Subjective probabilistic judgements for decision support to save the bees

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Overview

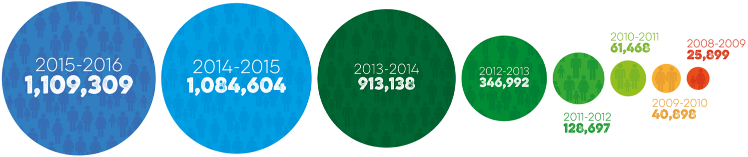
Food poverty: world

- Some 795 million people in the world do not have enough food to lead a healthy active life. That's about one in nine people on earth.
- Poor nutrition causes nearly half (45%) of deaths in children under five - 3.1 million children each year.
- One in four of the world's children are stunted. In developing countries the proportion can rise to one in three. *(World Food Programme figures)*

Food poverty is also an increasing problem in wealthy nations like the UK

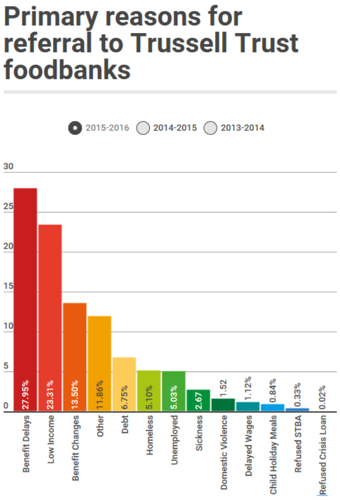
Food poverty: UK

Thirteen million people live below the poverty line in the UK, going hungry every day for a range of reasons, from benefit delays to receiving an unexpected bill on a low income. The Trussell Trusts 400-strong network of foodbanks provides a minimum of three days emergency food and support to people experiencing crisis in the UK.



Humanitarian aid, not a solution

Food Banks



Primary reasons for referral to Trussell Trust foodbanks
2015-2016
2014-2015
2013-2014
30
25
20
15
10
5
0
27.95%
23.31%
13.50%
11.86%
6.75%
5.10%
5.03%
2.67
1.52
1.12%
0.84%
0.33%
0.02%
Benefit Delays
Low Income
Benefit Changes
Other
Debt
Homeless
Unemployed
Sickness
Domestic Violence
Delayed Wages
Child Holiday Meals
Refused STBA
Refused Crisis Loan

Food Banks

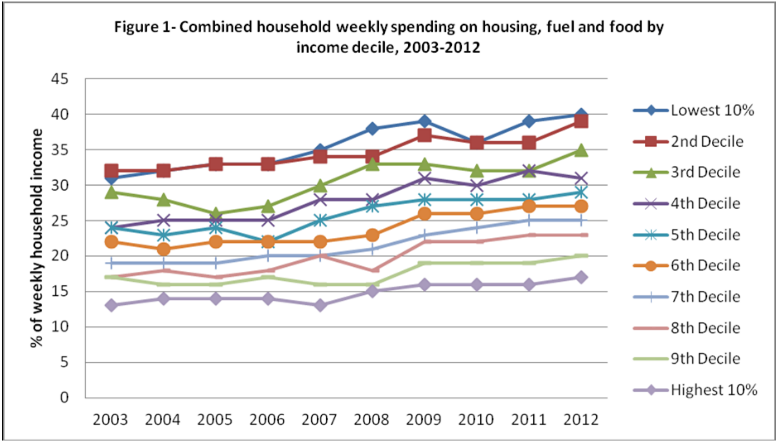
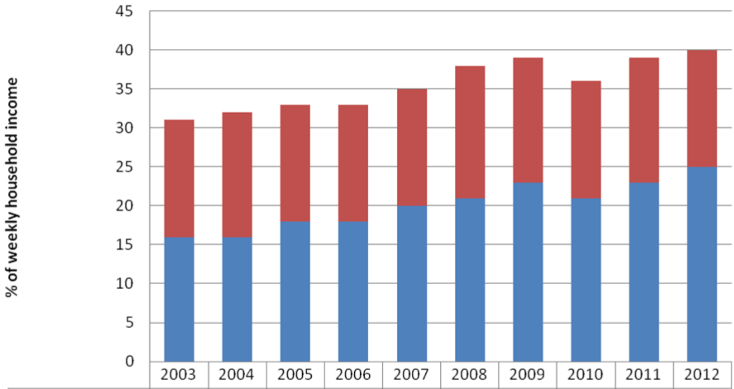


Figure 1- Combined household weekly spending on housing, fuel and food by income decile, 2003-2012
% of weekly household income
45
40
35
30
25
20
15
10
5
0
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Lowest 10%
2nd Decile
3rd Decile
4th Decile
5th Decile
6th Decile
7th Decile
8th Decile
9th Decile
Highest 10%

Food Banks

Figure 2- Household expenditure as a proportion of income in the poorest 10% of households



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Food	15	16	15	15	15	17	16	15	16	15
Housing and fuel	16	16	18	18	20	21	23	21	23	25

The Malnutrition problem

Malnutrition in the UK

- The number of those admitted to hospital with malnutrition in England and Wales rose from 5,469 to 6,520, a 19% increase in 2015.
- Birmingham Children's Hospital reported 31 instances of malnutrition in 2014, almost double the number for 2013.
- Recovery from illness can take a long time because of malnutrition.
- Malnutrition in older people, both in the community and in hospitals, is often left undetected.

Health professionals and those in social care need to spot the signs and then make sure that a suitable care plan is put in place.

The Malnutrition problem

President of the UK's Faculty of Public Health, John Middleton, said in 2014 that food-related ill health was getting worse

'through extreme poverty and the use of food bank.It's getting worse because people can't afford good quality food. It's getting worse where malnutrition, rickets and other manifestations of extreme poor diet are becoming apparent.'

What exactly is food security?

- Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO1996).
- The International Covenant on Economic, Social and Cultural Rights, ratified by the UK, guarantees the fundamental right of everyone to be free from hunger, and obliges state parties to take steps in this regard, including the improvement of methods of distribution of food, and dissemination of knowledge concerning the principles of nutrition.

Food insecurity in wealthy nations

- In UK, USA, Canada, food insecurity jumped sharply at the start of the 2008 recession and remains at historically high levels through to the latest data available.
- The widely-publicised increase in the use of food banks in the UK indicates that the number of households that feel the need to rely on charity provision to access sufficient food is increasing
- There are fears that the UK welfare system is not providing a robust last line of defence against hunger.
- Local City and County Councils are on the front line of provision; the most severe budget cuts have been made to the councils with the largest numbers of people living in poverty.

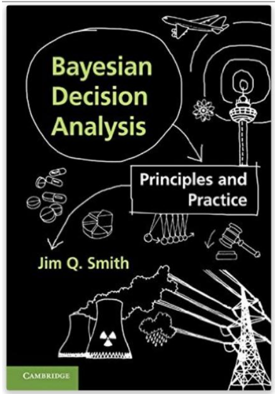
Working with Warwickshire County Council

For the last 3 years, we have been growing a collaboration with officers at Warwickshire County Council who are keen to tackle food poverty as part of their financial inclusion remit.
(also on the ‘feeding Coventry’ steering group and Warwickshire Food for Health group)

- Household food insecurity is not measured in the UK (it is measured in USA, Canada with 18-question HFSS)
- Need a proxy, affected by food poverty, measurable, pass clarity test [1]
- Warwickshire & Coventry added a single food security question to their 2016 household surveys - awaiting results

[1] Howard, R.A., 1988. Decision analysis: practice and promise. Management science, 34(6), pp.679-695.

A useful protocol



1. Identify the DM's Utility function
2. Identify the attributes
3. Identify the models
4. Identify the feasible class of decision rules
5. Code up the algorithms
6. Prune out infeasible or dominated decision rules
7. Design a graphical user interface
8. Develop real time graphics
9. Develop diagnostics

Towards decision support for UK food security

An integrating decision support system (IDSS) makes possible coherent inference over a network of probabilistic models.
Elicit from the users, Warwickshire County Council

- Purpose of the IDSS
- Range of decisions open to them
- Attributes of their utility
  - educational attainment
  - health
  - social cohesion
- How these attributes are measured

Schematic of high level factors affecting UK food poverty

From literature, academic experts; each has sub-networks and models.

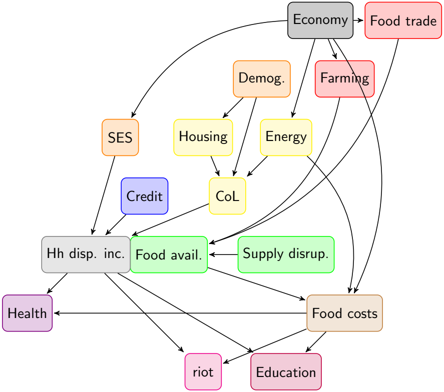


Figure: A plausible schematic of information flows for the modules of a UK food security IDSS. KEY: Economy: UK economic forecasts; Demog.:Demography; Farming: food production; SES: Socio-economic status; Credit: access to credit; CoL:cost of living; Food Avail: Food availability; Supply disrup: food supply disruption; disp. inc.: household disposable income

Why do we need decision support?

- The system is intrinsically dynamic (seasonal)
- Multi-faceted
  - Agriculture
  - Society
  - International, local regulations
  - Economy
  - Climate
  - Competing demands for land use

Why do we need decision support?

Panels of experts needed:

- Meteorologists
- Agriculturalists
- Economists
- Environmental scientists
- Entomologists & Bee-keepers
- Social scientists
- Crop production scientists ...

and a method to coherently combine their information

Communicating with the end-users

Communicating DSS outputs for end-users, not statisticians

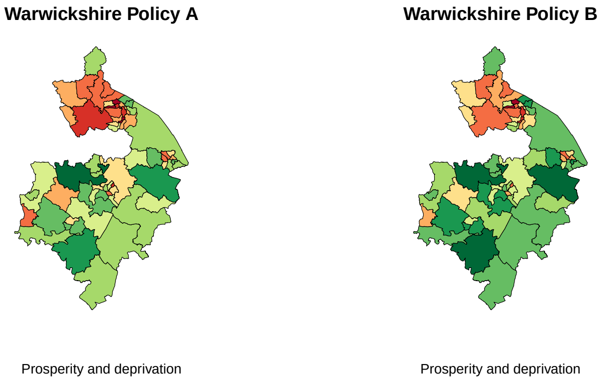


Figure: UK food security: illustration of the use of regional maps for decision support. Here an indicator of prosperity shows deprived areas in red. A clustering of deprivation (left map) is a risk factor for social unrest, such as food riots. Therefore, policies which specifically reduce and fragment large areas of poverty (right map) are to be preferred.

Key question

Key question

How can we network together inputs from these disparate expert domains in a coherent way, taking account of inherent uncertainties, so that different policy options can be compared in order to support decision-making?

We have contributed a methodology for doing this in a general system of this type and identified some frameworks which can be used to build such an integrating decision support system. We are now working to put theory into practice, starting to design an IDSS to evaluate policies designed to support pollinator abundance.

Integrating Decision Support systems

A formal & defensible statistical methodology to draw together inferences when:

- Users are decision *Centres*
- Expert judgements from disparate panels of experts
- Each component panel informed by complex models & huge data sets
- A single, comprehensive probabilistic model is inappropriate
    - infeasibly large
    - no shared structural assumptions so no centre can 'own' the full joint distribution
    - dynamic revisions lead to fast obsolescence

System requirements

- Dynamic for evolving environments.
- Distributed among disparate domain experts.
- Coherent: beliefs in different panels not contradictory.
- Networked probabilistic models.
- Can accommodate experimental and observational data.
- Balance strength of evidence.
- Compare risks of different policy decisions.
- Account for measures of uncertainty.
- Update in real time.
- Defensible decisions justifiable to external auditor or regulator.

Technical structure

- Processes are evaluated and overseen by m different panels of domain experts, $\{G_1, \ldots, G_m\}$
- Large vector of random variables measure various features of an unfolding future $\boldsymbol{Y} = (\boldsymbol{Y}_1, \boldsymbol{Y}_2, \ldots, \boldsymbol{Y}_m)$ where $\boldsymbol{Y}_i$ takes values in $\mathbb{Y}_i(d)$, $i = 1, 2, \ldots, m$, $d \in \mathbb{D}$ the decision space, e.g. expected impact on pollinators given the Neonicotinoid ban stays in place.

Technical structure

- Panel G_i will be responsible for the output vector $\{\boldsymbol{Y}_i : \ i = i \ldots m, \}$
- The implicit (albeit virtual) owner of these beliefs, who needs to aggregate the individual panels' judgements, will henceforth referred to as the *supraBayesian*, **SB** (This SB embodies the beliefs of the decision centre. Through this construction we are able to address issues such as statistical coherence or rationality as it applies to the system as a whole.)

Technical structure continued:

- G_i, $i = 1, 2, \ldots, m$, will be required to deliver to the integrating decision support system (IDSS) belief summaries denoted by $\Pi_i^y \triangleq \{\Pi_i^y(d) : d \in \mathbb{D}, \}$. These summaries will typically be various expectations of certain functions of $\boldsymbol{Y}_i$ taken by some subvector of $\boldsymbol{Y}$ for each decision $d \in \mathbb{D}$
- all panellists make their inferences in a parametric or semi-parametric setting where $\boldsymbol{Y}$ is parametrised by $\boldsymbol{\theta} = (\boldsymbol{\theta}_1, \boldsymbol{\theta}_2, \ldots, \boldsymbol{\theta}_m) \in \Theta(d) : d \in \mathbb{D}$ and the parameter vector $\boldsymbol{\theta}_i$ parametrises the G_i's relevant sample distributions $i = 1, 2, \ldots, m$.
- the panels are *variationally independent* when the parameter space of the system can be written as the product space
$\Theta(d) = \Theta_1(d) \times \Theta_2(d) \times \ldots \times \Theta_m(d),\ d \in \mathbb{D}$.

Technical structure continued:

In this parametric setting, for each decision $d \in \mathbb{D}$ that might be adopted, each panel G_i, $i = 1.2, \ldots, m$ has two quantities available to it.

- *sample densities* over the future measurements for which they have responsibility $\Pi_i^{y|\theta} \triangleq \left\{ \Pi_i^{y|\theta}(\boldsymbol{\theta}_i, d) : \boldsymbol{\theta}_i \in \Theta_i(d), d \in \mathbb{D} \right\}$.
- *beliefs about the parameters* $\Pi_i^{\theta} \triangleq \left\{ \Pi_i^{\theta}(d) : d \in \mathbb{D} \right\}$

Common Knowledge assumptions

- **Utility consensus:** *All agree on the class $\mathbb{U}$ of utility functions supported by the* **IDSS**.
- **Policy consensus:** *All agree the class of decision rules $d \in \mathbb{D}$ that might be examined by the* **IDSS**.
- **Structural consensus:** *All agree the variables $\boldsymbol{Y}$ defining the process of the developing crisis, where for each $d \in \mathbb{D}$, each $U \in \mathbb{U}$ is a function of $\boldsymbol{Y}(d)$, together with a set of qualitative statements about the dependence between various functions of $\boldsymbol{Y}$ and $\boldsymbol{\theta}$. Call this set of assumptions the* **structural consensus set** *and denote this by $\mathbb{S}$.*

Definition: CK class

Call the set of common knowledge assumptions shared by all panels and which contains the union of the utility, policy and structural consensus $(\mathbb{U}, \mathbb{D}, \mathbb{S})$ the *CK class*.

More common knowledge assumptions

- **Parametric union:** *All agree to adopt as their own G_i's beliefs about the sample families* $\Pi_i^{y|\theta}$ $i = 1, 2, \ldots, m$. This just assigns the specification of the future crisis variables to the appropriate panel.
- **Quantitative delegation:** *All agree to take on the sample summaries* $\Pi_i^{y|\theta}$, *the panel parameter distributions* Π_i^{θ} *and the panel marginal inputs* Π_i^{y} *provided by* G_i *as their own,* $i = 1, 2, \ldots, m$. i.e. it is appropriate to defer their judgements to the most well-informed panel about each domain vector.

Definition: Adequate IDSS

Call an IDSS *adequate* for a CK class $(\mathbb{U}, \mathbb{D}, \mathbb{S})$ when the SB can unambiguously calculate her expected utility score $\overline{U}(d)$ for any decisions $d \in \mathbb{D}$ she might take under any utility function $U \in \mathbb{U}$ she might be given by a user from the panel marginal inputs Π_i^y provided to her by the panels G_i, $i = 1, 2, \ldots, m$.

Definition: Sound IDSS

Call an IDSS *sound* for a CK class $(\mathbb{U}, \mathbb{D}, \mathbb{S})$ if it is adequate, and by adopting the structural consensus the SB would be able to admit coherently all the assessments $\Pi_i^{y|\theta}, \Pi_i^{\theta}$, (and hence Π_i^y), $i = 1, 2, \ldots, m$ as her own, the SB's underlying beliefs about a domain overseen by a panel G_i being $\left(\Pi_i^{y|\theta}, \Pi_i^{\theta}\right)$, $i = 1, 2, \ldots, m$.

Delegable IDSS

All useful information about parameters is the union of common knowledge and individual panels' specialist information.
Let I_0^t denote all the admissible evidence which is common knowledge to all panel members at time t. Let I_{ij}^t denote the subset of this admissible evidence panel G_i would use at time t if acting autonomously to assess their beliefs about $\boldsymbol{\theta}_j$, $i, j = 1, 2, \ldots, m$, were the SB to commit to policy $d \in \mathbb{D}$.
Define $I_+^t \triangleq \left\{ I_{ij}^t : 1 \leq i, j \leq m \right\}, I_*^t \triangleq \left\{ I_{jj}^t : 1 \leq j \leq m \right\}$

Definition: Delegable IDSS

Say that a CK class of an IDSS is *delegable* at time t if for any possible choice of policy $d \in \mathbb{D}$ and for $j = 1, 2, \ldots, m$ there is a consensus that for all $\boldsymbol{\theta} \in \boldsymbol{\Theta}(d) : d \in \mathbb{D}$ $I_+^t \perp\!\!\!\perp \boldsymbol{\theta} \mid I_0^t, I_*^t, d$

Distributivity

In order that panels may update their beliefs autonomously and the SB can use the existing IDSS with updated information $\Pi_i : 1 \leq i \leq m$ we require that the IDSS is panel separable.

Definition: panel separable IDSS

Call $l(\boldsymbol{\theta} \mid \boldsymbol{x}^t)$ *panel separable* over the panel subvectors $\boldsymbol{\theta}_i$, $i = 1, 2, \ldots, m$, when, given admissible evidence $\boldsymbol{x}^t$, it is in the CK class $\mathbb{S}$ that for all $d \in \mathbb{D}$

$$l(\boldsymbol{\theta} \mid \boldsymbol{x}^t) = \prod_{i=1}^{m} l_i(\boldsymbol{\theta}_i \mid \boldsymbol{t}_i(\boldsymbol{x}^t))$$

where $l_i(\boldsymbol{\theta}_i \mid \boldsymbol{t}_i(\boldsymbol{x}^t))$ is a function of $\boldsymbol{\theta}$ only through $\boldsymbol{\theta}_i$ and $\boldsymbol{t}_i(\boldsymbol{x}^t)$ is a statistic of $\boldsymbol{x}^t$, $i = 1, 2, \ldots, m$ known to G_i and perhaps others, collected under the admissibility protocol and accommodated formally by G_i into I_{ii}^t to form its own posterior assessment of $\boldsymbol{\theta}_i$.

i.e. separable likelihoods are key to distributivity

Examples of sound and distributive frameworks

- Staged trees
- Bayesian Networks
- Chain event graphs
- Decomposable graphs
- Multiregression dynamic models

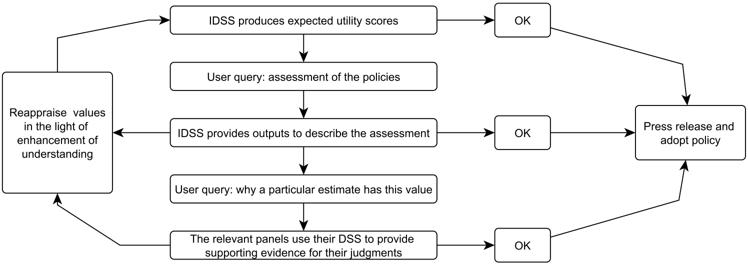


Figure: Manuele Leonelli & James Q. Smith(2015) Bayesian Decision Support for complex systems with many distributed experts Ann Op Res

Bayesian Networks: intuition

$BN = DAG + \perp\!\!\!\perp$ *statements*

- Let $(X_1, X_2, \ldots, X_n)$ be random variables
- if A, B and C are disjoint subsets of $X_1, X_2, \ldots, X_n$
- A conditional independence statement has the form *A is independent of B given C*
- in symbols $A \perp\!\!\!\perp B | C$

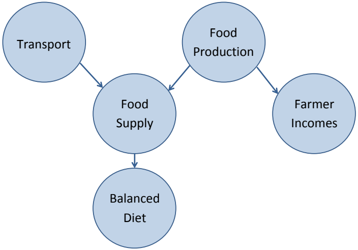


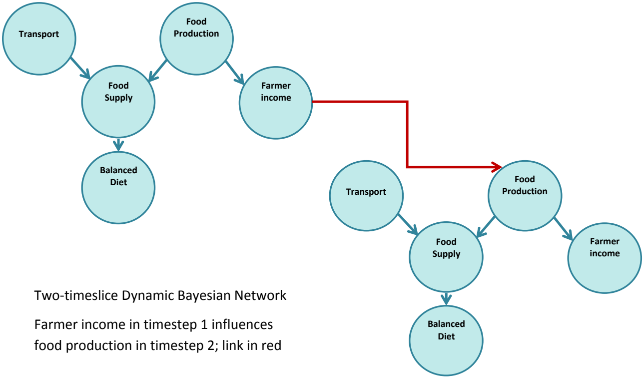
Figure: In this illustrative example, Balanced Diet depends on Food Supply. Food Supply depends on Food Production, which also dictates Farmer Incomes. Food Supply is also dependent on the ability to transport the food from the production site to where it is needed. Food Production and Transport are called the parents of Food supply.

Bayesian Networks

- A Bayesian Network is a simple and convenient way of representing a factorisation of a joint probability density function of a vector of random variables $\mathbf{X} = (X_1, X_2, \ldots, X_n)$.
- Bayes' theorem says that the joint density function can be factorised as a product $f(x) = \prod_{i=1}^{n} f_1(x_1) f_2(x_2|x_1) f_3(x_3|x_1, x_2) \ldots, f_n(x_n|x_1, x_2, \ldots, x_{n-1})$ where $f_i(x_i|x_1, \ldots, x_{i-1})$ denotes the conditional density of x_i given its predecessors.
- When all the components of (X) are independent we have $f(x) = \prod_{i=1}^{n} f_i(x_i)$

Dynamic Bayesian Networks

Each copy of the BN is called a time slice. **Intra-slice arcs** represent the relationships between variables in a time slice; **inter-slice arcs**, aka **temporal arcs** represent the relationships between variables between time slices.

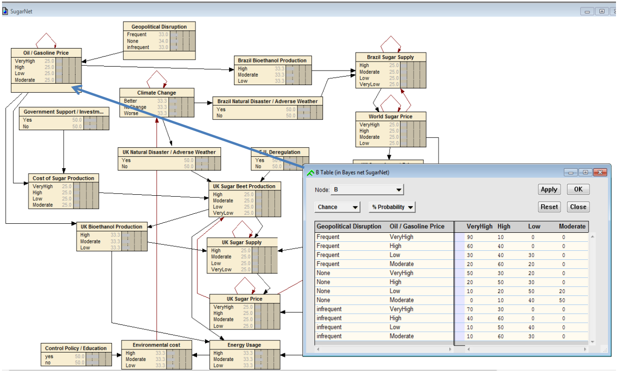


Two-timeslice Dynamic Bayesian Network

Farmer income in timestep 1 influences food production in timestep 2; link in red

Conditional probability tables elicited from Warwick Food GRP member, Dr Ben Richardson, expert in Brazil sugar market.

Note: Red loops indicate an influence from the variable to itself at a future time point



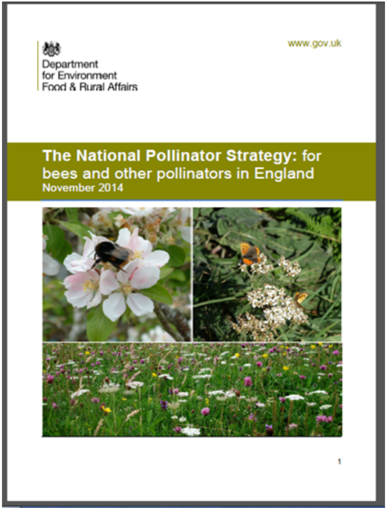
The Pollinator problem

Figure: Pollinator insects (Hymenoptera, Lepidoptera, Hemiptera) By Nbharakey, via Wikimedia Commons

- Pollination services is an eco-system service provided principally, but not exclusively, by insects.
- The world supply of food depends on the continued strength of the pollinator populations

The pollinator problem

- There is concern over the decline of insect pollinators (Potts2010)
- National Pollinator strategy Nov 2014
- Identified gaps in knowledge
- Insect Pollinator initiative



The Pollinator problem

Reasons for the decline are believed to include:

- Loss and fragmentation of habitat
- Loss of forage
- Intensification of agriculture (esp monocultures)
- Increasing incidence of disease and pests
- Imports of non-native species
- Pesticides

Data problems

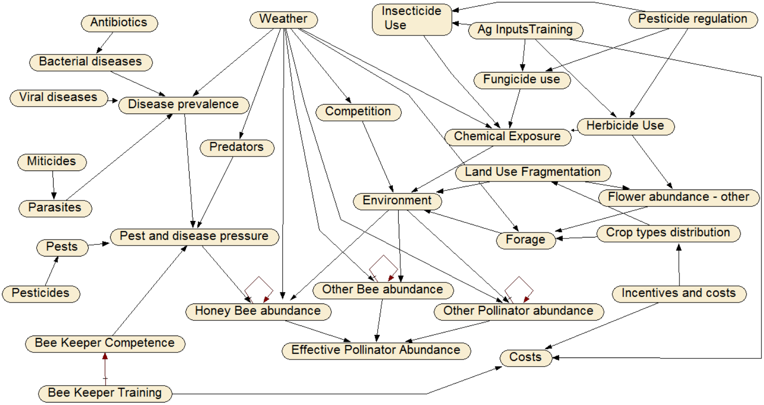
- Difficult to measure
- Reliance on citizen science
- Quality of data & experiments
- Statistical challenges using this data
- Experimental evidence mixed, sparse
- Margins have some evidence, conditionals little or none

Qualitative structure elicitation

- Academic experts (UK)
- Domain literature (International)
- Domain experts (UK & Australia)
- Policymakers
    - Honey bees
    - Wild bees
    - Other pollinators
- Commercial beekeepers
- Queen breeders

Qualitative structure: an iterative process

Qualitative structure, $\mathbb{S}$

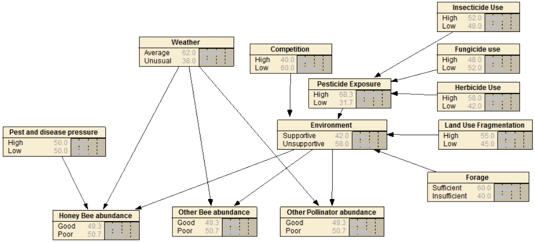


Data sources as recommended by domain experts

- Academic literature
- DEFRA
- Statisticians species distribution modelling
  - Presence-only data
  - Presence-absence data
- Domain experts advise where no data available

Expert Judgement

To quantify key unknown elements Using IDEA protocol



A.M. Hanea, M.F. McBride, M.A. Burgman, B.C. Wintle, F. Fidler, L. Flander, C.R. Twardy, B. Manning, S. Mascaro, 2016, **I***nvestigate* **D***iscuss* **E***stimate* **A***ggregate* for structured expert judgement, International Journal of Forecasting, accepted for publication on 25.02.2016

Identifying Experts

Identify experts

Expert	Affiliation	Expertise
Katherine Baldock	University of Bristol	plant - pollinator interactions
Lena Bayer-Wilfert	Exeter University	pollinator viruses
Norman Carreck	University of Sussex	pollinators
David Chandler	University of Warwick	integrated pest management inc bees
Samik Datta	University of Warwick	mathematical epidemiology inc bees
Chris Hartfield	National Farmers Union	bees & farming
Andrew Lucas	Swansea University	hoverflies
Jeff Ollerton	Northampton University	plant - pollinator relationships
Simon Potts	University of Reading	wild pollinators & pollination
Stuart Roberts	University of Reading	wild bees
Jessica Fannon	University of Warwick	honey bee viruses

Parameters Elicited

Honey Bee abundance

- Good: overwinter losses are less than 30% (as defined by Coloss)
- Poor: overwinter losses are more than 30% (as defined by Coloss)

Other Bee abundance

- Good: if there are 500 or more observations of bees on BWARS in the spring season
- Poor: if there fewer than 500 observations of bees on BWARS in the spring season

Other Pollinator abundance

- Good: if there are 500 or more observations on the Hoverfly recording scheme in the spring season
- Poor: if there fewer than 500 observations on the Hoverfly recording scheme in the spring season

Environment

- Supportive: If there is at least 1 patch of at least 1 hectare of open flowers within 1km spring forage range and pesticide usage is less than 0.3kg/hectare assuming the pesticide toxicity stays the same as at present.
- Unsupportive: : If there is no patch of 1 hectare of open flowers within 1km spring forage range and pesticide usage is more than 0.3kg/hectare assuming the pesticide toxicity stays the same as at present

Weather

- Average: if the number of days with more than 0.2mm of rain fall between 35-70, hours of sunshine fall between 240-480 and mean daily temperature falls between 3-10C
- Unusual: if rain, sunshine or temperature falls outside these ranges

Varroa control

- Good: if there are fewer than 1500 mites per hive in spring, as calculated by BeeBase calculator
- Poor: if there are more than 1500 mites per hive in spring, as calculated by BeeBase calculator

Modified definitions after the discussion

- Other Bee Abundance is all wild bees (Bumblebees and solitary bees) not simply Bombus (Bumble bees).
- Other Pollinator Abundance counts all hoverflies and flies but not butterflies.
- All numbers such as 500 observations in bee abundance definitions should be read as national average over the last five years.
- For a supportive environment rather than at least 1 hectare of open flowers it should be at least 15% proportion of semi-natural land.

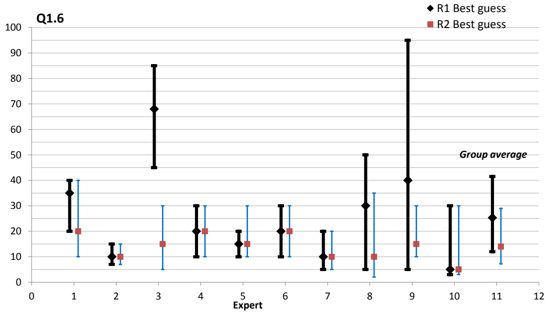
Expert Judgement

The protocol:

- Round 1: experts investigate and give individual estimates - lowest, highest then best estimate
- Discussion of anonymised results
- Round 2: second individual estimate, giving reasons for changes if appropriate
- Calibration questions (same protocol)
- Mathematical aggregation

Expert Judgement

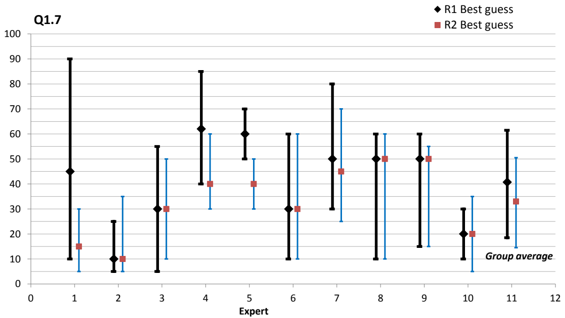
Expert elicitation using IDEA protocol
Q1.6: What is the probability of observing good honey bee abundance, given that the environment is *unsupportive*, the weather is *average*, and varroa control is *poor*?



Expert Judgement

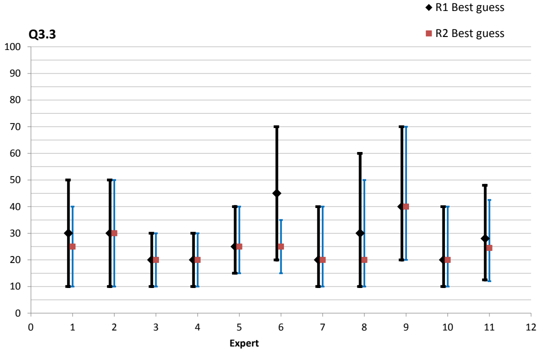
Expert elicitation using IDEA protocol

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*?

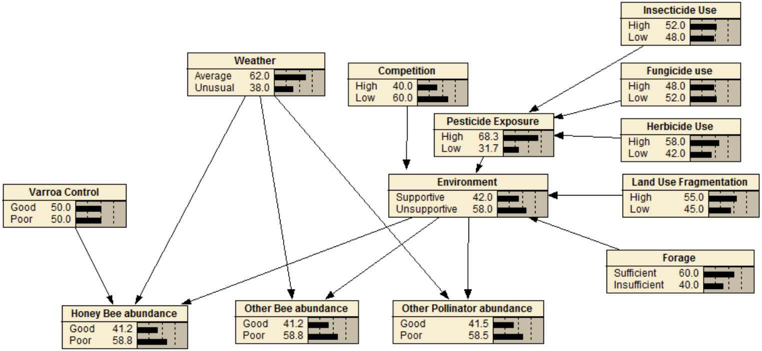


Expert Judgement

Expert elicitation using IDEA protocol
Q3.3: What is the probability of observing good other pollinator abundance, given that the environment is unsupportive, the weather is average?

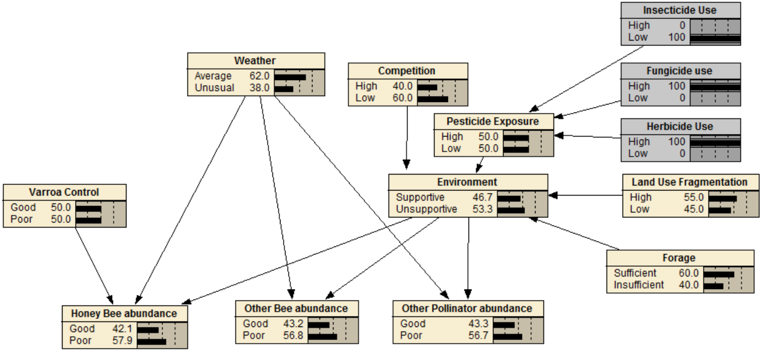


What-if analysis in Netica



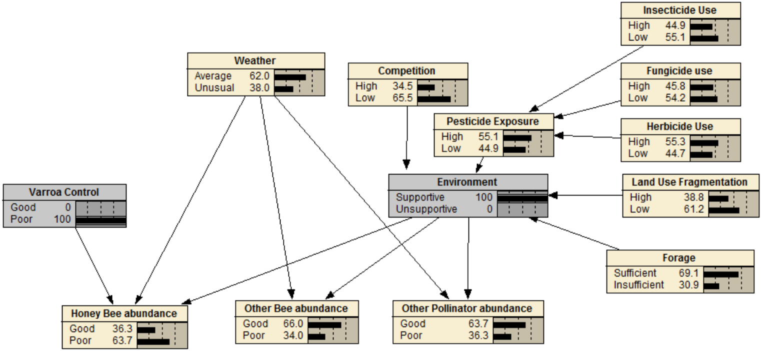
Simple group average; not accounting for uncertainties here

What-if analysis in Netica



Simple group average; not accounting for uncertainties here

What-if analysis in Netica



Simple group average; not accounting for uncertainties here

Calibrations Questions

Calibrations Questions

- Hard to come by, I am not the problem owner in the traditional sense
- But papers in press identified
- Started by email: Round 1, facilitated discussion via Skype 3rd August, Round 2 under way

Next...

The next steps are:

- Probability distributions will be derived from the aggregated expert judgement to populate the DBN
- The rest of the pollination sub-network will be populated with probability distributions from data
- The pollinator sub-network will be able to be used in its own right for decision support for pollinator abundance.
- It will also be aggregated into a wider expert panel for farming and food supply within the UK food security IDSS.

Watch this space....

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FOOD

Coherent Frameworks for Statistical Inference serving Integrating Decision Support Systems *Jim Q. Smith, Martine J. Barons & Manuele Leonelli*, on arXiv: 1507.07394 EPSRC EP/K039628/1