Integrated Assessment on Systemic Pesticides

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Systemic insecticides: revolution in plant protection

Professor Shinzo Kagabu received the 2010 American Chemical Society International Award for Research in Agrochemicals in recognition of his discovery of imidacloprid (IMI) and thiacloprid, which opened the neonicotinoid era of systemic pest management.

(Tomizawa & Casida, 2010, DOI:10.1021/jf103856c)
Parallel Declines in Pollinators and Insect-Pollinated Plants in Britain and the Netherlands


Despite widespread concern about declines in pollination services, little is known about the patterns of change in most pollinator assemblages. By studying bee and hoverfly assemblages in Britain and the Netherlands, we found evidence of declines (pre- versus post-1980) in local bee diversity in both countries; however, divergent trends were observed in hoverflies. Depending on the assemblage and location, pollinator declines were most frequent in habitat and flower specialists, in univoltine species, and/or in nonmigrants. In conjunction with this evidence, outcrossing plant species that are reliant on the declining pollinators have themselves declined relative to other plant species. Taken together, these findings strongly suggest a causal connection between local extinctions of functionally linked plant and pollinator species.

Patterns of widespread decline in North American bumble bees

Sydney A. Cameron, Jeffrey D. Lodier, James P. Strange, Jonathan B. Koch, Nils Gordo, Leelien F. Sotker, and Terry L. Griswold

Bumble bees (Bombus) are vitaly important pollinators of wild study in the United States identified lower genetic diversity and intensive nationwide surveys of >16,000 specimens. We show that the relative abundances of four species have declined by up to 96% and that their surveyed geographic ranges have contracted by 23–87%, some within the last 20 years. We also show that declining populations have significantly higher infection levels of the microsporidian pathogen Nosema bombi and lower genetic diversity compared
Neonicotinoid Pesticide Reduces Bumble Bee Colony Growth and Queen Production

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Growing evidence for declines in bee populations has caused great concern due to the valuable ecosystem services they provide. Neonicotinoid insecticides have been implicated in these declines as they occur at trace levels in the nectar and pollen of crop plants. We exposed colonies of the bumble bee Bombus terrestris in the lab to field-realistic levels of the neonicotinoid imidacloprid, then allowed them to develop naturally under field conditions. Treated colonies had a significantly reduced growth rate and suffered an 85% reduction in production of new queens compared to control colonies. Given the scale of use of neonicotinoids, we suggest that they may be having a considerable negative impact on wild bumble bee populations across the developed world.

Science, 29 Mar 2012 http://dx.doi.org/10.1126/science.1215025
The importance of pollinators

- 90 major crops (good for 35% world food production) depend on pollinators
- Key nutrients: 90-100% from pollinator mediated crops (vit C, antioxidants, lycopene, β-tocopherol, vit A and folic acid
- Value in Europe: 14.2 billion Euro / yr
- 80% of all flowering plants on earth depends on 25000 bee species for reproduction and evolution
Systemic insecticides

- Systemic: Contamination of nectar and pollen
- Very high toxicity for honeybees
- A long persistence in soils ($t_{1/2} = 9$ months) and water (160 days)
- Main metabolites as toxic as imidacloprid for bees
- Acute effects (overdosing, sowing...)
- Sublethal effects and chronic exposure
- Risks in fields: $\text{PEC}/\text{PNEC} >> 1$
- Synergies with other pesticides
- Synergies with other pathogens (Nosema, Wing Deform Virus)
- **Major weakening factor of bee colonies**
## Toxicity of neonicotinoids

<table>
<thead>
<tr>
<th>Pesticide</th>
<th>®</th>
<th>Use</th>
<th>LD50 (ng/honeybee)</th>
<th>Toxicity index relative to DDT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDT</td>
<td>Dinocide</td>
<td>insecticide</td>
<td>27000</td>
<td>1</td>
</tr>
<tr>
<td>Amitraz</td>
<td>Apivar</td>
<td>insecticide / acaricide</td>
<td>12000</td>
<td>2</td>
</tr>
<tr>
<td>Coumaphos</td>
<td>Perizin</td>
<td>insecticide / acaricide</td>
<td>3000</td>
<td>9</td>
</tr>
<tr>
<td>Tau-fluvalinate</td>
<td>Apistan</td>
<td>insecticide / acaricide</td>
<td>2000</td>
<td>13.5</td>
</tr>
<tr>
<td>Methiocarb</td>
<td>Mesurol</td>
<td>insecticide</td>
<td>230</td>
<td>117</td>
</tr>
<tr>
<td>Carbofuran</td>
<td>Curater</td>
<td>insecticide</td>
<td>160</td>
<td>169</td>
</tr>
<tr>
<td>λ-cyhalothrin</td>
<td>Karate</td>
<td>insecticide</td>
<td>38</td>
<td>711</td>
</tr>
<tr>
<td>Deltamethrine</td>
<td>Decis</td>
<td>insecticide</td>
<td>10</td>
<td>2700</td>
</tr>
<tr>
<td>Thiamethoxam</td>
<td>Cruise</td>
<td>insecticide</td>
<td>5</td>
<td>5400</td>
</tr>
<tr>
<td>Fipronil</td>
<td>Regent</td>
<td>Insecticide</td>
<td>4.2</td>
<td>6475</td>
</tr>
<tr>
<td>Clothianidine</td>
<td>Poncho</td>
<td>Insecticide</td>
<td>4.0</td>
<td>6750</td>
</tr>
<tr>
<td>Imidacloprid</td>
<td>Gaucho</td>
<td>Insecticide</td>
<td>3.7</td>
<td>7297</td>
</tr>
</tbody>
</table>

Toxicity of insecticides to honeybees compared to DDT. The final column expresses the toxicity relative to DDT. (Source: Bonmatin, 2009)  
### Table 3.1 Half-life in Soil of Neonicotinoids

<table>
<thead>
<tr>
<th>Neonicotinoid</th>
<th>Half-life in Soil (aerobic soil metabolism)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetamiprid</td>
<td>1–8 days(^1)</td>
</tr>
<tr>
<td>Clothianidin</td>
<td>148–1,155 days(^2)</td>
</tr>
<tr>
<td>Dinotefuran</td>
<td>138 days(^3)</td>
</tr>
<tr>
<td>Imidaclorpid</td>
<td>40–997 days(^4)</td>
</tr>
<tr>
<td>Thiaclorpid</td>
<td>1–27 days(^5)</td>
</tr>
<tr>
<td>Thiamethoxam (See note below)</td>
<td>25–100 days(^6)</td>
</tr>
</tbody>
</table>

**Note:** Clothianidin is a primary metabolite of thiamethoxam.

http://goo.gl/3HnYI
<table>
<thead>
<tr>
<th>Brand</th>
<th>Active Ingredient</th>
<th>Company</th>
<th>Application</th>
<th>Sales 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round-up</td>
<td>Glyphosate (I)</td>
<td>Monsanto</td>
<td>Herbicide</td>
<td>8.30</td>
</tr>
<tr>
<td>Admire, Gaacho</td>
<td>Imidacloprid (II)</td>
<td>Bayer</td>
<td>Insecticide</td>
<td>1.28</td>
</tr>
<tr>
<td>Heritage F 500</td>
<td>Azoxy strebin (III)</td>
<td>Syngenta</td>
<td>Fungicide</td>
<td>1.16</td>
</tr>
<tr>
<td>Flagship</td>
<td>Pyraclostrobin (IV)</td>
<td>BASF</td>
<td>Herbicide</td>
<td>1.10</td>
</tr>
<tr>
<td>Callisto</td>
<td>Thiemethoxam (V)</td>
<td>Syngenta</td>
<td>Insecticide</td>
<td>0.73</td>
</tr>
<tr>
<td>Grammoxone</td>
<td>Paraquat-dichloride (VII)</td>
<td>Syngenta</td>
<td>Herbicide</td>
<td>0.62</td>
</tr>
<tr>
<td>Flint</td>
<td>Trifloxystrobin (VIII)</td>
<td>Bayer</td>
<td>Fungicide</td>
<td>0.60</td>
</tr>
<tr>
<td>Horizon, Folicur</td>
<td>Tebuconazole (IX)</td>
<td>Bayer</td>
<td>Fungicide</td>
<td>0.55</td>
</tr>
<tr>
<td>Regent MG, Frontline</td>
<td>Fipronil (X)</td>
<td>BASF</td>
<td>Insecticide</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Sales 2008 ($ billion \(a\) and MT).

\(a\) Ex-factory.

11–20: (Figures in $ million/MT) clothienidin (509/546); chlorpyrifos (482/34,945); chlorothalonil (475/48,559); lambda-cyhalothrin (454/1085); 2,4-D (453/64,725); prothioconazole (417/1550); mesosulfuron-methyl (414/530); kresoxym-methyl (409/3450); acetochlor (400/39,000); glufosinate-ammonium (399/3990).

Source: Cropnosis Ltd—Agranova.

http://goo.gl/gLMNk
Production and Market of Imidacloprid in China

“Imidacloprid, as the largest application amount of neonicotinoid insecticide in the world, is embracing a rapid development and becoming a hot spot in China. China records 13,620 tonnes of imidacloprid technical output in 2010, accounting for more than 50% of world’s total, which is 20,000 tonnes.” (CCM International Ltd, March 2011)


• (compare to DDT peak-use of 80,000 tonnes in 1959 and remember that imidacloprid is 7297x more toxic to insects)
Integrated Assessment: Combine knowledge from many sources to get the full picture

Accelerating the collapse of the ecosystem

(Picture from: Japan Endocrine-disruptor Preventive Action)
Practitioners

- Empirical and anecdotal evidence
- Social discourse and extended peer review
- Disciplinary research e.g. physics, chemistry, biology, ecology, economics, sociology
- Integrated Assessment Modelling

Users
- International, national and regional public administrations
- NGOs
- Industrial lobby groups
- Business
- Mass media
- Public

Integrated Environmental Assessment
Policy development
The Integrated Assessment will address:

- Use / Trends / Applications / Mechanisms of neonics
- Environmental fate & exposure (soil, water, air, plants)
- Impacts on
  - Non target arthropods
    - Pollinators
    - Non-pollinators
  - Non arthropod invertebrates
  - Non-human vertebrates
- Ecosystem services
  - Pollination
  - Soil / organic decomposition
  - Fisheries (shell fish!)
  - Foodweb
- Shortcomings of market authorization risk assessment
- Alternatives
Simplified 6-point Weiss-scale for use in our Integrated Assessment to assess levels of evidence regarding impacts of neonics on selected non-target species (groups)

• Beyond (reasonable) doubt
• Clear and convincing evidence
• Substantial credible evidence
• Clear indication
• Reasonable grounds for suspicion
• Hunch

(as developed at the March 2011 meeting of the Task Force in Bath, UK)
Only 1.6 to 20% of applied neonicotinoid is absorbed by the growing crop (Sur & Storl 2003)
80 to 98.4% leaches to soil & water!

Since 2004, Netherlands surface water is heavily polluted with Imidacloprid

www.bestrijdingsmiddelenatlas.nl
Has this pollution impacts on insects?
To find out we combined 2 datasets:

- Monitoring data obtained from 23 of 26 NL water boards, covering 7 years
- >600000 data points \((x, y, t, \text{species, abundance})\) of macro invertebrates
- 18898 points with IMI data within 1 km radius & < 160 days time difference
- Data on 4009 species from 92 orders

Significant negative relationship between species abundance and imidacloprid concentration found for:

- All orders pooled
- Amphipoda (crustaceans)
- Diptera (true flies)
- Ephemeroptera (mayflies)
- Isopoda (crustaceans)
- Odonata (dragonflies & damselflies)
- Basommatophora (snails)

For one order we found significant positive relation: Actinedida (mites and spiders)
log10 imidacloprid concentration (ng/l) versus log10 macro-invertebrate species abundance in surface water for a) Amphipoda, b) its most abundant species *Gammarus tigrinus*, c) Actinedida and d) its most abundant species *Limnesia undulata*.
Polluted areas have ±70% less macro-invertebrates

Graph: Mean and standard error of aquatic macro-invertebrate species abundance at median imidacloprid concentration in NL surface water below and above the Maximum Tolerable Risk limit.

* Indicates significant difference at \( p < 0.05 \) Mann Whithney test.

<table>
<thead>
<tr>
<th>Year</th>
<th>Percentage samples exceeding MTR (( \geq 13 \text{ ng/l} ))</th>
<th>Highest concentration found (ng/liter)</th>
<th>Median (ng/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>39% (( n = 505 ))</td>
<td>320000</td>
<td>180</td>
</tr>
<tr>
<td>2006</td>
<td>43% (( n = 811 ))</td>
<td>38000</td>
<td>80</td>
</tr>
<tr>
<td>2007</td>
<td>54% (( n = 1031 ))</td>
<td>54000</td>
<td>90</td>
</tr>
<tr>
<td>2008</td>
<td>48% (( n = 1224 ))</td>
<td>94000</td>
<td>70</td>
</tr>
<tr>
<td>2009</td>
<td>39% (( n = 1529 ))</td>
<td>12000</td>
<td>60</td>
</tr>
</tbody>
</table>
Effects on honeybees

- Acute intoxication
- Chronic intoxication
- Sublethal effects
- Synergy effects
What are exposure pathways?

- Treated crops
  - Contact
  - Pollen (delayed consumption!, Bee bread etc.)
  - Nectar (delayed consumption!, honey)
  - Extrafloral nectar
  - Honey-dew (from aphids)
  - Guttation (plant sap excreted by the plant)
  - Dew/rain (waterdrops from the atmosphere)
  - Sweet remains of e.g. sugarbeets, etc.
- Systemic uptake by untreated wild plants and trees on same soil
- Systemic uptake of contaminated water by wild plants and trees
- Spray drift / dust drift to flowering fields
- Direct contact with dust (flying through the dust cloud)
- Foraging on polluted surface water (for drinking and COOLING!)
- Residues in sugar used for sugar syrup supplementary feeding
- Residues in water used by beekeepers to make sugar syrup (violation of drinking water norm in NL > 100 ng/liter)
- Can it travel through the air? On PM2.5? On diesel soot/black carbon? On aerosol-water?
- Brabant, NL scandal 2011: Waste-sand from treated Lilly bulbs used for trails in protected nature area
- Etc........
Pomurje, Slovenia April 2011, sowing period clothianidin corn

Damage
2500 colonies lost

> 100 million bees
Field test in Padua

Deadly dust cloud
< 30 seconds 10m away:
300 to 4000 ng imidacloprid per bee

http://www.bijensterfte.nl/en/node/507
Krupke e.a. 2012 study

Table 6. Pesticide concentrations found in unplanted fields near apiary during planting period in 2011, all concentrations shown are expressed as parts per billion.

<table>
<thead>
<tr>
<th>SAMPLE TYPE</th>
<th>Sample wt. (g)</th>
<th>THIAMETHOXAM LOD = 1.0</th>
<th>CLOTHIANIDIN LOD = 1.0</th>
<th>METOLACHLOR LOD = 0.5</th>
<th>ATRAZINE LOD = 0.2</th>
<th>AZOXYSTROBIN LOD = 0.2</th>
<th>COUMAPHOS LOD = 1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil, unplanted field 1, Soybeans 2010 (2 samples)</td>
<td>5.15, 5.01</td>
<td>ND</td>
<td>6.0 ± 0.3</td>
<td>1014 ± 14</td>
<td>771 ± 170</td>
<td>0.2 ± 0.1</td>
<td>ND</td>
</tr>
<tr>
<td>Soil, unplanted field 2, Soybeans 2010 (2 samples)</td>
<td>5.28, 5.43</td>
<td>ND</td>
<td>8.9 ± 0.1</td>
<td>8.3 ± 0.7</td>
<td>160 ± 15</td>
<td>26 ± 17</td>
<td>ND</td>
</tr>
<tr>
<td>Dandelions near maize field</td>
<td>2.96</td>
<td>ND</td>
<td>1.4</td>
<td>49</td>
<td>677</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Dandelions near maize field</td>
<td>3.81</td>
<td>1.6</td>
<td>5.9</td>
<td>64</td>
<td>1133</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Dandelions near maize field</td>
<td>4.51</td>
<td>1.3</td>
<td>3.1</td>
<td>28</td>
<td>522</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Dandelions near maize field</td>
<td>4.05</td>
<td>2.9</td>
<td>1.1</td>
<td>60</td>
<td>269</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Dandelions near maize field</td>
<td>3.10</td>
<td>1.1</td>
<td>1.6</td>
<td>5.7</td>
<td>125</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Dandelions near maize field</td>
<td>3.44</td>
<td>ND</td>
<td>9.4</td>
<td>295</td>
<td>1004</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Dandelion, CAES (non-agricultural area)</td>
<td>3.93</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

When two aliquots of the same sample were analyzed the results are expressed as ± the standard deviation of the two analyses.

ND = Not detected.
doi:10.1371/journal.pone.0029268.t006

Do trees translocate imidacloprid from surface water into pollen & nectar?

*In NL we took samples from willow trees (Salix) in polluted areas*
Exposure via guttation?

Via water for drinking and cooling?

**Figure 9.1** The spreading of water droplets by nurse bees when a colony’s broodnest is threatened by overheating. Spreading water, combined with fanning the wings to expel hot air from the hive, causes evaporative cooling of the brood combs. After Park 1925.

**T. Seeley, The wisdom of the hive**
Chapter 9 regulation of water collection
Chronic toxicity imidacloprid for bumblebees

Micro colonies fed with imidacloprid at

- 200 ppm  100% mortality few hours
- 20 ppm  100% mortality 14 days
- 2 ppm  100% mortality 28 days
- 0.2 ppm  100% mortality 49 days,
- 20 ppb  15% mortality (77 days)
- 10 ppb  0% mortality (77 days)

NOEC reproduction <2.5 ppb

http://dx.doi.org/10.1007/s10646-009-0406-2  Mommaerts e.a. 2010
Neonicotinoid/Organophosphorous pesticides disrupt the neural transmission

Neural transmission mechanism through acetylcholine

Humans and insects cannot live unless the neural transmission functions normally. Neurotransmitters such as acetylcholine and glutamic acid are important substances that carry out this neural transmission.

Organophosphorous pesticides block acetylcholinesterase (hydrolitic enzyme of acetylcholine) and make the neural transmission stay on. It has the same effect as dangerous toxic nerve gas such as the Sarin.

Neonicotinoids bind with acetylcholine receptors, and become “false-neurotransmitters”, where neural transmission switch will turn on even if there is no acetylcholine present.

(Picture from: Japan Endocrine-disruptor Preventive Action)
Sublethal effects

- Foraging behaviour / navigation
- Task differentiation in the hive
- Grooming
- Immune system
- Brood
- Larval development
- etc./.
Using video-tracking to assess sublethal effects of pesticides on honey bees

- Bees exposed to 0.05, 0.5, 5.0, 50, and 500 ppb imidacloprid in a sugar agar cube
- Significant reduction in distance moved at 50 and 500 ppb imidacloprid (p<0.001).
- Obvious biological gradient

Figure: a=distance, b=time in foodzone, c=time interacting
http://dx.doi.org/10.1002/etc.1830
In situ replication of honey bee colony collapse disorder

Figure 3. Dead hive (ID# 4-4) treated with 20 μg/kg of imidacloprid which shows the abundance of stored honey and some pollen, but no sealed brood or honey bees. Photo was taken on February 24th, 2011.

http://goo.gl/1a0Aa
Problems with field studies

• Some field studies have $n=1$ (Schmuck 2001)
• Many flaws in experimental set-up of field studies used for authorization
• Many field studies turned out to have a hidden sponsor: Bayer Cropscience
• Example: Cutler and Dupree 2007 study
• In authorization protocols field studies (even flawed ones and $n=1$ ones) get more weight than lab studies, but from a scientific point of view lab studies are more reliable!
Plurality and uncertainty in risk assessment: lessons learned

- **Diversity of the knowledge base:**
  - It must be based on the full spectrum of available scientific knowledge;

- **Robustness of the knowledge claims**
  - Include uncertainty, dissent and criticism in the analysis, synthesis and assessments;

- Make thorough **Knowledge Quality Assessment the key task in the science policy interface** and develop a joint language to communicate limitations to our knowledge and understanding clearly and transparently

- Make use of **information of non-scientific sources** (local knowledge)
  - But scrutinize this information and be clear on its status;

- **Clarify values, stakes and vested interests** that play a role in research and in the political and socioeconomic context within which the research is embedded.

(Maxim and van der Sluijs, 2007, 2012)
Further reading

Late lessons from early warnings

- The Threat of Neonicotinoid Pesticides on Honeybees, Ecosystems, and Humans (JEPA)
  http://www.bijensterfte.nl/sites/default/files/Neonicotinoid_e.pdf
- The Decline of England’s Bees: Policy Review and Recommendations
  http://www.foe.co.uk/resource/briefings/beesreport.pdf
- Global honey bee colony disorders and other threats to insect pollinators (UNEP 2011 report)
- The puzzle of honey bee losses: a brief review
  http://www.bulletinofinsectology.org/pdfarticles/vol63-2010-153-160maini.pdf
- The impact of neonicotinoid insecticides on bumblebees, Honey bees and other non-target invertebrates
- The Effects of Pesticide-Contaminated Pollen on Larval Development of the Honey Bee, Apis mellifera
  http://archives.evergreen.edu/masterstheses/Accession86-10MES/burlew_daMES2010.pdf
- Tennekes & Sánchez-Bayo 2011: Time-Dependent Toxicity of Neonicotinoids and Other Toxicants
- Effects of neonicotinoid pesticide pollution of Dutch surface water on non-target species abundance
- The systemic insecticides - A disaster in the making
  http://www.disasterinthemaking.com/
- http://www.bijensterfte.nl
www.jvds.nl

www.bijensterfte.nl