probability of average weather in combination with a probability of supportive environment of 45% would be required. Honey bees and hover flies would also be expected to have an increased probability of good abundance under these conditions. For good hover fly abundance, a further increase in the probability of average weather is required. The probability of supportive environment is lower than for other bees, but still more than double the baseline values (see Appendix 2, Figure A2.6).

Discussion

We have estimated the probability of good pollinator abundance under various combinations of weather conditions, environmental circumstances and disease pressure profiles using structured expert judgement, overcoming the prohibitive difficulties of obtaining these by designed experiment. Structured expert judgement provides a way to estimate these quantities in a transparent and defensible manner. In the elicitation of quantities from experts, we have also shown that the differences in expertise between acknowledged specialists can be properly and robustly dealt with and reduced by the careful use of facilitated discussion, avoiding the severe problems associated with unstructured elicitation.

We have shown that these quantities can be used to quantify the likely effects of changes in drivers on the abundances of various classes of pollinating insects. This leads to the ability to test policy interventions alone and in combination for the likely impact on pollinator abundance to inform policy choice or pilot studies. For example, the quantities provided by the experts show that Varroa control has an enormous effect on the abundance of honey bees, so interventions which include assistance in good Varroa control are likely to be supportive of good honey bee abundance (Figure A2.4). We see that a supportive environment is good for all pollinators, but its effect is more constrained for honey bees as these are still influenced by the quality of Varroa control (Figure 3). We can also determine likely effect of policies on pollinator abundance under the effects of uncontrollable drivers, like weather. As more evidence becomes available, for example evidence on disease pressure for other pollinators, this can be incorporated into this model to refine the estimates of pollinator abundance. This approach can also be extended to include other drivers. For example, estimating the effect of climate change on weather variability could be used to adjust the probability of unusual weather (as defined here) and so quantify the knock-on effect on pollinator abundance. Work to do this using the methods in (Smith et al., 2017) is currently under way and will be reported separately.

By eliciting not only best estimate values for the probability of good abundance, but also the lowest and highest plausible values (Table 1), it becomes evident that not all these influencing factors have a symmetrical effect. For example, unusual weather has the effect of lowering the lowest plausible probability of good abundance for all pollinator classes more than the highest plausible probability of good abundance, with other factors constant. The notable exception to this is for honey bees when Varroa control is poor; here additional weather effects are small.

Further interesting patterns can be seen in the similar and different responses of different classes of pollinators. Whenever the environment is unsupportive, the highest plausible value for the probability of good abundance in all pollinator classes is less than 43%, except in the case of honey bees with good Varroa control, where it is still under 60%. This suggests that a supportive environment is a key modifiable factor to support pollinator abundance. Whenever Varroa control is poor, the highest plausible value for the probability of good abundance of honey bees is below 45%, regardless of the other factors, suggesting that Varroa control is a key modifiable factor to support honey bee abundance. Using the BN to determine what the probabilities of good Varroa control, average weather and supportive environment need to be in order to be certain of good pollinator abundance, we have shown how the different classes of pollinator have differing requirements. Since, in the short term at least, weather is not a controllable factor, we return to the scenario in Figure A2.5 and show that in areas where the environment is supportive and Varroa control is good, then we can expect a probability of good abundance of pollinators of all classes in excess of 60%.

Important policy conclusions from this work are:

- Actions to improve the effectiveness of Varroa control should be a priority for the honeybee policy area. The results demonstrate the importance of Varroa management for individual beekeepers, but given that Varroa management was by far the most important driver for honeybee abundance identified in this study, it suggests also that improvements to government policy on Varroa management would also be a useful way forward,
- Improving the amount of supportive environment will have large benefits for wild bees and other pollinators, with some benefits also for honeybees – the results suggest this should be a priority policy area.

This study adds an estimate of how much change in pollinator abundance might be expected form implementation of policy recommendations.

The strengths of this study are the use of established and validated methods to derive quantities of interest, making this a unique contribution. The provision of the likely effect of combinations of factors on pollinator abundance is of great importance within ecosystem service management and conservation as well as policy design. In particular, the preservation of pollinators is of such importance that there are national strategies in the UK and elsewhere and these findings can be used to evaluate candidate policies in order to support policymakers in making evidence-based choices. The experts who contributed to the workshop and provided estimates are recognized as top experts in the field, and many have already given evidence to the UK government in the development of the national strategy, giving confidence that these estimates are likely to be reliable given the current state of knowledge.

The limitations of the study are the rough discretisation of the continuous variables and the choice of calibration questions. We had to reduce the levels of weather, disease pressure and environment to two levels each in order to complete the elicitation in the time available. Ideally a more nuanced categorisation would be preferred. However, more levels per variable lead to a rapid rise in the number of conditional probabilities to be elicited, hence in an increased elicitation burden. Future work could include the use of continuous BNs which can drastically reduce the number of parameters to be elicited (Hanea, Kurowicka, & Cooke, 2006; Morales, Kurowicka, & Roelen, 2008). Also only a subset of drivers were chosen which excluded some others known to be major stressors on pollinators, such as climate change and pesticides. Finding evidence on which to base calibration questions was enormously difficult and the calibration questions are not as similar to the elicitation questions as we would have liked. In our implementation of the protocol the difficulty was increased by having the calibration exercise remotely; for practical reasons, the calibration discussion was carried on by Skype and not face-to-face. It is likely that the intervals between the highest and lowest plausible estimates would have been smaller following a face-to-face discussion. Three questions were deemed beyond the experts' domain knowledge. However, by undertaking sensitivity analysis with respect to these questions, we have shown that the calibration score and so the weighting between experts is not significantly affected. To undertake structured expert elicitation well takes time and is very demanding for experts. These compromises, whilst not ideal, enabled the study to take place.

Future work will include the incorporation of these values with other evidence on major drivers of pollinator abundance to provide a proof of concept decision support system which could be used by policy-makers to evaluate the effect on pollinator abundance of plausible scenarios and policy interventions, based on new methodology for coherent inference in networked systems (Smith et al., 2017). We conclude that when evidence based decision-making is required, structured expert judgement can provide useful, transparent and defensible evidence, including in the ecosystem services domain.

Contributors

MJB conceived the study. MJB & AMH designed and implemented the study. SKW recorded the discussions and entered the data. NC advised on the form of the elicitation questions and provided material for the calibration questions. KB, LBW, DC, SD, JF, CH, AL, JO and SP were the experts whose opinions were elicited; they took part in both the face-to-face workshop and in the calibration exercise. AMH moderated and facilitated the workshop and calibration discussions (aided by MJB, SKW) and analysed the data. MJB drafted the paper. All authors critically revised the manuscript for important intellectual content and approved the final version to be published.

Acknowledgments

We acknowledge with gratitude the corresponding authors of (Alvarez, Lucia, Aquino, Ramello, & Abrahamovich, 2015; beeinformed.org, 2015; Jones et al., 2016; Liolios et al., 2015; Liu et al., 2016; Seitz et al., 2015; Spleen et al., 2013) for allowing us to have sight of their unpublished papers on which to base calibration questions.

We acknowledge the valuable contribution of Stuart Roberts to the elicitation workshop discussion.

We also acknowledge those who gave generously of their time to critique and advise on the model of the full pollinator system of which this work is a subset.

Funding

The workshop was generously funded jointly by two of the University of Warwick's Global Research Priorities (GRPs), the GRP for Behavioural Science and the Food GRP. MJB was funded by EPSRC grant number EP/K007580/1 and SKW was funded by EPSRC grant EP/L016710/1.

Competing Interests

We confirm no support from any organisation for the submitted work except as listed above; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years, no other relationships or activities that could appear to have influenced the submitted work.

References

Al-Ghamdi, A. A., Abou-Shaara, H. F., & Mohamed, A. A. (2014). Hatching rates and some characteristics of Yemeni and Carniolan honey bee eggs. *Journal of Entomology and Zoology Studies, 2*(1), 6-10.

Alvarez, L. J., Lucia, M., Aquino, D. A., Ramello, P. J., & Abrahamovich, A. H. (2015). Nesting biology and associated insect enemies of the exotic leaf cutter bee Megachile (Eutricharaea) concinna (Hymenoptera: Megachilidae) in Argentina. *Journal of Apicultural Research, 54*(4), 305-313.

Arundel, J. (2011). *Understanding the Spread of Honeybee Pests and Diseases: An agent-based modelling approach*. RIRDC Publication No. 11/102

Aspinall, W. (2010). A route to more tractable expert advice. *Nature, 463*, 294-295.

Aspinall, W. A. C., Roger M. (1998). Expert judgment and the Montserrat Volcano eruption. *Proceedings of the 4th international confernece on probabilisitic safety assessment and management, 3*, 2113-2118.

Bailes, E. J., Ollerton, J., Pattrick, J. G., & Glover, B. J. (2015). How can an understanding of plant-pollinator interactions contribute to global food security? *Current Opinion in Plant Biology., 26*, 72-79.

Baldock, K., Goddard, M. A., Kunin, W. E., Potts, S. G., Stone, G. N., & Memmott, J. (2015). Managing urban areas for insect pollinators: As town and cities continue to grow how can land managers help insect pollinators in urban areas? *Living With Environmental Change network*.

Baldock, K. C. R., Goddard, M. A., Hicks, D. M., Kunin, W. E., Mitschunas, N., Osgathorpe, *et al* Memmott, J. (2015). Where is the UK's pollinator biodiversity? The importance of urban areas for flower-visiting insects. *Proceedings of the Royal Society B: Biological Sciences*.

Barker, I., Garthwaite, D. G., & Parrish, G. (2014). *Pesticide usage survey report 266 potato stores in the United Kingdom 2014*. Retrieved from https://secure.fera.defra.gov.uk/pusstats/surveys/documents/potato_storage_2014-final_report-v1.pdf

Baron, G. L., Raine, N. E., & Brown, M. J. F. (2014). Impact of chronic exposure to a pyrethroid pesticide on bumblebees and interactions with a trypanosome parasite. *Journal of Applied Ecology, 51*(2), 460-469.

Baude, M., Kunin, W. E., Boatman, N. D., Conyers, S., Davies, N., Gillespie, M. A. K., *et al*. Memmott, J. (2016). Historical nectar assessment reveals the fall and rise of floral resources in Britain. *Nature Letter, 530*,85–88.

Becher, M. A., Grimm, V., Thorbek, P., Horn, J., Kennedy, P. J., & Osborne, J. L. (2014). BEEHAVE: a systems model of honey bee colony dynamics and foraging to explore multifactorial causes of colony failure. *Journal of Applied Ecology, 51*, 470-482.

Becher, M. A., Osborne, J. L., Thorbek, P., Kennedy, P. J., & Grimm, V. (2013). Towards a systems approach for understanding honey bee decline: a stocktaking and synthesis of existing models. *The Journal of Applied Ecology, 50(4)*, 868-880.

beeinformed.org. (2015). Colony loss 2014 2015 preliminary results.

Bishop, J., Jones, H. E., Lukac, M., & Potts, S. G. (2016). Insect pollination reduces yield loss following heat stress in faba bean (Vicia faba L.). *Agriculture, Ecosystems & Environment, 220*, 89-96.

Blaauw, B. R., & Isaacs, R. (2014). Flower plantings increase wild bee abundance and the pollination services provided to a pollination-dependent crop. *Journal of Applied Ecology, 51(4)*, 890-898.

Botias, C., David, A., Horwood, J., Abdul-Sada, A., Nicholls, E., Hill, E., & Goulson, D. (2015). Neonicotinoid Residues in Wildflowers, a Potential Route of Chronic Exposure for Bees. *Environ. Sci. Technol., 49 (21)*, 12731-12740.

Breeze, T. D., Roberts, S. P. M., & Potts, S. G. (2012). *The decline of England's bees*. Retrieved from https://friendsoftheearth.uk/sites/default/files/downloads/beesreport.pdf

Breeze, T. D., Vaissière, B. E., Bommarco, R., Petanidou, T., Seraphides, N., Kozák, L., *et al*. Potts, S. G. (2014). Agricultural Policies Exacerbate Honeybee Pollination Service Supply-Demand Mismatches Across Europe. *PLOS ONE, 9*(1), e82996. doi:10.1371/journal.pone.0082996

Brown, M. J. F., Dicks, L. V., Paxton, R. J., Baldock, K., Barron, A. B., Chauzat, M. P., *et al*. Stout, J. C. (2016). A horizon scan of future threats and opportunities for pollinators and pollination. *PeerJ, 4*.

Bull, J. C., Ryabov, E. V., Prince, G., Mead, A., Zhang, C., Baxter, L., *et al*. Chandler, D. (2012). .A strong immune response in young adult honeybees masks their increased susceptibility to infection compared to older bees. *PLoS Pathogens, 8*(12).

Burgman, M. A. (2016). *Trusting judgements: How to get the best out of experts*: Cambridge UK: Cambridge University Press.

Capri, E., Higes, M., & Kasiotis, K. M. (2013). *Bee health in Europe - Facts & figures 2013*. Retrieved from http://www.operaresearch.eu/files/repository/20130122162456_BEEHEALTHINEUROPE-Facts&Figures2013.pdf

Carreck, N. (2011). *Varroa - still a problem in the 21st Century?* : International Bee Research Association, Cardiff, UK.

Carreck, N. L., Ball, B. V., & Martin, S. J. (2010a). The epidemiology of cloudy wing virus infections in honey bee colonies in the UK. *Journal of Apicultural Research, 49*, 66-71.

Carreck, N. L., Ball, B. V., & Martin, S. J. (2010b). Honey bee collapse and changes in viral prevalence associated with Varroa destructor. *Journal of Apicultural Research, 49*, 93-94.

Carreck, N. L., & Ratnieks, F. L. W. (2014). The dose makes the poison: have “field realistic” rates of exposure of bees to neonicotinoid insecticides been over estimated in laboratory studies? *Journal of Apicultural Research, 53*(5), 607-614.

Carvell, C., Jitlal, N. I. M., Peyton, J., Powney, G., Roy, D., Vanbergen, A., *et al*. Roy, H. (2016). *Design and Testing of a National Pollinator and Pollination Monitoring Framework*. Retrieved from https://www.researchgate.net/publication/308201468_Design_and_Testing_of_a_National_Pollinator_and_Pollination_Monitoring_Framework

Chandler, D., Bailey, A., Tatchell, M., Davidson, G., Greaves, J., & Grant, W. (2011). The development, regulation and use of biopesticides for integrated pest management. *Philosophical Transactions of the Royal Society B: Biological Sciences, 366*(1573), 1987-1998.

Chandler, D., Davidson, G., Pell, J. K., Shaw, V. B., & Sunderland, K. D. (2000). Fungal Biocontrol of Acari. *Biocontrol Science and Technology, 10*, 357-384.

Chandler, D., Prince, G., & Pell, J. K. (2011). Biological control of varroa with entomopathogenic fungi : a sustainable solution for a globally important pest? *Microbiology Today, 39*(4), 222-225.

Chauzat, M.P., Laurent, M., Riviere, M.P., Saugeon, C., Hendrikx, P., on behalf of the Epilobee consortium, M. R.C. (2014). *A pan-European epidemiological study on honey bee colony losses 2012-2013*. Retrieved from http://www.ilfattoalimentare.it/wp-content/uploads/2014/04/bee-report_en1.pdf

Connolly, C. (2013). The risk of insecticides to pollinating insects. *Communicative & Integrative Biology, 6*(5), 25074-25074.

Cooke, R. (1991). *Experts in uncertainty: Opinion and subjective probability in science*: Oxford University Press.

Cooke, R., & Goossens, L. (2008). TU Delft expert judgment data base. *Reliability Engineering and System Safety, 93*(5), 657-674.

Cooke, R. M., Wilson, A. M., Tuomisto, J. T., Morales, O., Tainio, M., & Evans, J. S. (2007). A Probabilistic Characterization of the Relationship between Fine Particulate Matter and Mortality: Elicitation of European Experts. *Environmental Science & Technology, 41*(18), 6598-6605. doi:10.1021/es0714078

Cranmer, L., McCollin, D., & Ollerton, J. (2012). Landscape structure influences pollinator movements and directly affects plant reproductive success. *Oikos., 121*(4), 562-568.

Datta, S., Bull, J. C., Budge, G. E., & Keeling, M. J. (2013). Modelling the spread of American Foulbrood in honey bees. *Journal of The Royal Society Interface, 10*(88), DOI:-DOI: 10.1098/rsif.2013.0650.

Defra. (2013). *Bee Health Evidence Plan*. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/221079/pb13907-evidenceplan-bee-health.pdf

Defra. (2014). *The National Pollinator Strategy: for bees and other pollinators in England*. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/409431/pb14221-national-pollinators-strategy.pdf

Dicks, L. V., Viana, B., Bommarco, R., Brosi, B., Arizmendi, M. d. C., Cunningham, S. A., *et al.* Potts, S. G. (2016). Ten policies for pollinators. *Science, 354*(6315), 975-976. doi:10.1126/science.aai9226

Dicks, L. V., Baude, M., Roberts, S. P. M., Phillips, J., Green, M., & Carvell, C. (2015). How much flower-rich habitat is enough for wild pollinators? Answering a key policy question with incomplete knowledge. *Ecological Entomology, 40*, 22-35.

Dively, G. P., Embrey, M. S., Kamel, A., Hawthorne, D. J., & Pettis, J. S. (2015). Assessment of Chronic Sublethal Effects of Imidacloprid on Honey Bee Colony Health. *PLOS ONE, 10(3)*, e0118748.-e0118748. doi:0118710.0111371/journal.pone.0118748.

E. Benjamin, F., R. Reilly, J., & Winfree, R. (2014). Pollinator body size mediates the scale at which land use drives crop pollination services. *Journal of Applied Ecology, 51*(2), 440-449.

EASAC. (2015). Ecosystem services, agriculture and neonicotinoids. *European Academies Science Advisory Council* retrieved from https://www.easac.eu/fileadmin/Reports/Easac_15_ES_web_complete.pdf

EFSA. (2012). *Statement on the findings in recent studies investigating sub-lethal effects in bees of some neonicotinoids in consideration of the uses currently authorised in Europe*. Retrieved from http://www.efsa.europa.eu/en/efsajournal/pub/2752

EFSA. (2013). *Guidance on the risk assessment of plant protection products on bees (Apis mellifera, Bombus spp. and solitary bees)*. Retrieved from

EFSA. (2014). Guidance on Expert Knowledge Elicitation in Food and Feed Safety Risk Assessment. *European Food safety Authority (EFSA) Journal, 12(6)*, 3734-3734.

Elith, J. (2009). Spatial Conservation Prioritization: Quantitative Methods and Computational Tools. In A. Moilanen, A. W. Kerrie, & H. Possingham (Eds.): Oxford University Press.

Fithian, W., Elith, J., Hastie, T., & Keith, D. A. (2014). Bias correction in species distribution models: pooling survey and collection data for multiple species. *Methods in Ecology and Evolution, 6*(4), 424-438.

Fürst, M. A., McMahon, D. P., Osborne, J. L., Paxton, R. J., & Brown, M. J. F. (2014). Disease associations between honeybees and bumblebees as a threat to wild pollinators. *Nature, 506*, 364-366.

Garibaldi, L. A., Steffan-Dewenter, I., Kremen, C., Morales, J. M., Bommarco, R., Cunningham, S. A., *et al*. Klein, A. M. (2011). Stability of pollination services decreases with isolation from natural areas despite honey bee visits. *Ecology Letters, 14*(10), 1062-1072.

Garratt, M. P. D., Truslove, C. L., Coston, D. J., Evans, R. L., Moss, E. D., Dodson, C., *et al* Potts, S. G. (2014). Pollination deficits in UK apple orchards. *Journal of Pollination Ecology, 12*(2), 9-14.

Garthwaite, D., Barker, I., Laybourn, R., Huntly, A., Parrish, G., Hudson, S., *et al.* Macarthur, R. (2014a). *Pesticide usage survey report 265 orchards in the United Kingdom 2014*. Retrieved from https://www.gov.uk/government/statistics/pesticide-usage-survey-orchards-in-the-united-kingdom-2014

Garthwaite, D., Barker, I., Laybourn, R., Huntly, A., Parrish, G. P., Hudson, S., & Thygesen, H. (2014). *Pesticide usage survey report 263 arable crops in the United Kingdom 2014*. Retrieved from https://secure.fera.defra.gov.uk/pusstats/surveys/documents/arable2014v2.pdf

Garthwaite, D., Barker, I., Laybourn, R., Huntly, A., Parrish, G. P., Hudson, S., *et al.* Macarthur, R. (2014b). *Pesticide usage survey report 264 soft fruit in the United Kingdom 2014*. Retrieved from https://secure.fera.defra.gov.uk/pusstats/surveys/documents/softFruit2014.pdf

Gill, R. J., Baldock, K. C. R., Brown, M. J. F., Cresswell, J. E., Dicks, L. V., Fountain, M. T., *et al.* Potts, S. G. (2015). Protecting an Ecosystem Service: Approaches to Understanding and Mitigating Threats to Wild Insect Pollinators. *Advances in Ecological Research, vol 54., pp. 135-206*.

Godfray, H. C. J., Blacquière, T., Field, L. M., Hails, R. S., Petrokofsky, G., Potts, S. G., *et al.* McLean, A. R. (2014). A restatement of the natural science evidence base concerning neonicotinoid insecticides and insect pollinators. *Proceedings of the Royal Society B Biological sciences*.

Gordon, R., Bresolin-Schott, N., & East, I. J. (2014). Nomadic beekeeper movements create the potential for widespread disease in the honeybee industry. *The Journal of the Australian Veterinary Association Ltd., 92*, 283-290.

Granger Morgan, M., Pitelka, L. F., & Shevliakova, E. (2001). Elicitation of Expert Judgments of Climate Change Impacts on Forest Ecosystems. *Climatic Change, 49*(3), 279-307. doi:10.1023/a:1010651300697

Guillera-Arroita, G., Lahoz-Monfort, J. J., Elith, J., Gordon, A., Kujala, H., Lentini, P. E., *et al.* Wintle, B. A. (2015). Is my species distribution model fit for purpose? Matching data and models to applications. *Global Ecology and Biogeography, 24*(3), 276-292.

Hall, D. M., Camilo, G. R., Tonietto, R. K., Smith, D. H., Ollerton, J., Ahrné, K., *et al.* Threlfall, C. G. (2016). The city as a refuge for insect pollinators. *Conservation Biology.*

Hanea, A. M., Kurowicka, D., & Cooke, R. M. (2006). Hybrid Method for Quantifying and Analyzing Bayesian Belief Nets. *Quality and Reliability Engineering International, 22*(6).

Hanea, A. M., McBride, M. F., Burgman, M. A., Wintle, B. C., Fidler, F., Flander, L., *et al.* Mascaro, S. (2016). Investigate Discuss Estimate Aggregate for structured expert judgement. *International Journal of Forecasting, .* .-.

Hartfield, C. (2017). *Clarity, not more confusion, needed in neonics debate*. Retrieved from https://www.nfuonline.com/sectors/crops/crops-news/clarity-not-more-confusion-needed-in-neonics-debate/

Hicks, D. M., Ouvrard, P., Baldock, K., Baude, M., Goddard, M. A., Kunin, W. E., *et al.* Stone, G. N. (2016). Food for Pollinators: Quantifying the Nectar and Pollen Resources of Urban Flower Meadows. *PLoS ONE, vol 11*.

Jaffé, R., Dietemann, V., Allsopp, M. H., Costa, C., Crewe, R. M., Dall'olio, R., *et al.* Moritz, R. F. (2010). Estimating the density of honeybee colonies across their natural range to fill the gap in pollinator decline censuses. *Conserv Biol, 24*(2), 583-593.

Jones, C. E., Allen, R., Hoffman, F., Muñoz, A., Erickson, M., Stone, D., & Atallah, Y. (2016). Spatiotemporal variation in pollinator taxa on the Santa Ana River Woolly Star Eriastrum densifolium ssp. sanctorum (Milliken) Mason (Polemoniaceae). *Unpublished study*.

Kahneman, D., & Tversky, A. (1984). Choices, values, and frames. *American Psychologist, 39*(4), 341-350.

Keeney, R., & von Winterfeldt, D. (1991). Eliciting probabilities from experts in complex technical problems. *IEEE Transactions on Engineering Management, 38*, 191-201.

Kennedy, C. M., Lonsdorf, E., Neel, M. C., Williams, N. M., Ricketts, T. H., Winfree, R., *et al.* Kremen, C. (2013). A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. *Ecology Letters, 16*(5), 584-599.

Kerr, J. T., Pindar, A., Galpern, P., Packer, L., Potts, S. G., Roberts, S. M., *et al.* Pantoja, A. (2015). Climate change impacts on bumblebees converge across continents. *Science, 349*(6244), 177-180.

Klein, A.-M., Vaissière, 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*(1608), 303-313. doi:10.1098/rspb.2006.3721

Krayer von Krauss, M. P., Casman, E. A., & Small, M. J. (2004). Elicitation of Expert Judgments of Uncertainty in the Risk Assessment of Herbicide-Tolerant Oilseed Crops. *Risk Analysis, 24*(6), 1515-1527. doi:10.1111/j.0272-4332.2004.00546.x

Lecocq, A., Jensen, A. B., Kryger, P., & Nieh, J. C. (2016). Parasite infection accelerates age polyethism in young honey bees. *Sci Rep., 6 doi: 10.1038/srep22042.*(22042).

Liolios, V., Tananaki, C., Dimou, M., Kanelis, D., Goras, G., Karazafiris, E., & Thrasyvoulou, A. (2015). Ranking pollen from bee plants according to their protein contribution to honey bees. *Journal of Apicultural Research, 54*(5), 582-592.

Liu, Z., Chen, C., Niu, Q., Qi, W., Yuan, C., Su, S., *et al*. Shi, W. (2016). Survey results of honey bee (Apis mellifera) colony losses in China (2010–2013). *Journal of Apicultural Research, 55*(1), 29-37. doi:10.1080/00218839.2016.1193375

Lonsdorf, E., Kremen, C., Ricketts, T., Winfree, R., & Greenleaf, N. W. S. (2009). Modelling pollination services across agricultural landscapes. *Annals of Botany, 103*, 1589-1600.

Lucas, A. (2017). *The role of hoverflies as pollinators in Welsh conservation grasslands.* Swansea University.

Manley, R., Boots, M., & Wilfert, L. (2015). Emerging viral disease risk to pollinating insects: ecological, evolutionary and anthropogenic factors. *J Appl Ecol, 52*, 331-340.

Martin, S. J., Ball, B. V., & Carreck, N. L. (2010). Prevalence and persistence of deformed wing virus (DWV) in untreated or acaricide treated Varroa destructor infested honey bee (Apis mellifera) colonies. *Journal of Apicultural Research, 49*, 72-79.

Matheson, A., & Carreck, N. (2014). *Forage for pollinators in an agricultural landscape*: International Bee Research Association; Treforest, UK.

Mayer, C., Adler, L., Armbruster, W. S., Dafni, A., Eardley, C., Huang, S. Q., *et al.* Potts, S. G. (2011). Pollination ecology in the 21st Century: key questions for future research. *Journal of Pollination Ecology. 3, pp. 8-23. 1920-7603.*

McGrath, M. (2013). Honey bee losses double in a year due to poor winter.

Meixner, M. D., Büchler, R., Costa, C., Francis, R., Hatjina, F., Kryger, P., *et al.* Carreck, N. L. (2014). Honey bee genotypes and the environment. *Journal of Apicultural Research, 53*(2), 183-187.

Morales, O., Kurowicka, D., & Roelen, A. (2008). Eliciting conditional and unconditional rank correlations from conditional probabilities. *Reliability Engineering & System Safety, 93*(5), 699-710. doi:https://doi.org/10.1016/j.ress.2007.03.020

O'Hagan, A., Buck, C., Daneshkhah, A., Eiser, J., Garthwaite, P., Jenkinson, D., *et al.* Rakow, T. (2006). *Uncertain judgements: Eliciting experts' probabilities*: Wiley.

Ollerton, J. (2012). The importance of native pollinators. *The Plantsman., 11*(2), 86-89.

Ollerton, J., Erenler, H. E., Edwards, M., & Crockett, R. G. M. (2014). Extinctions of aculeate pollinators in Britain and the role of large-scale agricultural changes. *Science. 346(6215), pp. 1360-1362. 1095-9203.*

Ollerton, J., Rouquette, J. R., & Breeze, T. D. (2016). Insect pollinators boost the market price of culturally important crops: holly, mistletoe and the spirit of Christmas. *Journal of Pollination Ecology. 19, pp. 93-97. 1920-7603.*

Orford, K. A., Murray, P. J., Vaughan, I. P., & Memmott, J. (2016). Modest enhancements to conventional grassland diversity improve the provision of pollination services. *Journal of Applied Ecology, 53*(3), 906-915.

Pearl, J. (1985). Bayesian Networks: A Model of Self-Activated Memory for Evidential Reasoning. *Proc. of Cognitive Science Society (CSS-7), 7*, 329-334.

Perry, C. J., Sovik, E., Myerscough, M. R., & Barron, A. B. (2015). Rapid behavioral maturation accelerates failure of stressed honey bee colonies. *Proceedings of the National Academy of Sciences, 112*(11), 3427-3432.

Pettis, J. S., Lichtenberg, E. M., Andree, M., Stitzinger, J., Rose, R., & Vanengelsdorp, D. (2013). Crop Pollination Exposes Honey Bees to Pesticides Which Alters Their Susceptibility to the Gut Pathogen Nosema ceranae. *PLOS ONE, 8(7)*, e70182. doi: 70110.71371/journal.pone.0070182-e0070182.

Polce, C., Termansen, M., Aguirre-Gutiérrez, J., Boatman, N. D., Budge, G. E., Crowe, A., *et al.* Biesmeijer, J. C. (2013). Species Distribution Models for Crop Pollination: A Modelling Framework Applied to Great Britain. *PLOS* ONE, 8(10): e76308. DOI: 10.1371/journal.pone.0076308

Potts, S. G., Imperatriz-Fonseca, V., Ngo, H. T., Biesmeijer, J. C., Breeze, T. D., Dicks, L. V., *et al* Vanbergen, A. J. (2016). *Summary for policymakers of the assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production*. Retrieved from https://www.researchgate.net/publication/310132044_IPBES_2016_Summary_for_policymakers_of_the_assessment_report_of_the_Intergovernmental_Science-Policy_Platform_on_Biodiversity_and_Ecosystem_Services_on_pollinators_pollination_and_food_production_2016

Rader, R., Bartomeus, I., Garibaldi, L. A., Garratt, M. P. D., Howlett, B. G., Winfree, R., *et al.* Woyciechowski, M. (2016). Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences, 113*, 146-151.

Renner, I. W., Elith, J., Baddeley, A., Fithian, W., Hastie, T., Phillips, S. J., *et al.* Warton, D. I. (2015). Point process models for presence-only analysis. *Methods in Ecology and Evolution, 6*(4), 366-379.

Ryabov, E. V., Wood, G. R., Fannon, J. M., Moore, J. D., Bull, J. C., Chandler, D., *et al.* Evans, D. J. (2014). A Virulent Strain of Deformed Wing Virus (DWV) of Honeybees (Apis mellifera) Prevails after Varroa destructor-Mediated, or In Vitro, Transmission. *PLOS Pathog, 10(6)*, DOI:-DOI: 10.1371/journal.ppat.1004230.

Scheper, J., Holzschuh, A., Kuussaari, M., Potts, S. G., Rundlöf, M., Smith, H. G., & Kleijn, D. (2013). Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss – a meta-analysis. *Ecology Letters, 16*(7), 912-920.

Seitz, N., Traynor, K. S., Steinhauer, N., Rennich, K., Wilson, M. E., Ellis, J. D., *et al.* vanEngelsdorp, D. (2015). A national survey of managed honey bee 2014–2015 annual colony losses in the USA. *Journal of Apicultural Research* 54:4, 292-304, DOI: 10.1080/00218839.2016.1153294.

Senapathi, D., Goddard, M., Kunin, W. E., & Baldock, K. (2016). Landscape impacts on pollinator communities in temperate systems: evidence and knowledge gaps. *Functional Ecology.*

Settele, J., Bishop, J., & Potts, S. G. (2016). Climate change impacts on pollination. *Nature Plants*. doi:10.1038/nplants.2016.92

Slovic, P. (1999). Trust, emotion, sex, politics, and science: surveying the risk-assessment battle Field. *Risk Analysis, ,19*, 689-701.

Smith, J. Q., Barons, M. J., & Leonelli, M. (2017). Coherent inference for integrating decision support systems. arXiv 1507.07394.

Spleen, A. M., Lengerich, E. J., Rennich, K., Caron, D., Rose, R., Pettis, J. S., *et al.* vanEngelsdorp, D. (2013). A national survey of managed honey bee 2011-12 winter colony losses in the United States: results from the Bee Informed Partnership. *Journal of Apicultural Research, 52*(2), 44–53-44–53.

Staley, J. T., Sparks, T. H., Croxton, P. J., Baldock, K. C. R., Heard, M. S., Hulmes, S., *et al.* Pywell, R. F. (2012). Long-term effects of hedgerow management policies on resource provision for wildlife. *Biological Conservation. 145, p.24 - 29*.

Stanley, D. A., Smith, K. E., & Raine, N. E. (2015). Bumblebee learning and memory is impaired by chronic exposure to a neonicotinoid pesticide. *Nature Scientific Reports, 5*(16508).

Sutherland, W. J., & Burgman, M. (2015). Policy advice: Use experts wisely. *Nature*, 317–318-317–318.

Tarrant, S., Ollerton, J., Rahman, M. L., Tarrant, J., & McCollin, D. (2013). Grassland restoration on landfill sites in the East Midlands, United Kingdom: an evaluation of floral resources and pollinating insects. *Restoration Ecology. 21(5), pp. 560-568. 1061-2971.*

Tuell, J. K., & Isaacs, R. (2010). Weather during bloom affects pollination and yield of highbush blueberry. *J Econ Entomol., 103*(3), 557-562.

van der Zee, R., Gray, A., Holzmann, C., Pisa, L., Brodschneider, R., Chlebo, R., *et al.* Wilkins, S. (2013). Standard survey methods for estimating colony losses and explanatory risk factors in Apis mellifera. *Journal of Apicultural Research and Bee World*.

Vanbergen, A. J., & The Insect Pollinatoors Initiative, (2013). Threats to an ecosystem service: pressures on pollinators. *Frontiers in Ecology and the Environment* 11(5): 251–259, doi:10.1890/120126.

Vicens, N., & Bosch, J. (2014). Weather-Dependent Pollinator Activity in an Apple Orchard, with Special Reference to Osmia cornuta and Apis mellifera (Hymenoptera: Megachilidae and Apidae). *Environmental Entomology, 29*(3), 413-413.

Wilfert, L., Long, G., Leggett, H. C., Schmid-Hempel, P., Butlin, R., Martin, S. J. M., & Boots, M. (2016). Deformed wing virus is a recent global epidemic in honeybees driven by Varroa mites. *Science, 351*, 594-597.

Appendix 1.

A.1 The IDEA protocol

Like most structured elicitation protocols, IDEA has a pre- and post- elicitation stage. Prior to the elicitation the questions must be formulated and the experts identified. Two types of questions may be asked during the elicitation: the questions of interest, and the so-called calibration questions which can be then used to calibrate the experts' assessments, calculate performance measures to be used as weights for the mathematical aggregation step of the protocol. The IDEA protocol was refined and tested as part of a forecasting "tournament" that started in 2011 as an initiative of the US Intelligence Advanced Research Projects Activity (IARPA). In making their estimates for each question, experts may answer questions about quantities / variables measured on a continuous scale, or about probabilities of discrete variables. In asking about probabilities, IDEA uses a 3 step format (Hanea et al., 2016; Sutherland & Burgman, 2015).

In the pre-elicitation stage, the problem needs to be defined as precisely as possible to minimise any risk of semantic or other misunderstandings arising, and to aid in the identification of the suitable experts. A detailed search is used to find potential experts and these are approached for their involvement. The data on which the calibration questions will be based is ideally identified at this stage and designed to be as close to the experts' domain and the questions of interest as possible. Finally, some training is delivered to the experts to explain what is required of them and, if relevant, discuss the estimation of probabilities. The elicitation stage consists of three phases: investigate, discuss and estimate. It begins with experts investigating several resources, individually. A list of essential documents and resources is circulated amongst experts. If any expert knows of relevant evidence which does not appear in the list, they suggest these to the facilitator who makes the resource available to all the experts. However, the amount of resources provided should be limited to the essential reading, since too much information might bias the experts. In the discussion stage, more information and resources are revealed and discussed. Based on these investigations, the experts provide individual estimates of the quantities of interest by answering the questions without discussing with, or disclosing their responses to, the other experts. They are asked to provide their estimates in a particular order: their lowest plausible, highest plausible and then best estimate of the quantities of interest. This ordering is designed to avoid anchoring the upper and lower estimates around the best estimate and leads to better accuracy.

The second phase is a facilitated discussion of the anonymised results for each question in turn, which irons out any residual semantic difficulties and allows experts to share their reasoning and any further additional evidence with each other. This ensures that every expert is answering the same question based on the same evidence. The third phase is a second round of individual, private estimates, allowing experts the opportunity to revise (or not) their estimates, based on what they heard in the discussion. The privacy afforded for providing their second round estimates protects them from any pressure to conform to the views of others.

The calibration exercise is identical in format to the elicitation. The principal difference is that the `answers' to the calibration questions can be checked - either they will become known shortly or they are already known to the elicitation facilitator, but not accessible to the experts. The calibration data is used to construct a set of test questions for which experts are asked to give highest plausible, lowest plausible and best estimate with a facilitated discussion and second private estimate identical to the elicitation exercise. It is important that these questions are as central to the experts' area of expertise as possible and sufficiently similar to the quantities of interest in the main elicitation. The experts' estimates on the test questions can be compared by the elicitation team to the known values and performance measures can be calculated. These performance measures can be used to inform the mathematical aggregation into a single distribution or point estimate.

Performance Measures

(See (Hanea et al., 2016) for details):

- The Brier score is twice the squared difference between an estimated probability of an event (best guess) and the actual outcome; therefore it takes values between 0 and 2. Lower values are better and are achieved if an expert assigns large probabilities to events that occur, or small probabilities to events that do not occur. We calculated this per question, per expert.
- The average Brier score is a participant's accuracy is measured over many questions and averaged to represent long term accuracy. Since scores close to 0 are good for the individual questions, it follows that scores close to 0 are good for the average of those individual question scores and that a big score corresponds to poor performance. A score of 0.5 can be achieved by setting all answers to 50% i.e. 'I don't know'. We calculated this per expert.

- The length of the uncertainty interval is an indication of an experts' confidence in the best estimate given; small scores are better because they represent certainty. We calculated this per question, per expert.
- The calibration term of the Brier score places forecasts into groups or bins with the same forecast probability and is based on the difference between the empirical and the theoretical distribution of each bin, therefore smaller scores are better. We calculated one number per expert calculated from all questions.
- Relative informativeness is based on measuring entropy. For details see (R. Cooke, 1991). We calculated one score per expert calculated from all answers. Larger scores are better

The final stage is the mathematical aggregation of experts' judgements. Commonly, some form of weighting is used based on the calibration exercise, which provides insight into the ability of the experts to estimate probabilities - a task known to be difficult. The ideal expert is both expert in the domain of interest and good at estimating probabilities.

A.2 Background materials

These materials were circulated as background ahead of the elicitation:
(K. C. R. Baldock et al., 2015; Barker, Garthwaite, & Parrish, 2014; Baron, Raine, & Brown, 2014; Baude et al., 2016; Matthias A. Becher et al., 2014; M. A. Becher, Osborne, Thorbek, Kennedy, & Grimm, 2013; Blaauw & Isaacs, 2014; Botias et al., 2015; Breeze, Roberts, & Potts, 2012; N. L. Carreck & Ratnieks, 2014; Chauzat et al., 2014; Connolly, 2013; Datta et al., 2013; Defra, 2013; L. Y. N. N. V. Dicks et al., 2015; Dively et al., 2015; Easac, 2015; EFSA, 2012, 2013; Fürst et al., 2014; Garibaldi et al., 2011; Garratt et al., 2014; Garthwaite, Barker, et al., 2014a; Garthwaite, Barker, Laybourn, Huntly, Parrish, Hudson, & Thygesen, 2014; Garthwaite, Barker, et al., 2014b; Godfray et al., 2014; Jaffé et al., 2010; Kennedy et al., 2013; Kerr et al., 2015; Lecocq, Jensen, Kryger, & Nieh, 2016; Lonsdorf et al., 2009; Manley et al., 2015; McGrath, 2013; Orford et al., 2016; Perry, Sovik, Myerscough, & Barron, 2015; Polce et al., 2013; Potts et al., 2016; Rader et al., 2016; Renner et al., 2015; Ryabov et al., 2014; Scheper et al., 2013; Stanley, Smith, & Raine, 2015; Tuell & Isaacs, 2010; Vanbergen & Initiative, 2013; Vicens & Bosch, 2014)

A.3 The elicitation questions

The experts then gave their individual, subjective estimates of the lowest plausible, highest plausible and best estimate of probabilities (in %) for the questions:

Q1.1 What is the probability of observing good honey bee abundance, given that the environment is supportive, the weather is average, and the Varroa control is good?

Q1.2 What is the probability of observing good honey bee abundance, given that the environment is supportive, the weather is average, and the Varroa control is poor?

Q1.3 What is the probability of observing good honey bee abundance, given that the environment is supportive, the weather is unusual, and the Varroa control is good?

Q1.4 What is the probability of observing good honey bee abundance, given that the environment is supportive, the weather is unusual, and the Varroa control is poor?

Q1.5 What is the probability of observing good honey bee abundance, given that the environment is unsupportive, the weather is average, and the Varroa control is good?

Q1.6 What is the probability of observing good honey bee abundance, given that the environment is unsupportive, the weather is average, and Varroa control is poor?

Q1.7 What is the probability of observing good honey bee abundance, given 32 that the environment is unsupportive, the weather is unusual, and the Varroa control is good?

Q1.8 What is the probability of observing good honey bee abundance, given that the environment is unsupportive, the weather is unusual, and the Varroa control is poor?

Q2.1 What is the probability of observing good other bee abundance, given that the environment is supportive, the weather is average?

Q2.2 What is the probability of observing good other bee abundance, given that the environment is supportive, the weather is unusual?

Q2.3 What is the probability of observing good other bee abundance, given that the environment is unsupportive, the weather is average?

Q2.4 What is the probability of observing good other bee abundance, given that the environment is unsupportive, the weather is unusual?

Q3.1 What is the probability of observing good other pollinator abundance, given that the environment is supportive, the weather is average?

Q3.2 What is the probability of observing good other pollinator abundance, given that the environment is supportive, the weather is unusual?

Q3.3 What is the probability of observing good other pollinator abundance, given that the environment is unsupportive, the weather is average?

Q3.4 What is the probability of observing good other pollinator abundance, given that the environment is unsupportive, the weather is unusual?

A.4 Calibrations Questions

Based on (beeinformed.org, 2015; Seitz et al., 2015; Spleen et al., 2013)

CQ1 Total losses over winter together with a 95% CI were reported. What is the probability that the upper bound of the reported CI is higher than 25%?

CQ2 Total losses over the entire 20142015 beekeeping year, together with a 95% CI were reported? What is the probability that the upper bound of the reported CI is less than 45%?

CQ3 Participants of the survey indicated a loss up to 18.7% on average as acceptable over winter. What is the probability that the proportion of all beekeepers who had higher colony losses than they deemed acceptable was less than 70%?

Based on (Liolios et al., 2015)

CQ4 Bees collected pollen from a large number of taxa, but only some of those contributed significantly to their nutritional requirements. What is the probability that the proportion of the taxa that included more than 80% of the total proteins that were available for bees, to be larger than 25%?

CQ5 What is the probability that the average crude protein of these selected pollen sources was larger than 30%?

CQ6 What is the probability that the average protein content of the plants blooming in the spring is less than 20%?

CQ7 What is the probability that the correlation between the average protein content per mixed sample and the corresponding average amount of collected pollen was statistically significant (significantly different than 0) during the year?

CQ8 What is the probability that the correlation between the protein content and the number of collected taxa was statistically significant (significantly different than 0) during the year?

Based on (Alvarez et al., 2015)

CQ9 What is the probability that the average length of the cells constructed by *M. concinna* is larger than 10mm?

CQ10 33 nests were studied. What is the probability that the average number of cells per nest is lower than 10?

CQ11 What is the probability that the proportion of overall cells of *M. concinna* which did not reach maturity (for whatever reasons) is larger than 40 %?

Based on (Jones et al., 2016)

CQ12 Given that in 2008, during January, February, and March, total rainfall was 14.22 cm, 51.5% of total annual rainfall, and during the growing season the highest average monthly temperature recorded was 27.63C for August and 10.57C for December, what is the probability that the total number of bumble bees observed (at all sites) decreased by more than 80%?

CQ13 If the season and sites are combined the primary pollinators by percent of visits in 2008 were: hummingbirds, Acton giant flower-loving y; western honey bee; long-tongued digger bees; longhorned digger bees and sweat bees. What is the probability that hummingbirds and Acton giant flower-loving flies accounted for more than 50% of the total visits?

CQ14 If the season and sites are combined the primary pollinators by percent of visits in 1995 were: longhorn digger bees; hummingbirds; sweat bees; bumble bees and the Acton giant flower-loving y. What is the probability that hummingbirds and digger bees accounted for more than 50% of the total visits?

CQ15 A comparison of the pollination data collected for early, mid, and late blooming seasons during the 1995 and 2008 efforts elicits patterns of abundance, indicating transition of pollinator presence across the season. During the 1995 season, the distribution of visitor abundance relative to total abundance was similar in early (39%) and mid-season (37%), whereas it tapered off during late season (24%). What is the probability that the visit abundance during the early season of 2008 is significantly different than the visit abundance during the early 34 season of 1995 (as indicated by a one-way ANOVA)?

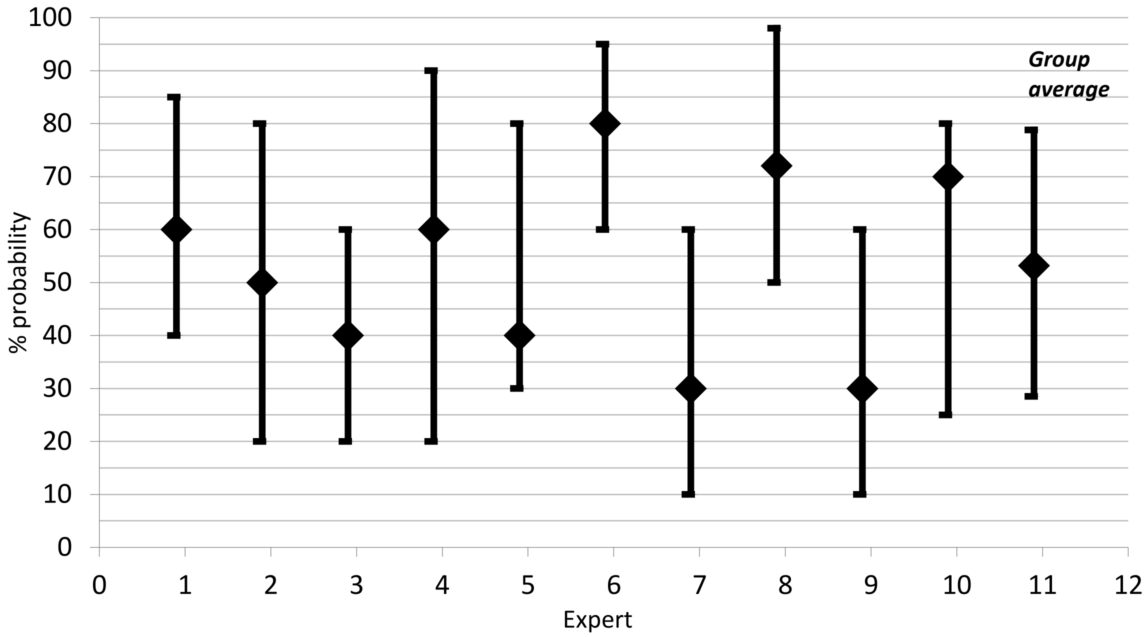
CQ16 Abundance of primary pollinators observed for years when data were available was correlated to mean annual precipitation for the year before observations to elicit trends in pollinator abundance. What is the probability that a statistically significant positive relationship was found for the collective grouping of butteries and moths?

Based on (Liu et al., 2016)

CQ17 Given that all *Nosema bombi* infections from 2013 were detected using PCR methods, what is the probability of commercial Bombus colonies (detected to be) infected with *Nosema bombi* to amount to more than 1% in 2013?

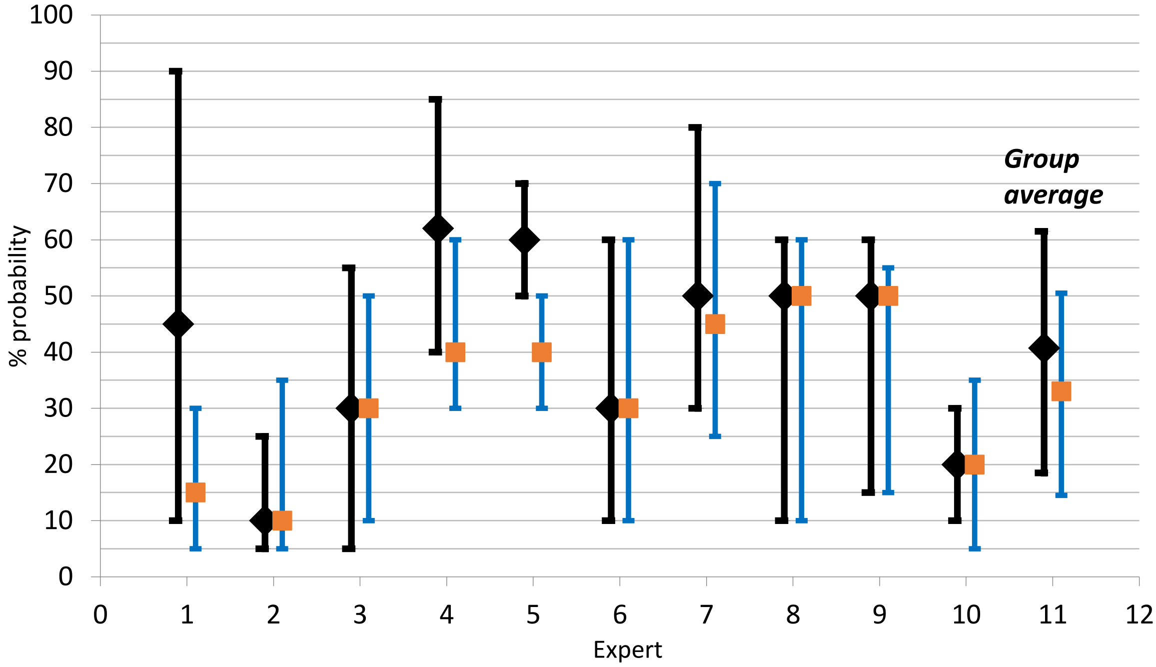
CQ18 Consider the entire period of the study, all the inspected colonies, and the four pathogens and parasites tested for. What is the probability of the total (detected to be) infected colonies to amount to less than 0.5 %?
CQ19 Consider the entire period of the study and all the inspected colonies. What is the probability of commercial Bombus colonies (detected to be) infected with *Crithidia bombi* to amount to more than 0.3%?

Appendix II Supplementary figures



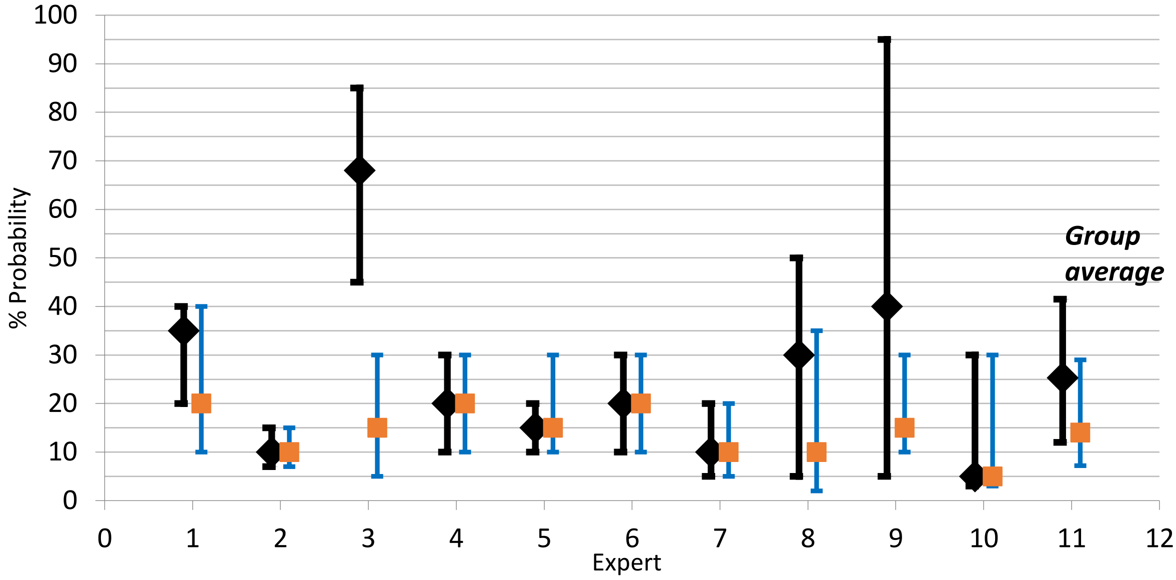
Q1.3 What is the probability of observing good honey bee abundance, given that the environment is supportive, the weather is unusual, and the Varroa control is good

Figure A2.1. The first round-estimates of lowest plausible, highest plausible and best estimate of the probability of good pollinator abundance for each expert were anonymously compared along with the mean of the upper, lower and best estimates for comparison.



Q1.7 What is the probability of observing good honey bee abundance, given that the environment is unsupportive, the weather is unusual, and the varroa control is good?

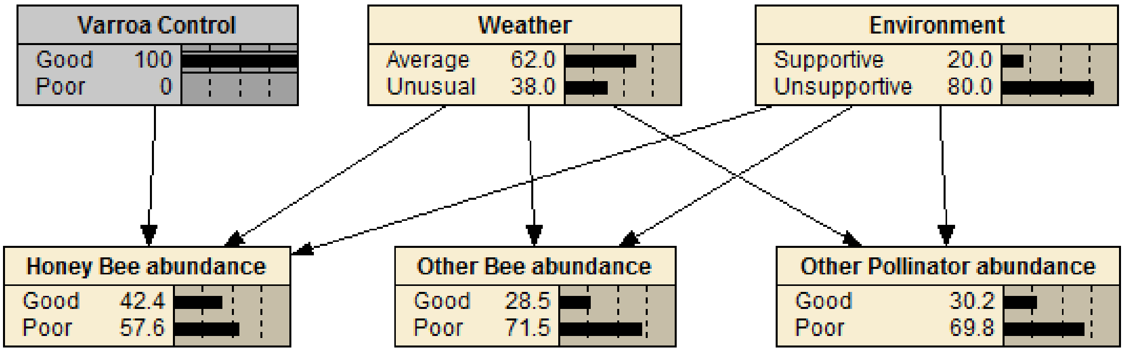
Figure A2.2. Second round estimates for each expert, given following the discussion of first round estimates, were anonymously compared along with the mean of the upper, lower and best estimates for round 2. Each estimate was compared with the estimates for the same expert in round one.



Q1.6 What is the probability of observing good honey bee abundance, given that the environment is unsupportive, the weather is average, and Varroa control is poor?

Figure A2.3. Second round estimates for each expert, given following the discussion of round one estimates, were compared with the estimates for the same expert in round one anonymously, along with the mean of the upper, lower and best estimates for round 2.

A



B

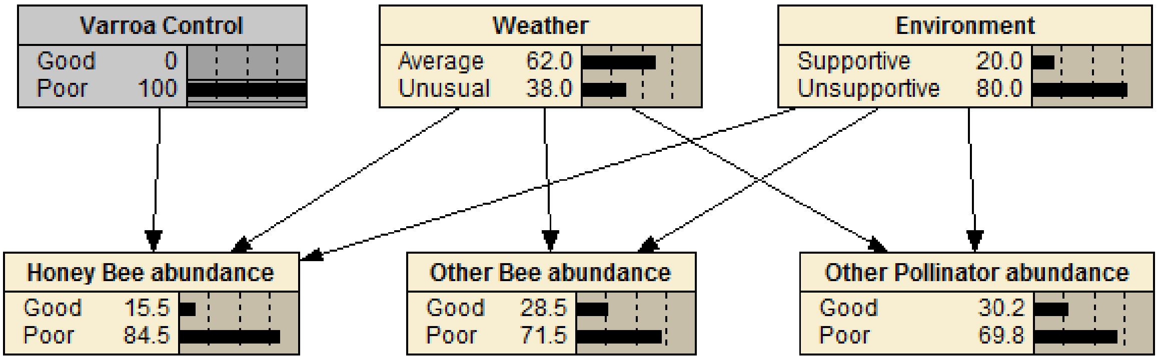
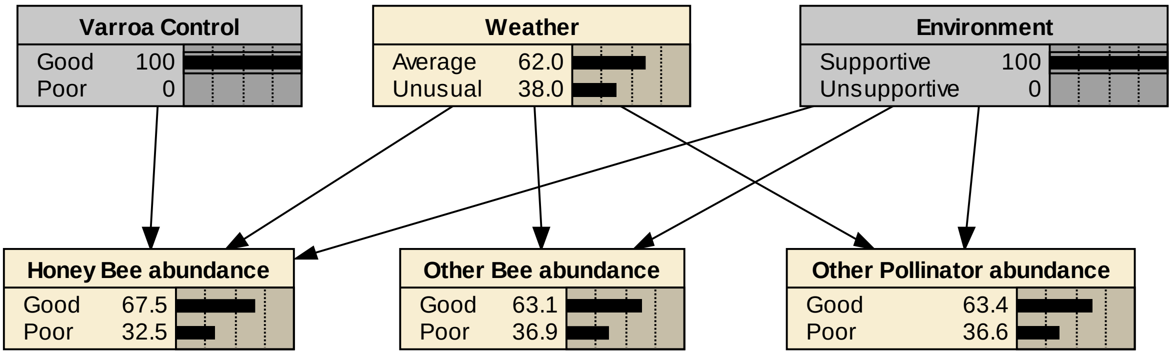


Figure A2.4. Bayesian network populated with the best estimate probabilities from the Table 1 with A. good Varroa control and B. poor Varroa control. The numbers and bars show the probability of each state being true. Image produced in NETICA.

A



B

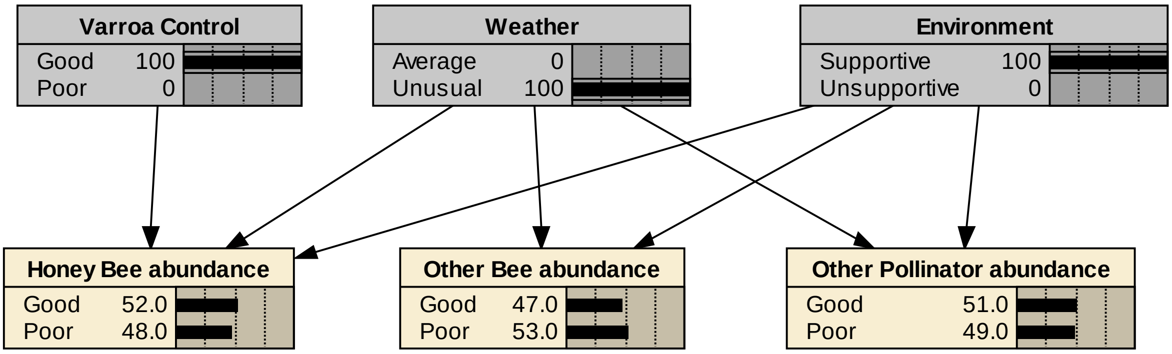


Figure A2.5. Bayesian network populated with the best estimate probabilities from the Table 1 with a combination of A. good Varroa control and supportive environment and B. unusual weather, good Varroa control and supportive environment. The numbers and bars show the probability of each state being true. Image produced in NETICA.

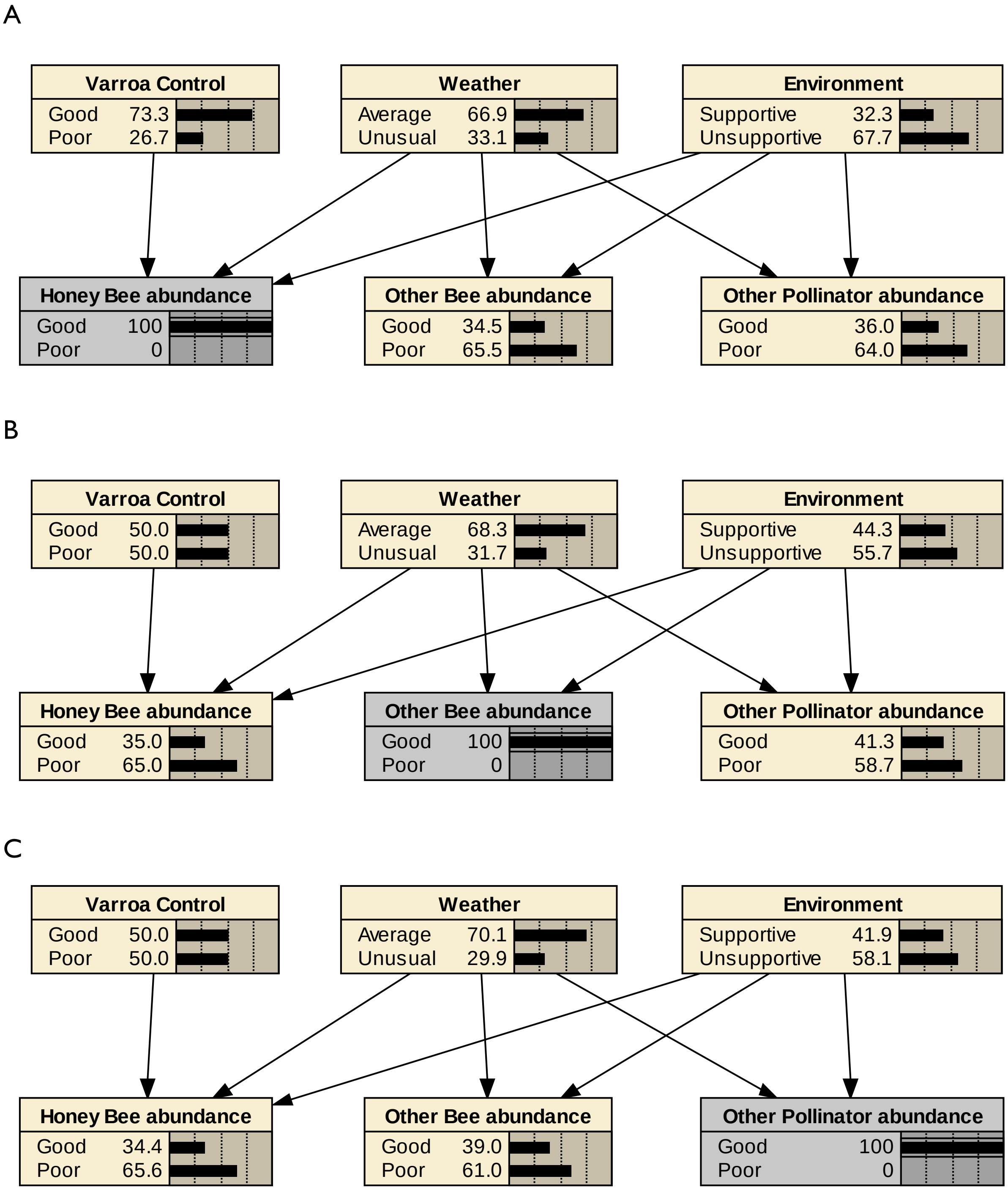


Figure A2.6. Bayesian network populated with the best estimate probabilities from Table 1 showing the values for Varroa control, weather and environment which would be required to ensure good abundance of A. honey bees alone, B other bees alone, C. hover flies alone. The numbers and bars show the probability of each state being true. Image produced in NETICA

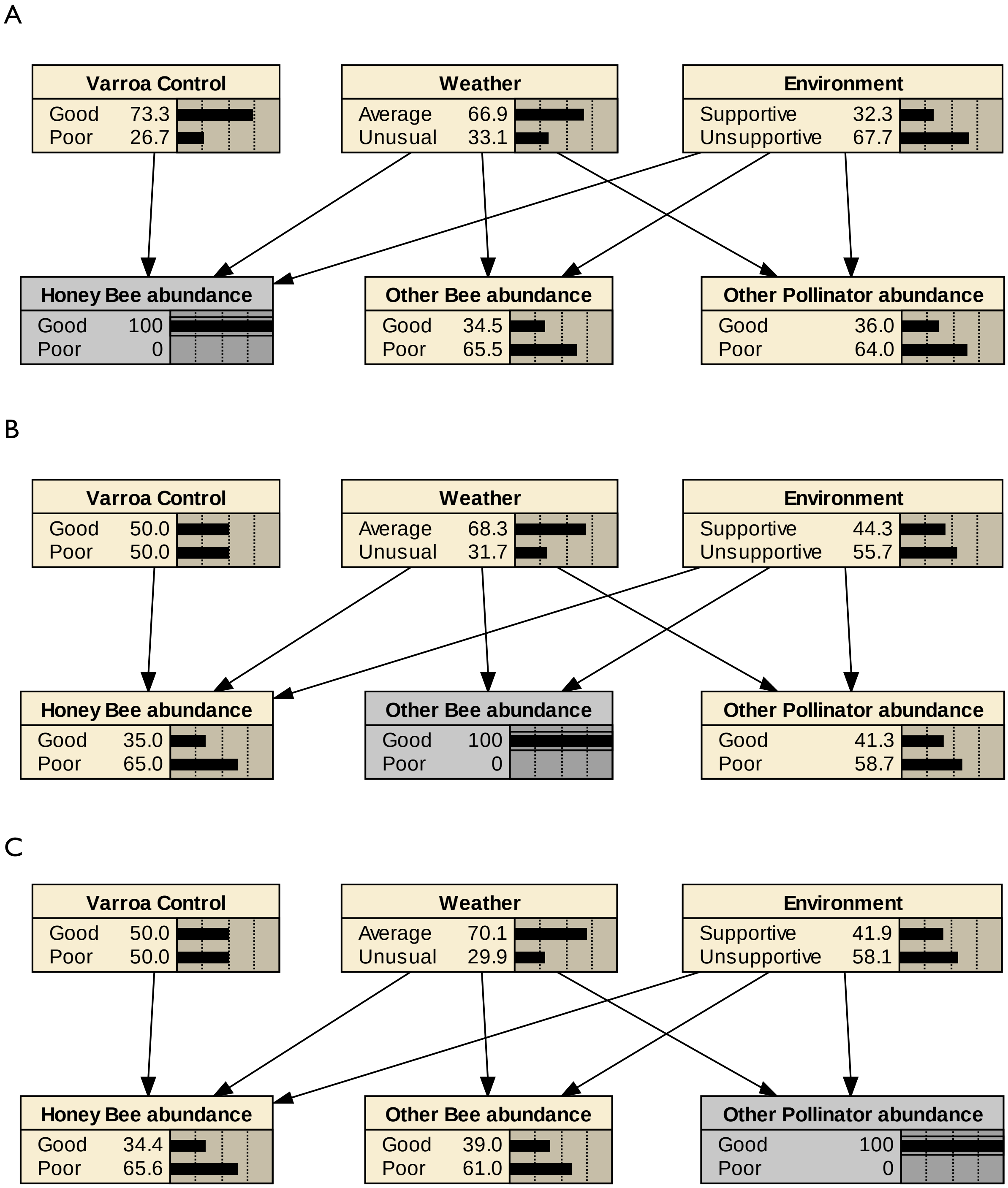


Figure A2.6. Bayesian network populated with the best estimate probabilities from Table 1 showing the values for Varroa control, weather and environment which would be required to ensure good abundance of A. honey bees alone, B other bees alone, C. hover flies alone. The numbers and bars show the probability of each state being true. Image produced in NETICA.

Figures and tables

Table 1. The best estimate (lowest plausible, highest plausible) for the probability that abundance of honey bees, other bees and hover flies is good, under all combinations of environment, weather and disease pressure.

Environment	Weather	Varroa control	Probability abundance is good		
			Honey bees	Other bees	Hover flies
Supportive	Average	Good	0.77 (0.57, 0.89)	0.73 (0.49, 0.87)	0.71 (0.48, 0.87)
Supportive	Average	Poor	0.27 (0.16, 0.45)	0.73 (0.49, 0.87)	0.71 (0.48, 0.87)
Supportive	Unusual	Good	0.52 (0.29, 0.76)	0.47 (0.29, 0.73)	0.51 (0.32, 0.71)
Supportive	Unusual	Poor	0.24 (0.13, 0.44)	0.47 (0.29, 0.73)	0.51 (0.32, 0.71)
Unsupportive	Average	Good	0.38 (0.21, 0.59)	0.21 (0.11, 0.42)	0.25 (0.12, 0.43)
Unsupportive	Average	Poor	0.14 (0.07, 0.29)	0.21 (0.11, 0.42)	0.25 (0.12, 0.43)
Unsupportive	Unusual	Good	0.33 (0.15, 0.51)	0.18 (0.07, 0.41)	0.17 (0.06, 0.37)
Unsupportive	Unusual	Poor	0.11 (0.05, 0.23)	0.18 (0.07, 0.41)	0.17 (0.06, 0.37)

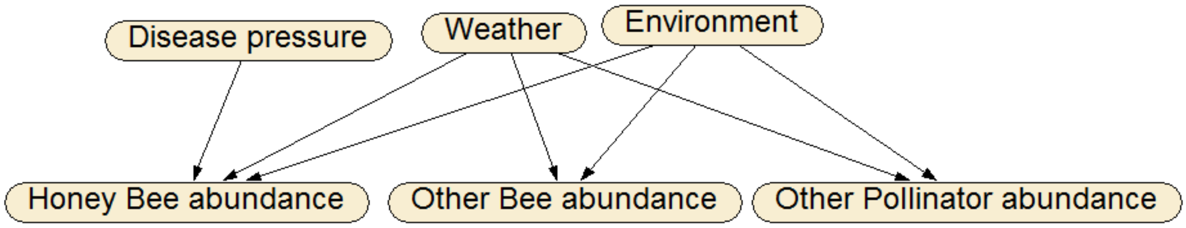


Figure 1. The effects on the honey bee, wild bee and other insect pollinator abundance of all combinations of possible states of weather, the environment and disease pressure were elicited from a panel of experts. Evidence for the link between disease and honeybees is strong, but relatively incomplete for other bees and other pollinators. For this reason, we did not ask the experts to estimate the effects of disease on other bees and other pollinators and omit the link between disease pressure and other bees and other pollinators in the schematic. Image produced in NETICA.

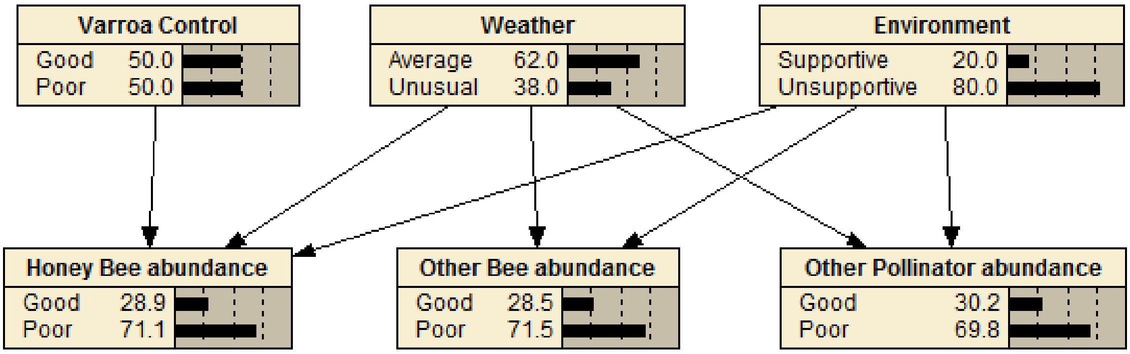


Figure 2. Bayesian network populated with the best estimate probabilities from the Table 1 with the baseline probabilities that weather is average 62% of the time and 20% of UK environment is supportive as defined previously. At baseline, no evidence has been added as to whether Varroa control is good or not, so these probabilities are 50:50. The numbers and bars show the probability of each state being true. Image produced in NETICA.

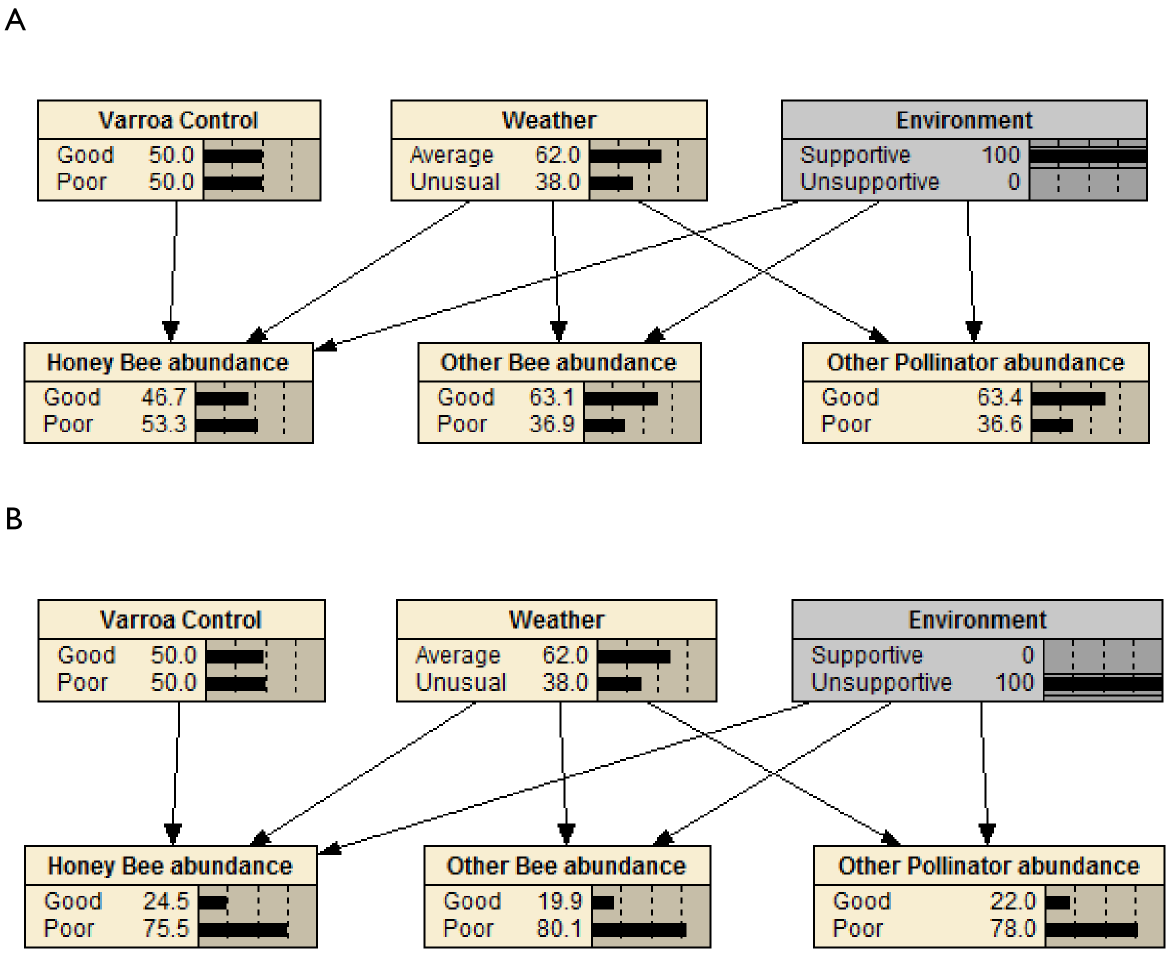


Figure 3. Bayesian network populated with the best estimate probabilities from the Table 1 with A. a supportive environment, B. an unsupportive environment. The numbers and bars show the probability of each state being true. Image produced in NETICA.

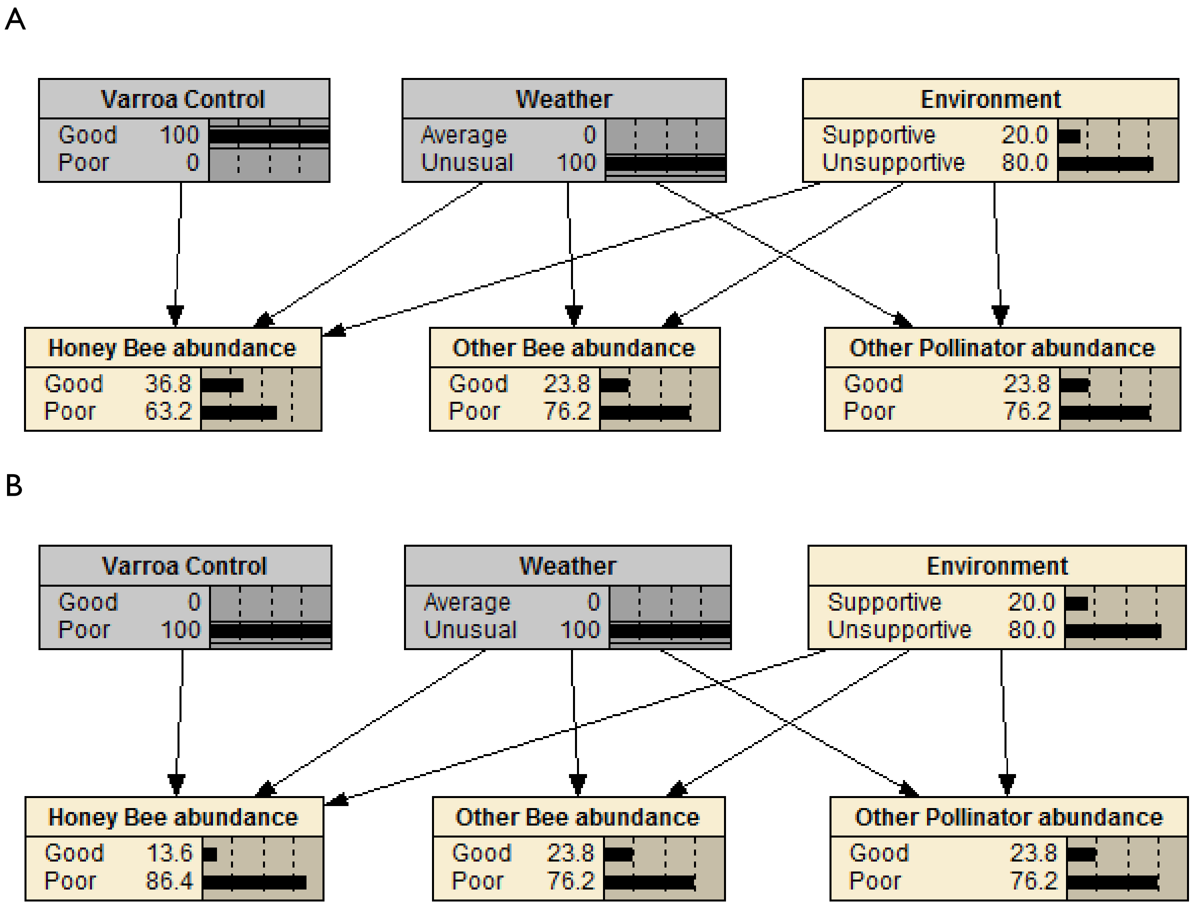


Figure 4. Bayesian network populated with the best estimate probabilities from the Table 1 with a combination of unusual weather and A. good Varroa control and B. poor Varroa control captures the balance of the influencing factors. The numbers and bars show the probability of each state being true. Image produced in NETICA.

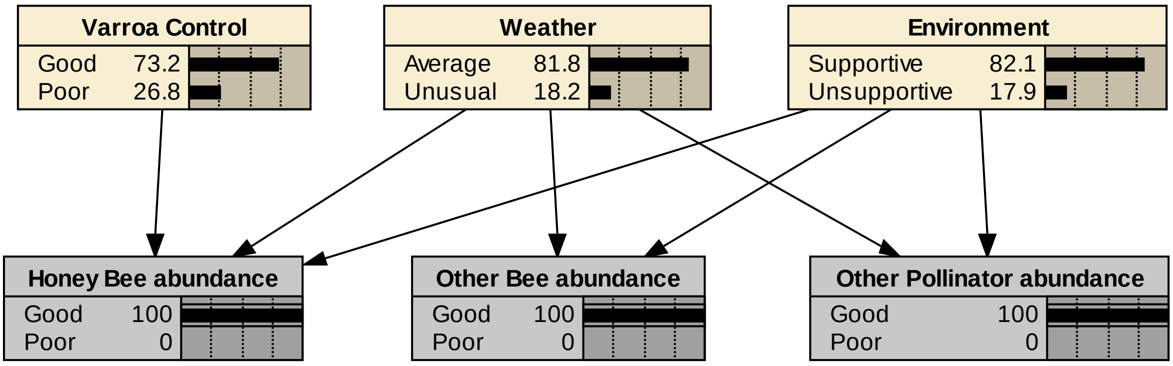


Figure 5. Bayesian network populated with the best estimate probabilities from Table 1 showing the values for Varroa control, weather and environment which would be required to ensure good abundance of honey bees and other bees and hover flies. The numbers and bars show the probability of each state being true. Image produced in NETICA.