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Integrated Assessment on Systemic Pesticides

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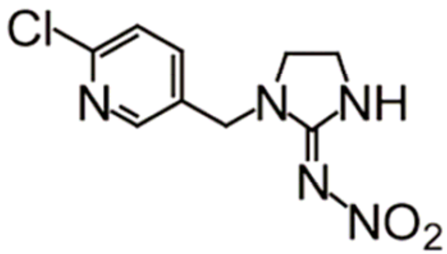
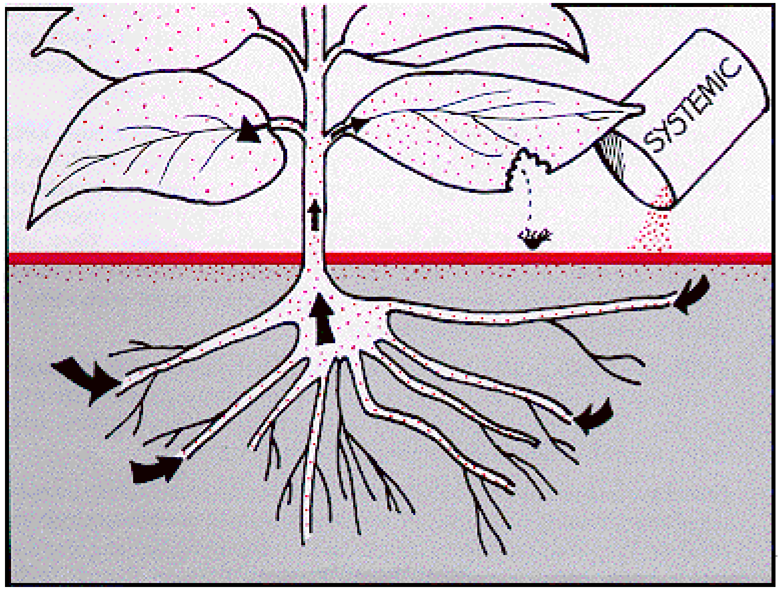
Systemic insecticides: revolution in plant protection

Shinzo Kagabu



imidacloprid (1991)



Systemic = crop takes it up into its plantsap: chemical makes plant toxic from inside

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

2006

J. C. Biesmeijer,[1]* S. P. M. Roberts,[2] M. Reemer,[3] R. Ohlemüller,[4] M. Edwards,[5] T. Peeters,[3,6] A. P. Schaffers,[7] S. G. Potts,[2] R. Kleukers,[3] C. D. Thomas,[4] J. Settele,[8] W. E. Kunin[1]

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.

PNAS

Patterns of widespread decline in North American bumble bees

Sydney A. Cameron[a,1], Jeffrey D. Lozier[a], James P. Strange[b], Jonathan B. Koch[b,c], Nils Cordes[a,2], Leellen F. Solter[d], and Terry L. Griswold[b]

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Edited* by Gene E. Robinson, University of Illinois, Urbana, IL, and approved November 24, 2010 (received for review October 3, 2010)

Bumble bees (*Bombus*) are vitally important pollinators of wild   study in the United States identified lower genetic diversity and

2011

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 y. We also show that declining populations have significantly higher infection levels of the microsporidian pathogen *Nosema bombi* and lower genetic diversity compared

2011

Neonicotinoid Pesticide Reduces Bumble Bee Colony Growth and Queen Production

Penelope R. Whitehorn,[1] Stephanie O'Connor,[1] Felix L. Wackers,[2] Dave Goulson[1]*

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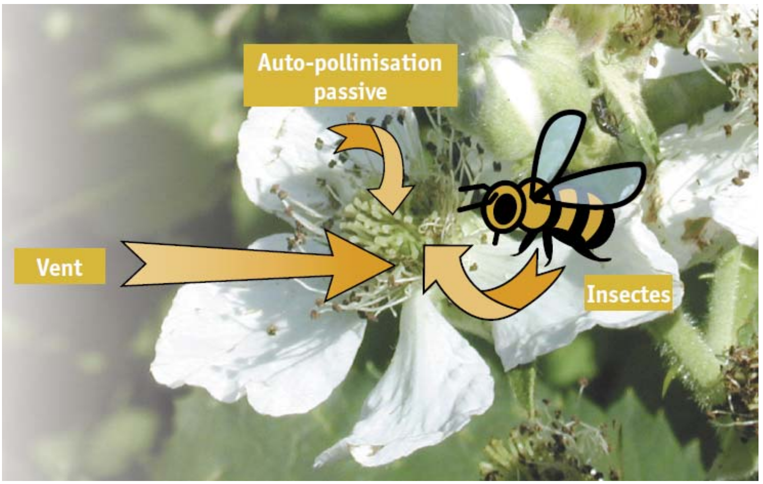
Growing evidence for declines in bee populations has caused great concern due to the valuable ecosystem services they provide. Neonicotinoid insecticides have been implicated in these declines as they occur at trace levels in the nectar and pollen of crop plants. We exposed colonies of the bumble bee *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…)
- Subletal effects and chronic exposure
- Risks in fields : PEC/PNEC >> 1
- Synergies with other pesticides
- Synergies with other pathogens (Nosema, Wing Deform Virus)
- **Major weakening factor of bee colonies**

Toxicity of neonicotinoids

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

Toxicity of insecticides to honeybees compared to DDT. The final column expresses the toxicity relative to DDT. (Source: Bonmatin, 2009)

http://www.bijensterfte.nl/images/Bonmatin-conclusions-sentinelle-gb-2009.pdf

Table 3.1 Half-life in Soil of Neonicotinoids

Neonicotinoid	Half-life in Soil (aerobic soil metabolism)
Acetamiprid	1–8 days[1]
Clothianidin	148–1,155 days[2]
Dinotefuran	138 days[3]
Imidacloprid	40–997 days[4]
Thiacloprid	1–27 days[5]
Thiamethoxam (See note below)	25–100 days[6]

Note: Clothianidin is a primary metabolite of thiamethoxam.

http://goo.gl/3HnYl

TABLE 11.6 Top 10 Agrochemicals/Key Data

Brand	Active Ingredient	Company	Application	Sales 2008	
				$ billion[a]	MT
Round-up	Glyphosate (**I**)	Monsanto	Herbicide	8.30	620,000
Admire, Gaucho	Imidacloprid (**II**)	Bayer CropScience.	Insecticide	1.28	5450
Heritage	Azoxystrobin (**III**)	Syngenta	Fungicide	1.16	7000
F 500	Pyraclostrobin (**IV**)	BASF	Herbicide	1.10	7200
Flagship	Thiemethoxam (**V**)	Syngenta	Insecticide	0.73	1895
Callisto	Mesotrione (**VI**)	Syngenta	Herbicide	0.62	2040
Grammoxone	Paraquat-dichloride (VII)	Syngenta	Herbicide	0.60	26,000
Flint	Trifloxystrobin (VIII)	Bayer CropScience.	Fungicide	0.60	3405
Horizon, Folicur	Tebuconazole (**IX**)	Bayer CropScience.	Fungicide	0.55	2860
Regent MG, Frontline	Fipronil (**X**)	BASF	Insecticide	0.53	1375

[a] Ex-factory.

11–20: (Figures in $ million/MT) clothienidin (509/546); chlorpyrifos (482/34,945); chlorothalonil (475/48,559); lambda-cyanhalothrin (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)*

Source: http://www.researchandmarkets.com/reportinfo.asp?report_id=649028&t=d&cat_id=

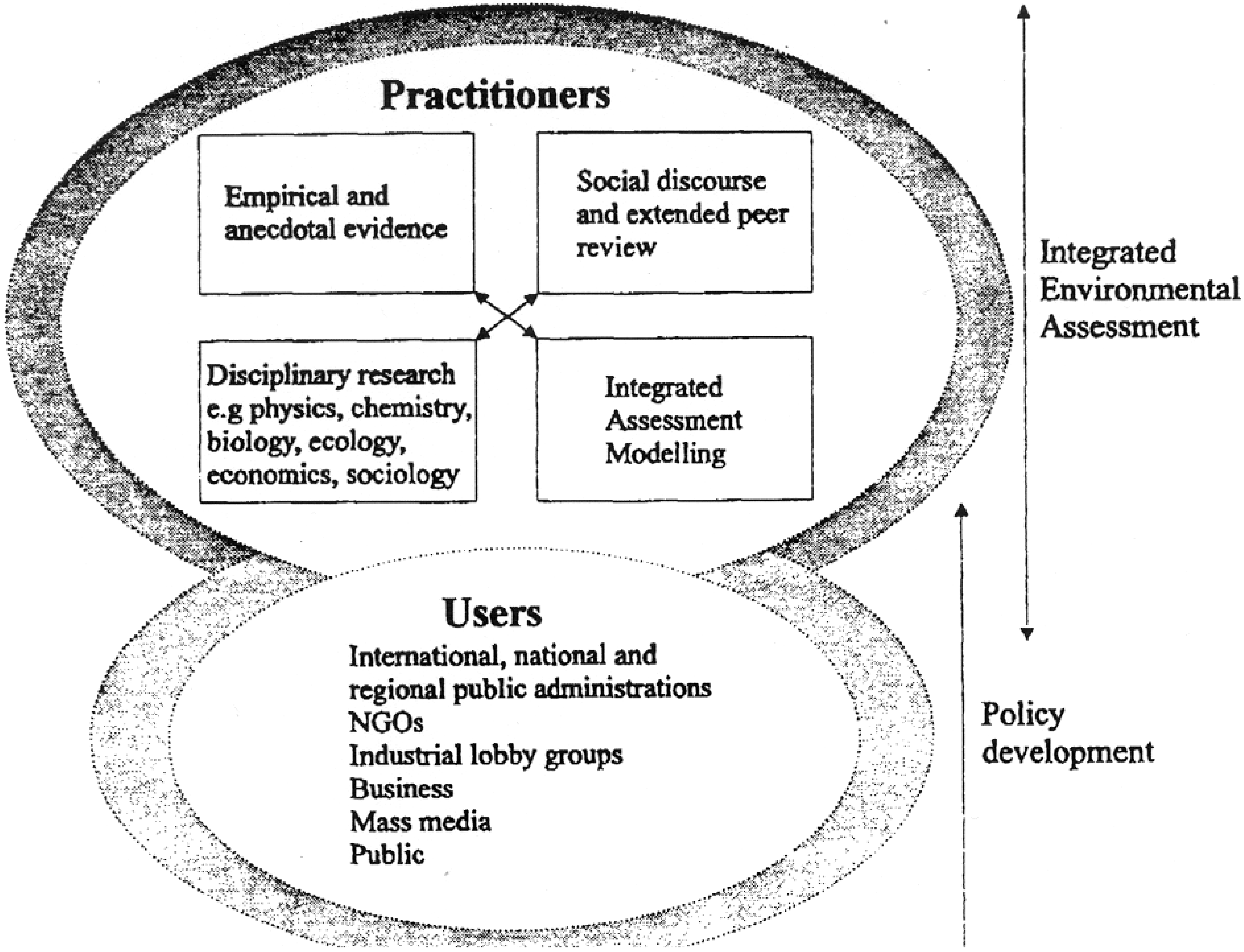
- (compare to DDT peak-use of 80,000 tonnes in 1959 and remember that imidacloprid is 7297x more toxic to insects)

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)

Illustration: Saori Yasutomi


Practitioners
Empirical and anecdotal evidence
Social discourse and extended peer review
Disciplinary research e.g physics, chemistry, biology, ecology, economics, sociology
Integrated Assessment Modelling
Integrated Environmental Assessment
Users
International, national and regional public administrations
NGOs
Industrial lobby groups
Business
Mass media
Public
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)

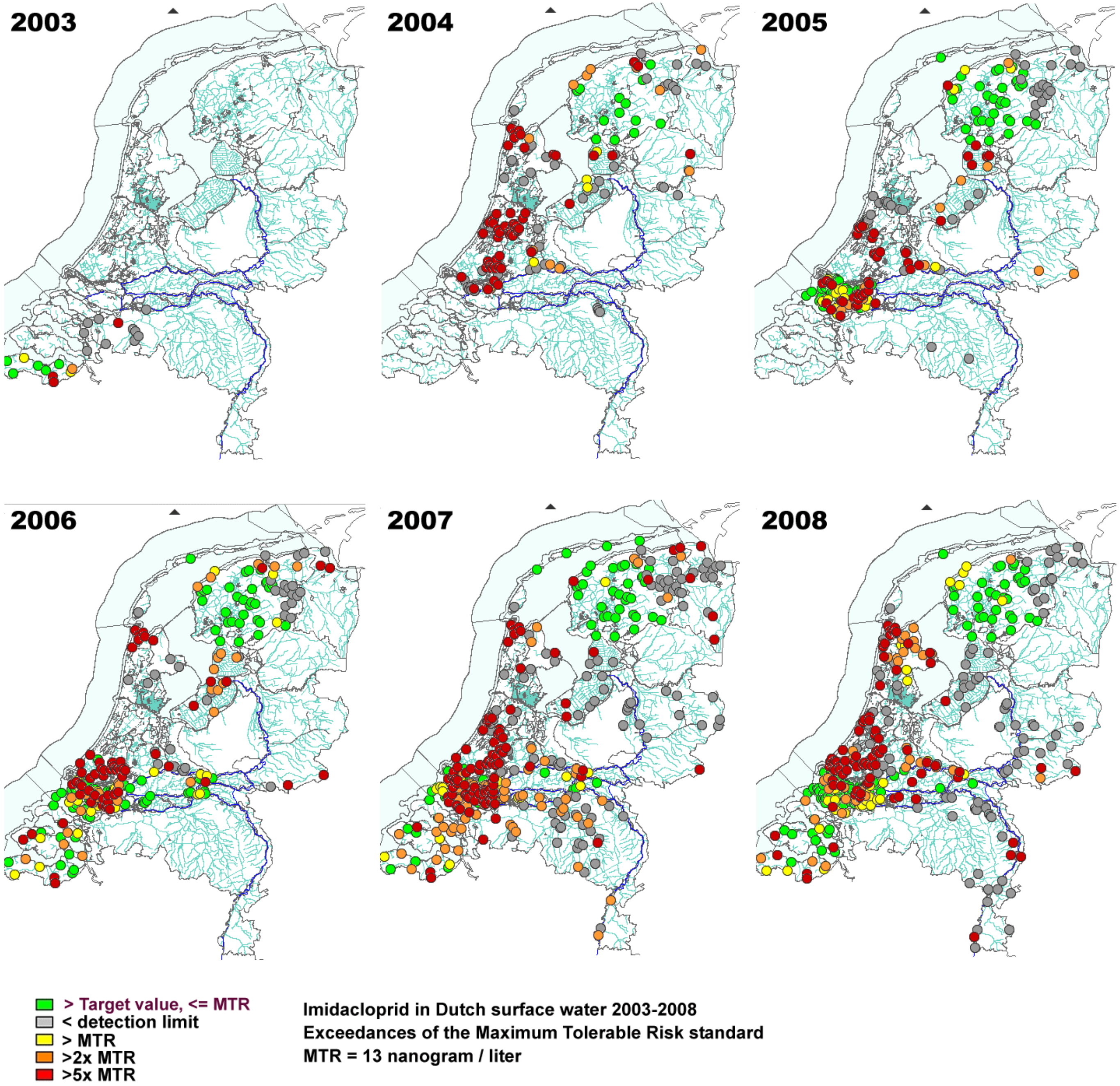
- Beyond (reasonable) doubt
- Clear and convincing evidence
- Substantial credible evidence
- Clear indication
- Reasonable grounds for suspicion
- Hunch

(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



Imidacloprid in Dutch surface water 2003-2008
Exceedances of the Maximum Tolerable Risk standard
MTR = 13 nanogram / liter

Has this pollution impacts on insects? To find out we combined 2 datasets:

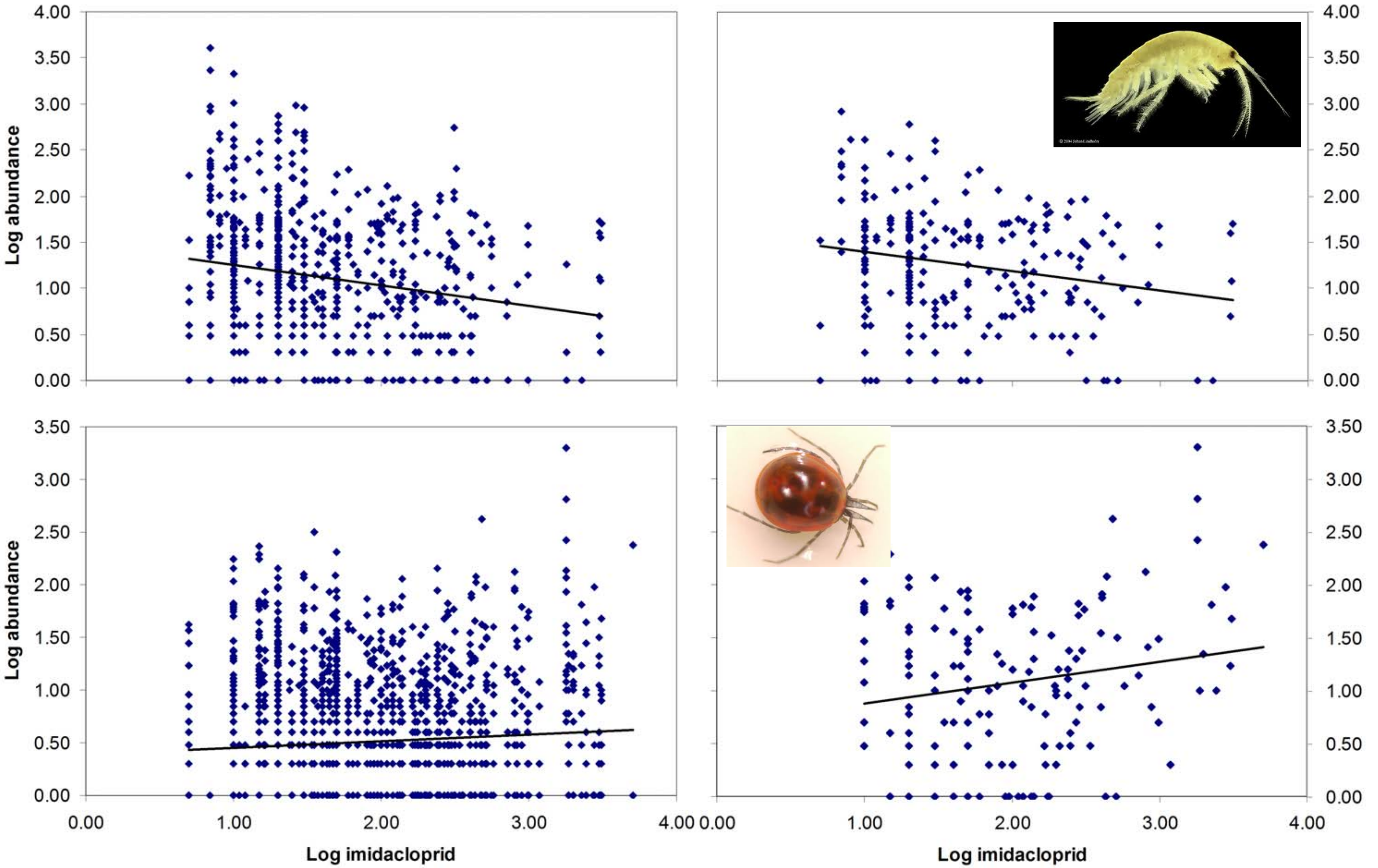
- Monitoring data obtained from 23 of 26 NL water boards, covering 7 years
- >600000 data points (x, y, t, species, abundance) of macro invertebrates
- 18898 points with IMI data within 1 km radius & < 160 days time difference
- Data on 4009 species from 92 orders

http://www.bijensterfte.nl/sites/default/files/FinalThesisTvD.pdf

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

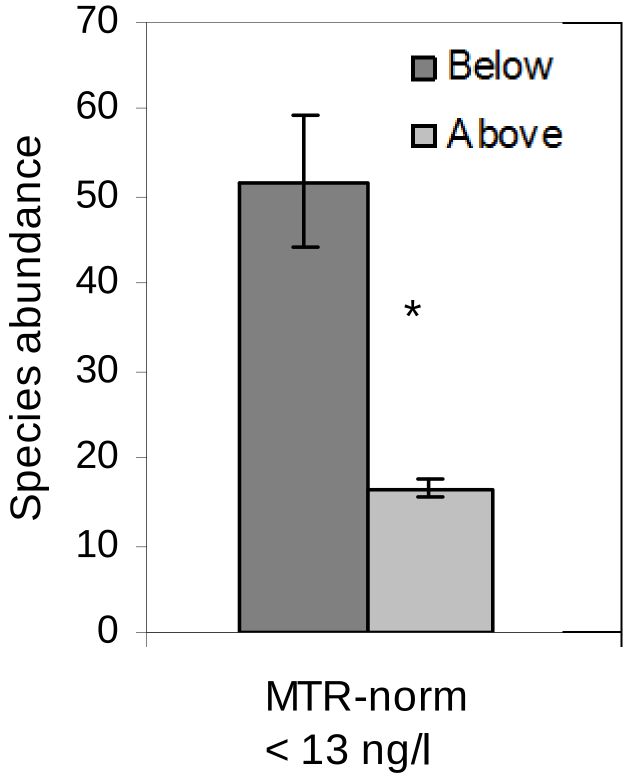
- All orders pooled
- Amphipoda (crustaceans)
- Diptera (true flies)
- Ephemeroptera (mayflies)
- Isopoda (crustaceans)
- Odonata (dragonflies & damselflies)
- Basommatophora (snails)

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



Year	Percentage samples exceeding MTR (>=13 ng/l)	Highest concen-tration found (ng/liter)	Median (ng/l)
2005	39% (*n*=505)	320000	180
2006	43% (*n*=811)	38000	80
2007	54% (*n*=1031)	54000	90
2008	48% (*n*=1224)	94000	70
2009	39% (*n*=1529)	12000	60

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.

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 drinkingwater norm in NL > 100 ng/liter)
- Can it travel trough the air? On PM2.5? On diessel soot/black carbon? On airosol-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.[1]

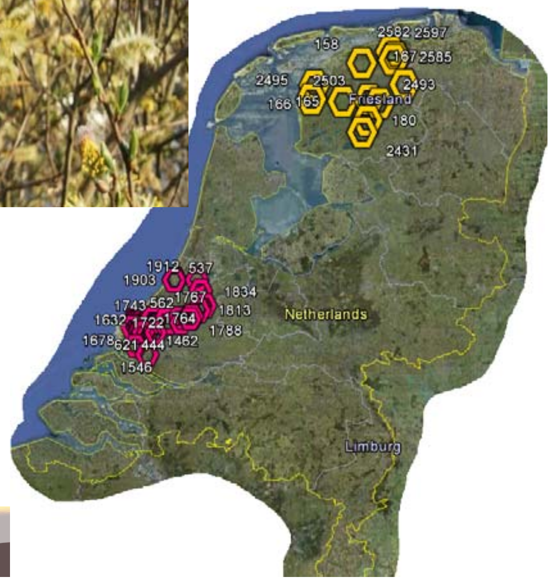
SAMPLE TYPE	Sample wt. (g)	THIAMETHOXAM LOD = 1.0	CLOTHIANIDIN LOD = 1.0	METOLACHLOR LOD = 0.5	ATRAZINE LOD = 0.2	AZOXYSTROBIN LOD = 0.2	COUMAPHOS LOD = 1.0
Soil, unplanted field 1, Soybeans 2010 (2 samples)	5.15, 5.01	ND	6.0±0.3	1014±14	771±170	0.2±0.1	ND
Soil, unplanted field 2, Soybeans 2010 (2 samples)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

When two aliquots of the same sample were analyzed the results are expressed as ± the standard deviation of the two analyses.
[1]ND = Not detected.
doi:10.1371/journal.pone.0029268.t006

Krupke e.a. 2012. Multiple Routes of Pesticide Exposure for Honey Bees Living Near Agricultural Fields. http://dx.doi.org/10.1371/journal.pone.0029268

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)

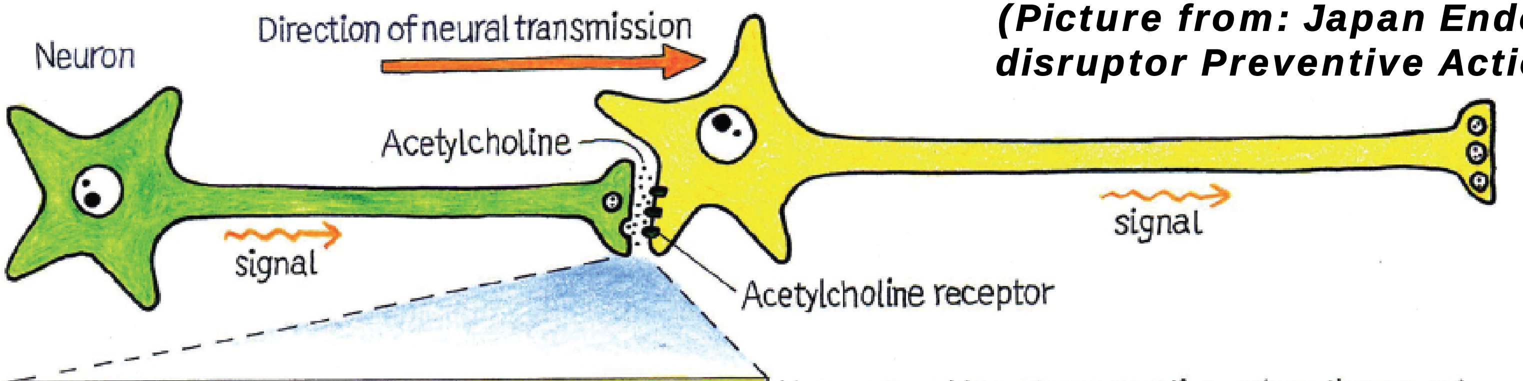
NOEC reproduction <2.5 ppb

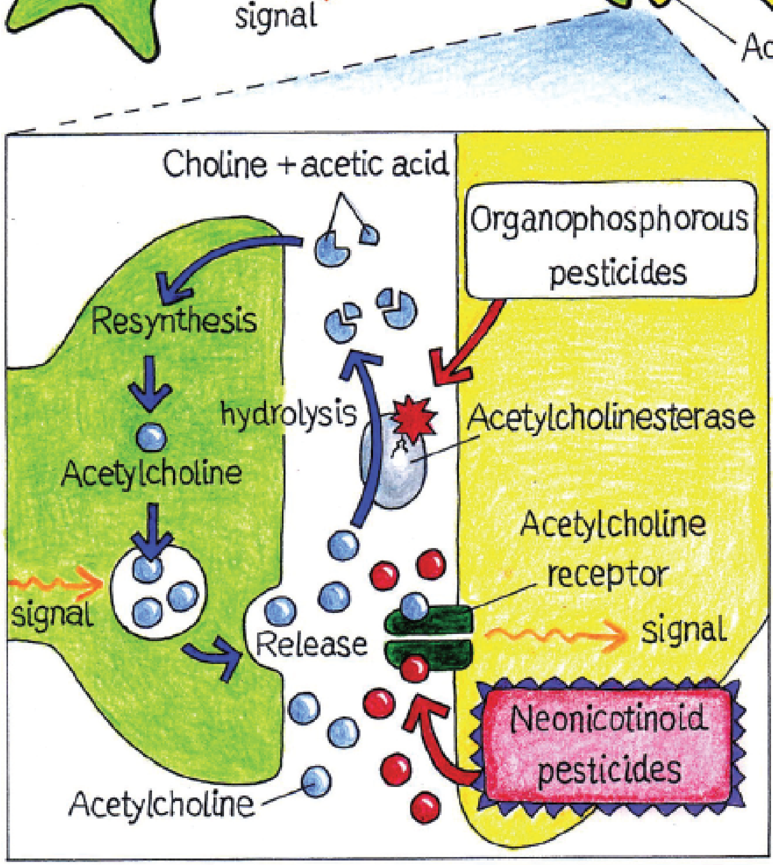
http://dx.doi.org/10.1007/s10646-009-0406-2 Mommaerts e.a. 2010

Neonicotinoid / Organophosphorous pesticides disrupt the neural transmission

Neural transmission mechanism through acetylcholine

(Picture from: Japan Endocrine-disruptor Preventive Action)





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

Organophosphorous pesticides block acetylcholin-esterase(hydrolytic 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.

Illustration: Saori Yasutomi

http://www.bijensterfte.nl/sites/default/files/Neonicotinoid_e.pdf

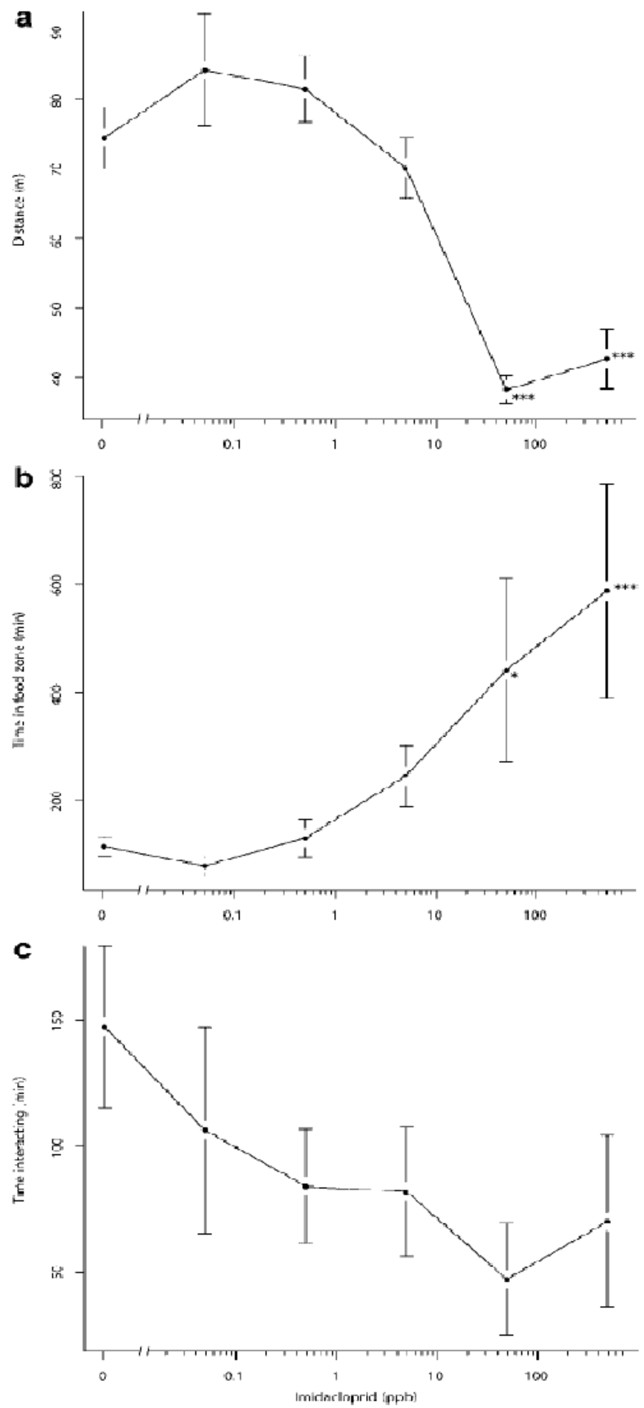
Sublethal effects

- 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



Lu e.a. 2012 Harvard University- 5 Apr 2012

In situ replication of honey bee colony collapse disorder

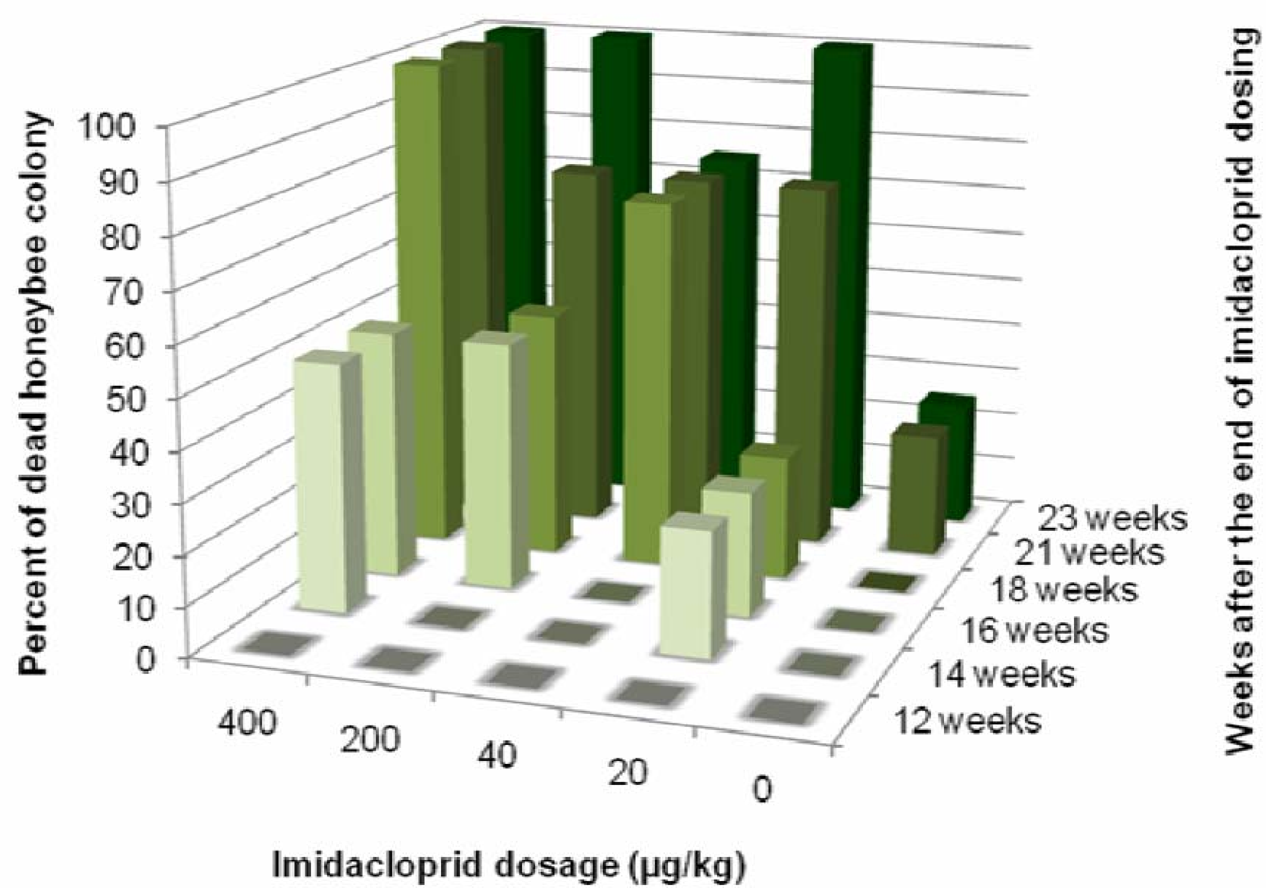


Figure 3. Dead hive (ID# 4-4) treated with 20 µg/kg of imidacloprid which shows the abundance of stored honey and some pollen, but no sealed brood or honey bees. Photo was taken on February 24th, 2011.

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
http://www.eea.europa.eu/publications/environmental_issue_report_2001_22
http://www.eea.europa.eu/publications/late-lessons-2012

- 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)
  http://www.unep.org/dewa/Portals/67/pdf/Global_Bee_Colony_Disorder_and_Threats_insect_pollinators.pdf
- 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
  http://www.bijensterfte.nl/sites/default/files/Iimpact_neonicotinoid_insecticides_non-target_invertebrates.pdf
- 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
  http://www.boerenlandvogels.nl/sites/default/files/Tennekes_Sanchez-Bayo_JEAT_2011_Review%20Article_7.pdf
- Effects of neonicotinoid pesticide pollution of Dutch surface water on non-target species abundance
  http://www.bijensterfte.nl/sites/default/files/FinalThesisTvD.pdf
- The systemic insecticides - A disaster in the making
  http://www.disasterinthemaking.com/
- http://www.bijensterfte.nl

www.jvds.nl

www.bijensterfte.nl