Understanding the impacts of sublethal exposure to pesticides on bee colony health

Prof Dave Goulson

Life Sciences
University of Sussex
Why bumblebees?

- V. significant contributors to crop pollination (e.g. oilseed rape, field beans, tomatoes, peppers, raspberries, strawberries…) and >1,000s spp. of wildflowers

- Discrete, measurable endpoint to colony cycle
Conservation – current status

25 UK species, 3 extinct, 7 BAP species, 2 critically endangered.


N. America: precipitous declines since 1990s of subgenus *Bombus*: *B. franklini*, *B. occidentalis*, *B. affinis*, *B. terricola*

South America: Collapse of *B. dahlbomii*…
Causes of bumblebee declines?

**Habitat loss**
Agricultural intensification, e.g. UK loss of unimproved grasslands ~7,000,000 ha → 250,000 ha (~97%)
Hay → Silage
Abandonment of clover leys

**Disease**

**Pesticides??**
## Neonicotinoids

<table>
<thead>
<tr>
<th>Pesticide</th>
<th>UK use 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imidacloprid</td>
<td>188,000 Ha</td>
</tr>
<tr>
<td>Clothianidin</td>
<td>728,000 Ha</td>
</tr>
<tr>
<td>Thiamethoxam</td>
<td>298,000 Ha</td>
</tr>
<tr>
<td>Thiacloprid</td>
<td>49,000 Ha</td>
</tr>
<tr>
<td>Acetamiprid</td>
<td>7,000 Ha</td>
</tr>
</tbody>
</table>

Mainly used as seed dressing on rape (canola), cereals, maize, sunflower, beet.

Also sprayed on top fruit, soft fruit, and as a soil drench or granular formulation for turf / pasture.

Widely sold for garden use e.g. *Ultimate Bug Killer*
UK usage

- thiamethoxam
- thiacloprid
- clothianidin
- acetamiprid
- imidacloprid

Weight applied (kg)


kg values: 0, 10000, 20000, 30000, 40000, 50000, 60000, 70000, 80000, 90000
# Toxicity of imidacloprid to wildlife

<table>
<thead>
<tr>
<th>Species</th>
<th>LD50 = dose that kills 50%</th>
<th>LC50 = concentration that kills 50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honeybee</td>
<td>4 ng (10^{-9}g)</td>
<td></td>
</tr>
<tr>
<td>Grey Partridge</td>
<td>5 mg (10^{-3}g)</td>
<td></td>
</tr>
<tr>
<td>Rat</td>
<td>177 mg</td>
<td></td>
</tr>
<tr>
<td>Brown dun mayfly</td>
<td>0.6 ppb (parts per billion)</td>
<td></td>
</tr>
<tr>
<td>Freshwater shrimp</td>
<td>7.1 ppb</td>
<td></td>
</tr>
</tbody>
</table>

Typical concentration in crop tissues: 5-10 ppb

**Comparators:**
- LD50 in honeybees: Imidacloprid 5 ng/bee, Dimethoate 191 ng/bee, DDT 27,000 ng/bee
Routes of exposure of bees

- Arable crops
  e.g. oilseed rape, sunflower, maize
- Horticultural crops
- Field margin plants
- Gardens and amenity areas
Concentrations found in pollen and nectar in the field

Seed-treated crops
0.6 – 51 ppb found in pollen and nectar

Foliar Sprays in Horticulture
Higher concentrations, e.g. thiamethoxam 122 ppb in pollen and 17.6 ppb in nectar of curcubits

Pasture: 171 ppb clothianidin in nectar of clover given foliar spray (Larson et al. 2013)

Non-target plants: 1-9 ppb clothianidin in dandelions growing in field margin adjacent to seed-treated crop (Krupke et al. 2012)

Gardens?

Enough to cause mortality???
Evidence for sublethal effects?

1998-2011: Various lab or cage studies suggest that sublethal exposure of honeybees or bumblebees impairs learning / food collection / navigation / reduces fecundity.

Impacts on foraging likely to be far greater in field?
Dosage: Imidacloprid, 0.7ppb in nectar, 6ppb in pollen

Fed bumblebee nests for 2 weeks on:
a) Nectar, pollen (control)
b) Nectar, pollen + field realistic imidacloprid (low)
c) Nectar, pollen + 2 x field realistic imidacloprid (high)

After 2 weeks, nests placed in the field…..

![Graph showing cumulative weight gain (g) over weeks for Lab and Field conditions with Control, Low, and High treatments. The graph demonstrates that the weight gain for the Control treatment is consistently lower than the other treatments, especially after the fourth week.](image)
Potential scale of effects is large…
Fera study, unpublished 2012

Repeated Whitehorn et al. but with field exposure – bumblebee nests adjacent to canola fields treated with imidacloprid, clothianidin or control

Results
Control nests contaminated with thiamethoxam and clothianidin…
Fera/Defra concluded that no major effects of pesticides on bumblebees???
Findings dismissed by EFSA
RFID tagged honeybees
Exposed them to a single dose of thiamethoxam (1.34 ng in a 20-µl sucrose solution) or control
Examined homing success

Results
Released at a familiar location 70m from hive (simulating field trial), homing success reduced very little
Released at a familiar location 1km from hive, homing success reduced by ~10%
Released at an unfamiliar location 1km from hive, homing success reduced by 32%
Gill et al. Nature 2012

- RFID tagged bumblebees
- Exposed to 10ppb imidacloprid in nectar in nests

**Results**
- Reduced worker production
- Increased worker mortality
- Reduced pollen collection
Feltham et al. (provisional acceptance, Ecotoxicology)

- RFID tagged bumblebees
- Exposed nests to 0.7 ppb in nectar, 6 ppb in pollen.

**Results**
- Reduced freq. of pollen collection (37%) + reduced efficiency of pollen collection (31%) = pollen collection reduced by 57%
- Effects last for at least 4 weeks after dosing
Laycock et al. 2012, Ecotoxicology

• Fed queenless micro-colonies of *B. terrestris* on a range of doses of imidacloprid

• Found:
  • Diet containing 1ppb reduced fecundity by 33%

Henry et al. + Gill et al + Feltham et al. + Laycock et al. = explanation for reduced colony performance in Whitehorn et al?
Why are results clear and consistent for bumblebees, but not for honeybees?

Large colony (~40,000)
Large food store
No discrete end point

Small colony (~100)
Small food store
Measurable nest success
So far, interest has focussed very much on impacts on bees,

but....
In Europe, most farmland wildlife is in decline:

- Birds
- Butterflies
- Bees
- Moths
- Carabid beetles
Declines 1945-1990 are easy to explain…

**Agricultural intensification:**

> loss of 97% of haymeadows and chalk grassland
> Introduction of pesticides and inorganic fertilizers
> Abandonment of leys and rotations
> Loss of hedgerows
> Drainage of marshes etc…

… but why do declines continue despite £400 million spend on agri-environment schemes in UK alone?
Environmental fate of neonic seed dressings

- 0.5-2% lost as dust
- ~2% absorbed by crop
- ~96% remains in soil / soil water
- Waterways ~unknown %
Persistence in soil

Estimates of half lives vary. Most are in the range 200 – 500 days. Some exceed 1,000 days. This would lead us to predict accumulation:
Levels of imidacloprid detected in soil into which treated wheat seeds were sown each autumn (1991-1996). Study sites are both in the East of England. Treatment rates were 66 or 133 g a.i./ha. Data from EU Draft Assessment Report for Imidacloprid, 2006.
“Long-term field dissipation trials of imidacloprid in soil with its repeated use as a seed treatment over 6 consecutive years have confirmed that the compound has no potential for accumulation in soil”
Persistence in plants

• Vines treated in spring via irrigation maintain levels of imidacloprid sufficient to control pests through the growing season

• A single application of imidacloprid to maple trees protected them against insect pests for 4 years

[Note – recent Oregon bee disaster following spray application to ornamental trees]
Prevalence in the environment?

Neonics likely to have accumulated in farmed soils - potential for broad-scale impacts on soil fauna?

Potential for uptake by field margin and hedgerow plants (often the target of agri-environment measures) – and hence impacts on herbivores e.g. butterfly caterpillars?

Knock-on effects for predators e.g. birds?

Aquatic fauna?
Prevalence in waterways?

Starner and Goh (2012): Sampling of Californian waterways:

- Imidacloprid in 89% of water samples

- 19% of samples exceeding the US Environmental protection Agency guideline of 1.05 ppb.
Direct impacts on vertebrates?

Grey Partridge LD$_{50} = 5$ mg = 5 maize seeds (or 6 beet seeds or 32 oilseed rape seeds)

A grey partridge eats ~25 g seed / day = 600 maize seeds

~0.5-1% of drilled seeds remain accessible to (USEPA)

Sowing rates ~50,000 seeds/ha for maize, 800,000 seeds/ha for oilseed rape: expect sufficient seed to be available on the soil surface to deliver an LD$_{50}$ to 100 partridge or 167 mice for every hectare sown.
Do we need neonics?

[A ban on neonicotinoids] “would have tremendous economic implications. Over a five year period, the EU could lose €17 billion... and... 50,000 jobs” From Humboldt Forum, 2013

The evidence underlying these claims seems to be absent. Calculations based on “We asked some farmers how much they thought their yield might drop if they didn’t have neonicotinoids”. Which farmers? How would they know?

What evidence is there?
UK oilseed rape yields did not increase AT ALL with the switch to neonicotinoids.
Whatever happened to IPM?

Mean productivities of the soybean crops (kg/ha) obtained in three different counties in Brazil from Bueno et al. 2011 *Crop Protection*, 30, 937-945.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Castelândia, GO</th>
<th>Santa Helena de Goiás, GO</th>
<th>Senador Canedo, GO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated pest management</td>
<td>3180.4</td>
<td>2447.01</td>
<td>2913.56</td>
</tr>
<tr>
<td>Biological Control</td>
<td>3171.21</td>
<td>2336.39</td>
<td>2709.65</td>
</tr>
<tr>
<td>Neonicotinoid</td>
<td>2981.49</td>
<td>2441.33</td>
<td>2832.85</td>
</tr>
<tr>
<td>Control</td>
<td>2555.12</td>
<td>2228.62</td>
<td>2487.32</td>
</tr>
<tr>
<td>F</td>
<td>12.64</td>
<td>3.71</td>
<td>0.96</td>
</tr>
<tr>
<td>P</td>
<td>0.0014</td>
<td>0.055</td>
<td>0.4526</td>
</tr>
<tr>
<td>df</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

IPM = integrated pest management; BC = biological control; PUI = prophylactic use of insecticides; C = control without pest treatment.

Yields are higher when using an Integrated Pest Management approach (monitor pests and spray when necessary) than when using neonics.
Further Observations

- Agrochemical companies conduct their own safety tests for registering new products
- Close and private relationship between regulators and regulated
- In Europe, these studies are not available for public or scientific scrutiny
- Most agronomic advice to European farmers is provided by agrochemical companies
- Why do we allow highly toxic compounds to be sold to gardeners, and used for cosmetic purposes in urban areas?
Knowledge gaps

- Levels of neonicotinoids in environment – water/ soil / foliage of field margin / hedgerow plants
- Impacts of chronic versus acute exposure
- Impacts of exposure of larvae
- Interactions with other chemicals, disease, food stress v poorly understood...
Current Regulatory Position

European Food Standards Agency: neonics pose unacceptable risks on crops visited by bees

Environmental Audit Committee (UK): Support moratorium on neonics

EU: Vote for 2 year moratorium March 2013 – not passed. 2\(^{nd}\) vote 26 April – passed, starts December 2013 for 2 years (UK voted against).

[No apparent plans to monitor effect]
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