

# Effects of Neonicotinoids on Pollinators

**MAJ RUNDLÖF**

*LUND UNIVERSITY, DEPARTMENT OF BIOLOGY, SWEDEN &  
UNIVERSITY OF CALIFORNIA DAVIS, DEPARTMENT OF  
ENTOMOLOGY AND NEMATOLOGY, USA*







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# Pollination

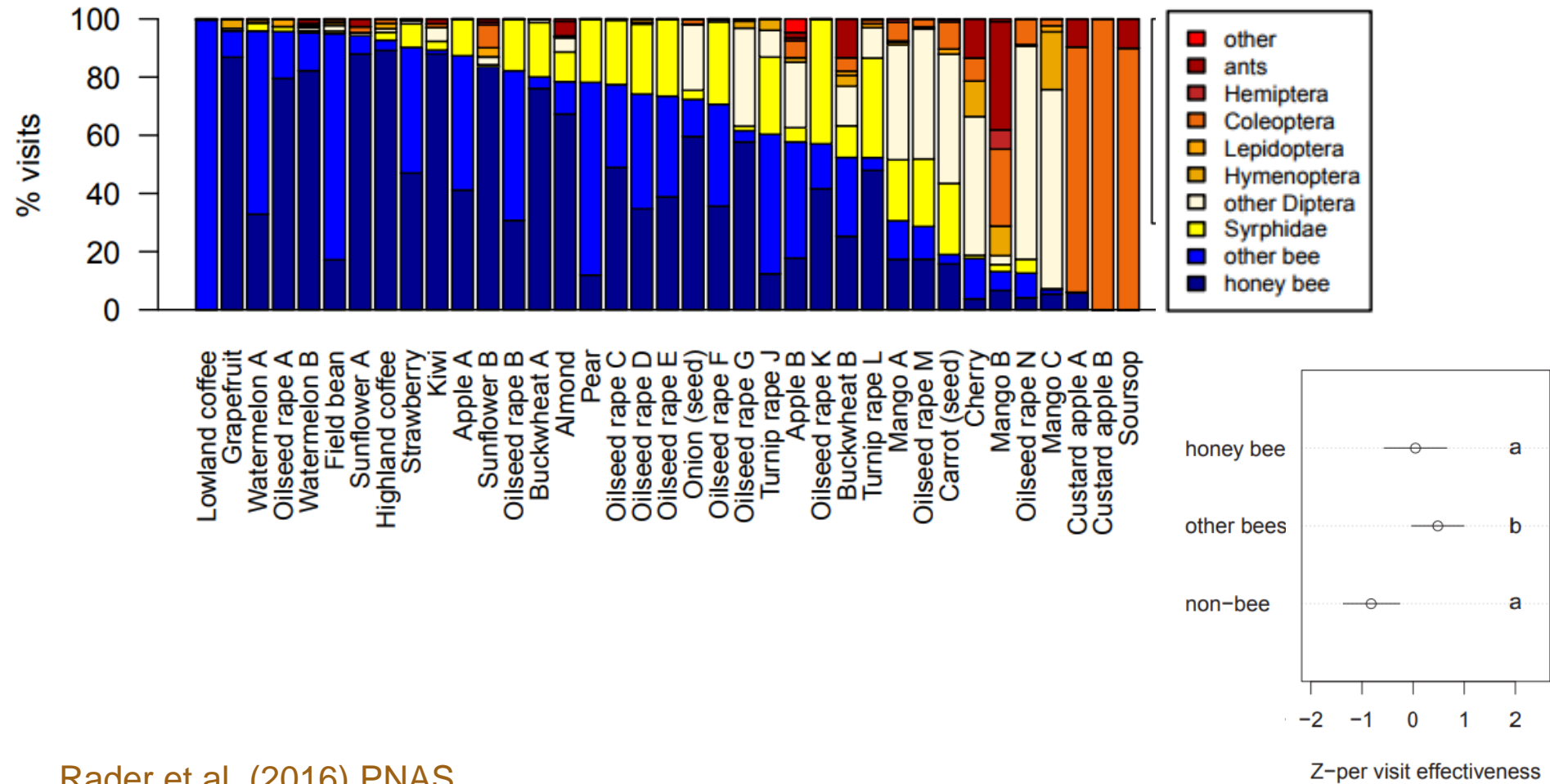
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- 90% of all flowering wild plants depend on insect pollination
- At least  $\frac{1}{3}$  of the global crop production is from crops that to some extent depend on insect pollination



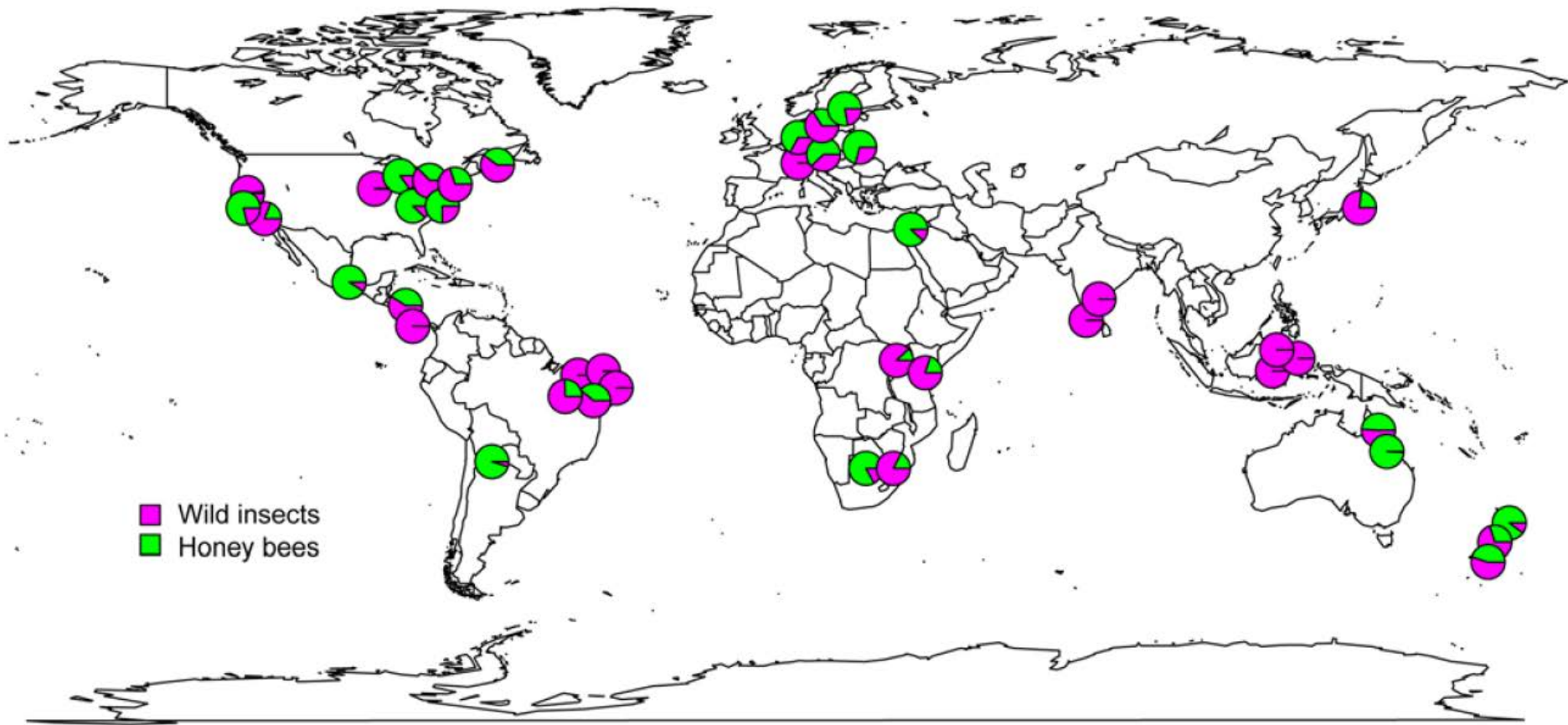


# Both **bee** and **non-bee** pollinators



# Both honey bees and wild bees

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Both wild insect and honey bees contribute to crop pollination and rather complement than replace each other.

Garibaldi et al. (2013) Science

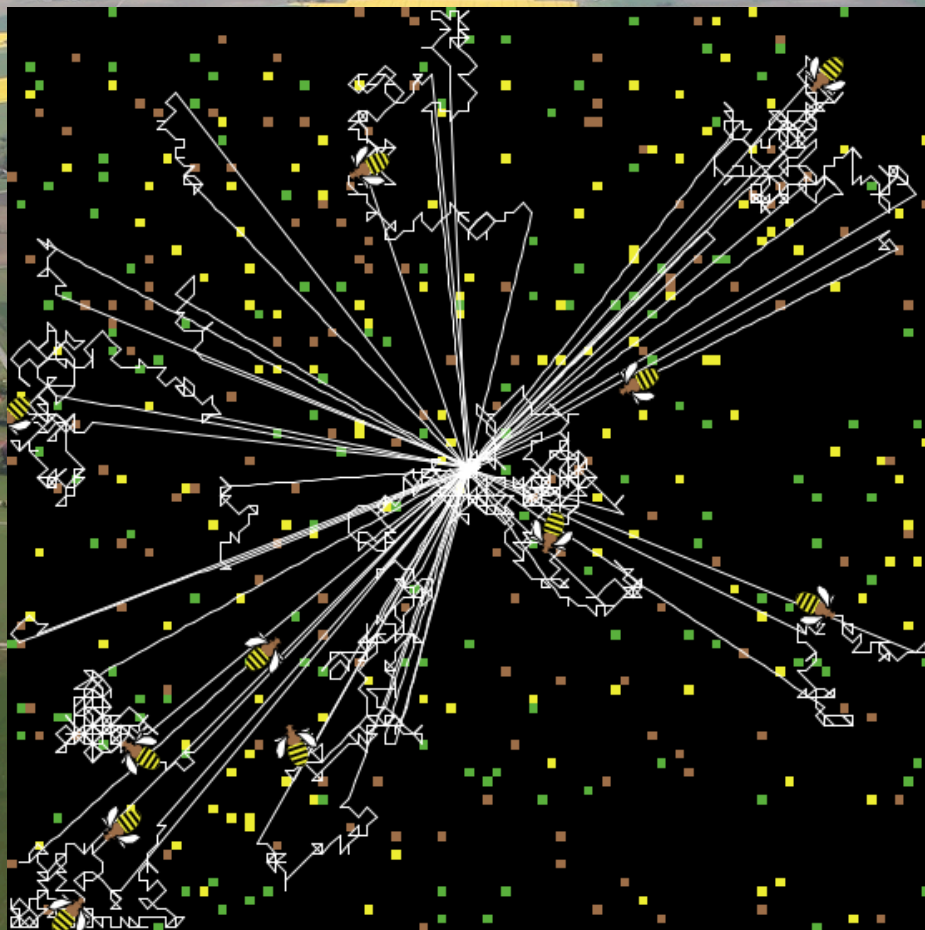
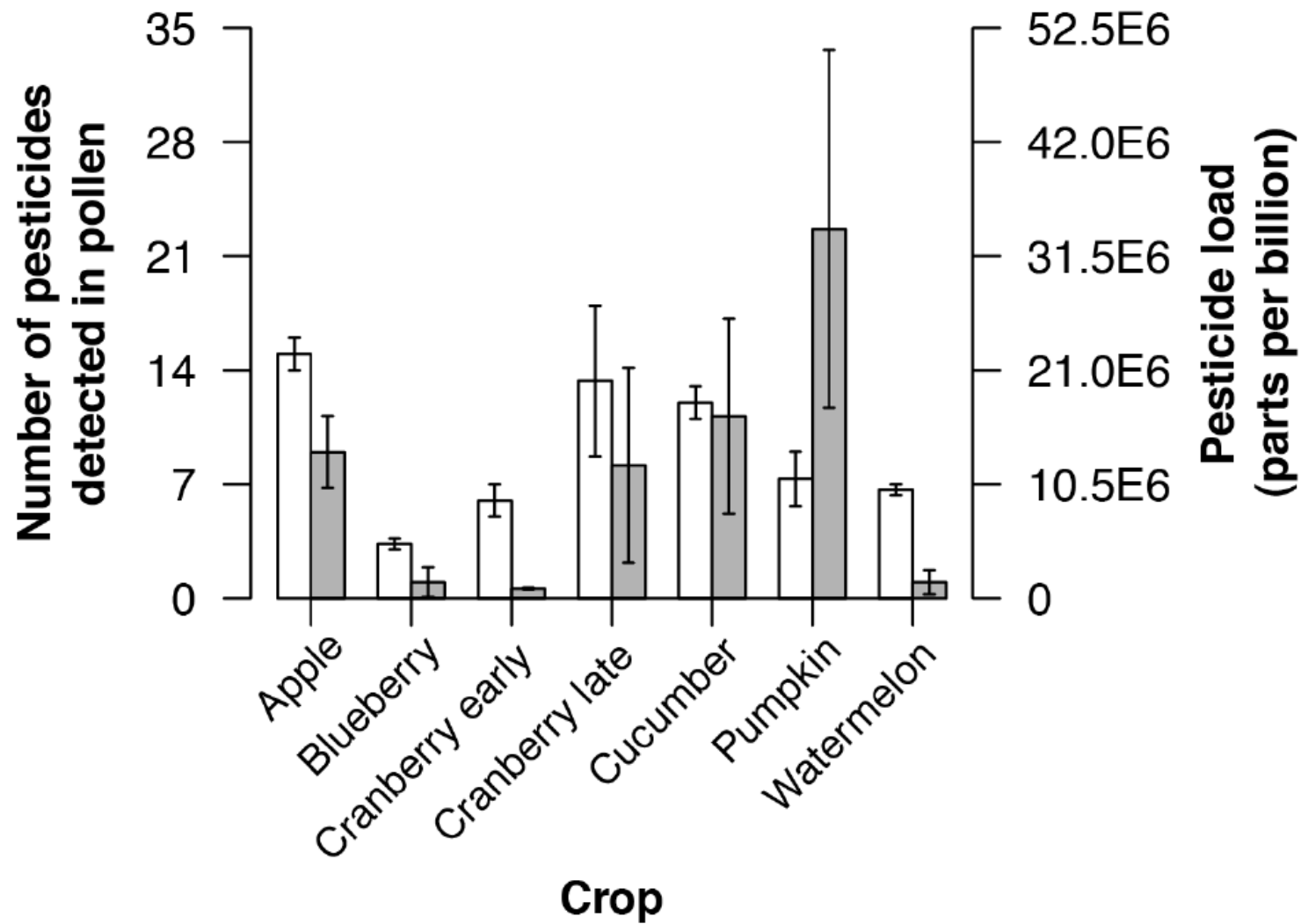


Photo: Sampo Laukkanen





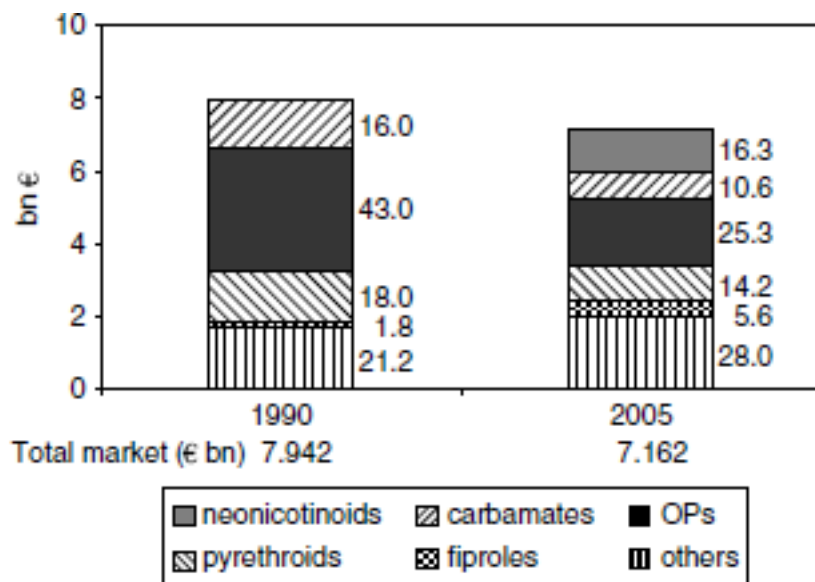
# Review

## Neonicotinoids – from zero to hero in insecticide chemistry

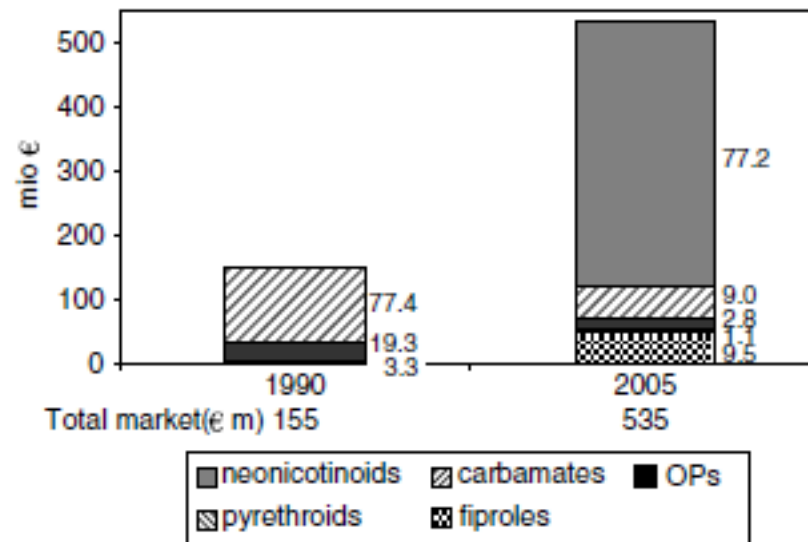
Peter Jeschke<sup>1\*</sup> and Ralf Nauen<sup>2</sup>

<sup>1</sup>Bayer CropScience AG, Research Insecticides Chemistry Insecticides, Building 6240, Alfred-Nobel Str. 50, D-40789 Monheim am Rhein, Germany

<sup>2</sup>Bayer CropScience AG, Research Insecticides Biology Insecticides, Building 6220, Alfred-Nobel Str. 50, D-40789 Monheim am Rhein, Germany



**Figure 1.** Development of insecticidal classes in crop protection, 1990–2005, expressed as percentage of total.



**Figure 2.** Development of insecticidal classes in seed treatment, 1990–2005, expressed as percentage of total.





# Neonicotinoids

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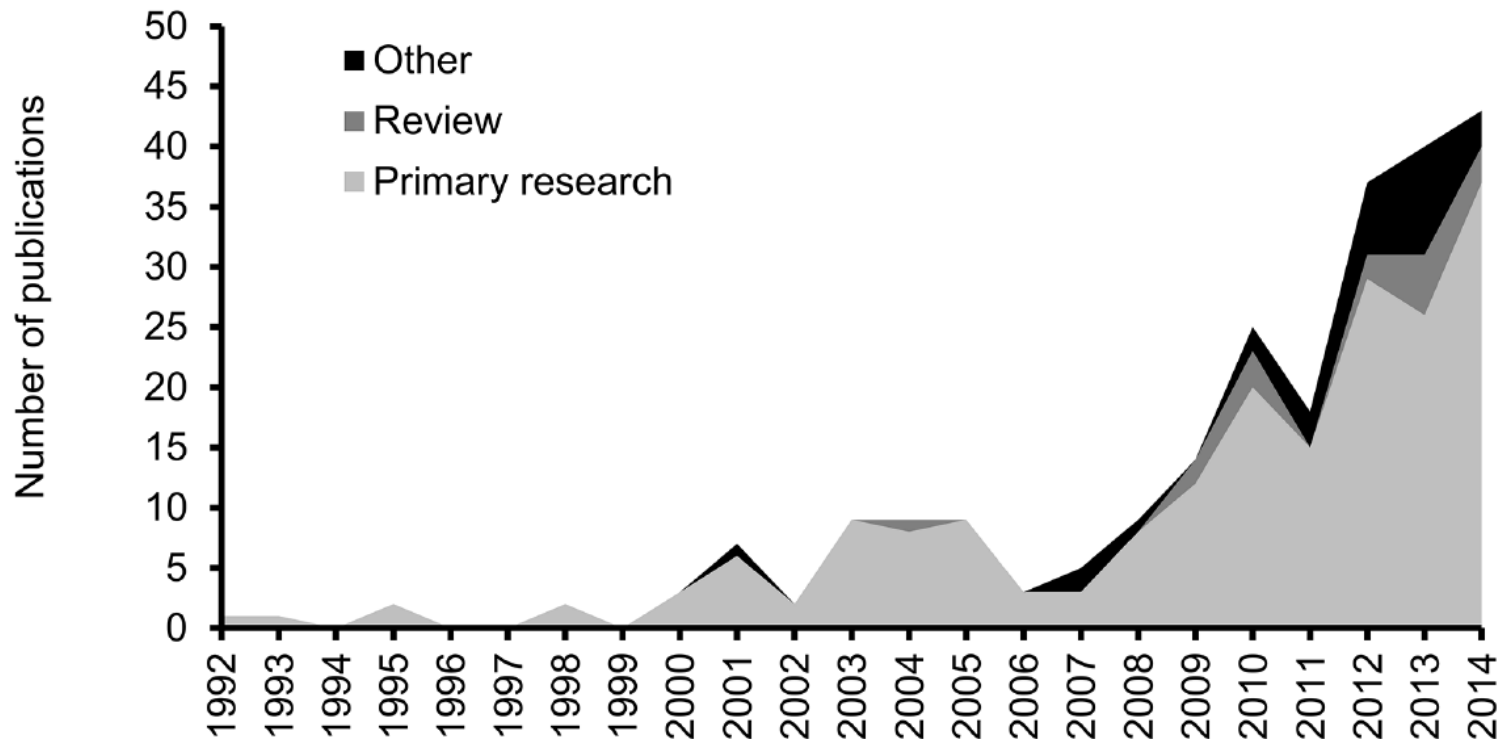
- Imidacloprid (Bayer Crop Science) was the first (1991)
- Acetamiprid, nitenpyram, thiamethoxam, thiacloprid, clothianidin, dinotefuran (1995-2002)
- Effective against many insect pests
- **Systemic**
- Water soluble
- **Slow degradation (long half-life)**
- **High selectivity against insects over mammals**

Elbert et al. 2008 J. Agri. Food Chem., Jeschke & Nauen 2008 Pest Man. Sci., Jeschke et al. 2011 J. Agri. Food Chem.



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# Increasing knowledge on neonics and bees










# Most known about seed treatment in corn

**Table 1.** Total number of studies on neonicotinoids and bees in different crops, study examples for each crop, and number of studies for each method of application in each crop ('Seed' = seed treatment application, 'Foliar' = foliar spray application, 'Soil' = furrow, drench or drip irrigation application, Granulate = granulate application).

Crop Linnean name	Common name	# studies	Study example	Application method			
				Seed	Foliar	Soil	Granulate
<i>Zea mays</i>	Maize	28	[28]	28			
<i>Brassica napus</i>	Oilseed rape	7	[29]	6	3		
<i>Helianthus annuus</i>	Sunflower	7	[30]	7			
-	Turfgrass	4	[31]		4		1
<i>Cucumis melo</i>	Cantaloupe	3	[32]		1	2	
<i>Gossypium spp.</i>	Cotton	3	[33]	1	2		
<i>Solanum lycopersicum</i>	Tomato	3	[34]		2	2	
<i>Citrus spp.</i>	Citrus fruits	2	[35]		1	1	
<i>Cucurbita pepo</i>	Pumpkin, squash	2	[36]	1	1	2	
<i>Malus domestica</i>	Apple	2	[37]		2		
<i>Brassica juncea</i>	Mustard	2	[38]	1	1		
<i>Actinidia spp.</i>	Kiwifruit	1	[39]				
<i>Brassica rapa</i>	Turnip rape	1	[40]		1		
<i>Glycine max</i>	Soybean	1	[33]	1			
<i>Medicago sativa</i>	Alfalfa	1	[10]		1		
<i>Triticum spp.</i>	Wheat	1	[41]	1			

# Most knowledge about honey bees

Species	N studies	
<i>Apis mellifera</i> , <i>Apis cerana</i>	168	7 species  Photo: Albin Andersson
<i>Bombus terrestris</i> , <i>Bombus impatiens</i> , <i>Bombus</i> spp.	42	250 species 
<i>Megachile rotundata</i> , <i>Apoidea</i> spp., <i>Melipona quadrifasciata</i> , <i>Osmia bicornis</i> , <i>Osmia lignaria</i> , <i>Nannotrigona perilampoides</i> , <i>Nomia melanderi</i> , <i>Osmia cornifrons</i> , <i>Scaptotrigona postica</i>	17	>20 000 species 

# Most knowledge from lab studies

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...and field studies  
estimating exposure in  
honey bee collected  
pollen or nectar/honey  
(but very few on  
effects)

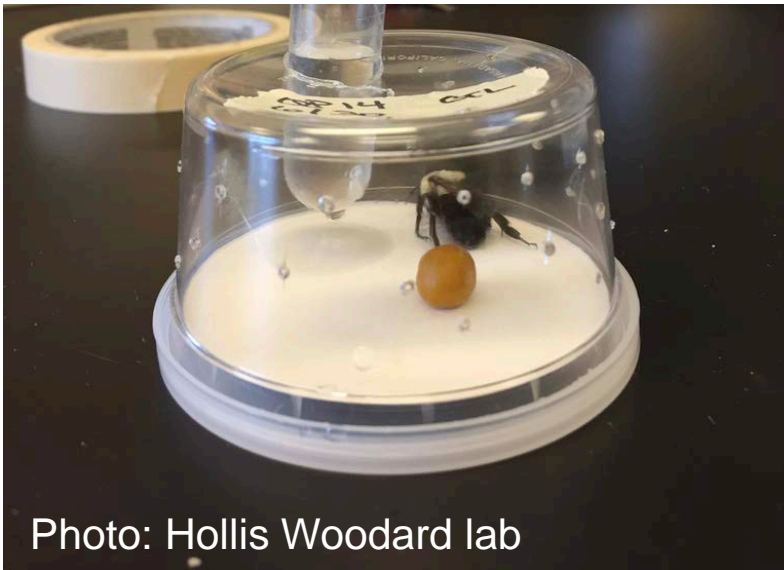
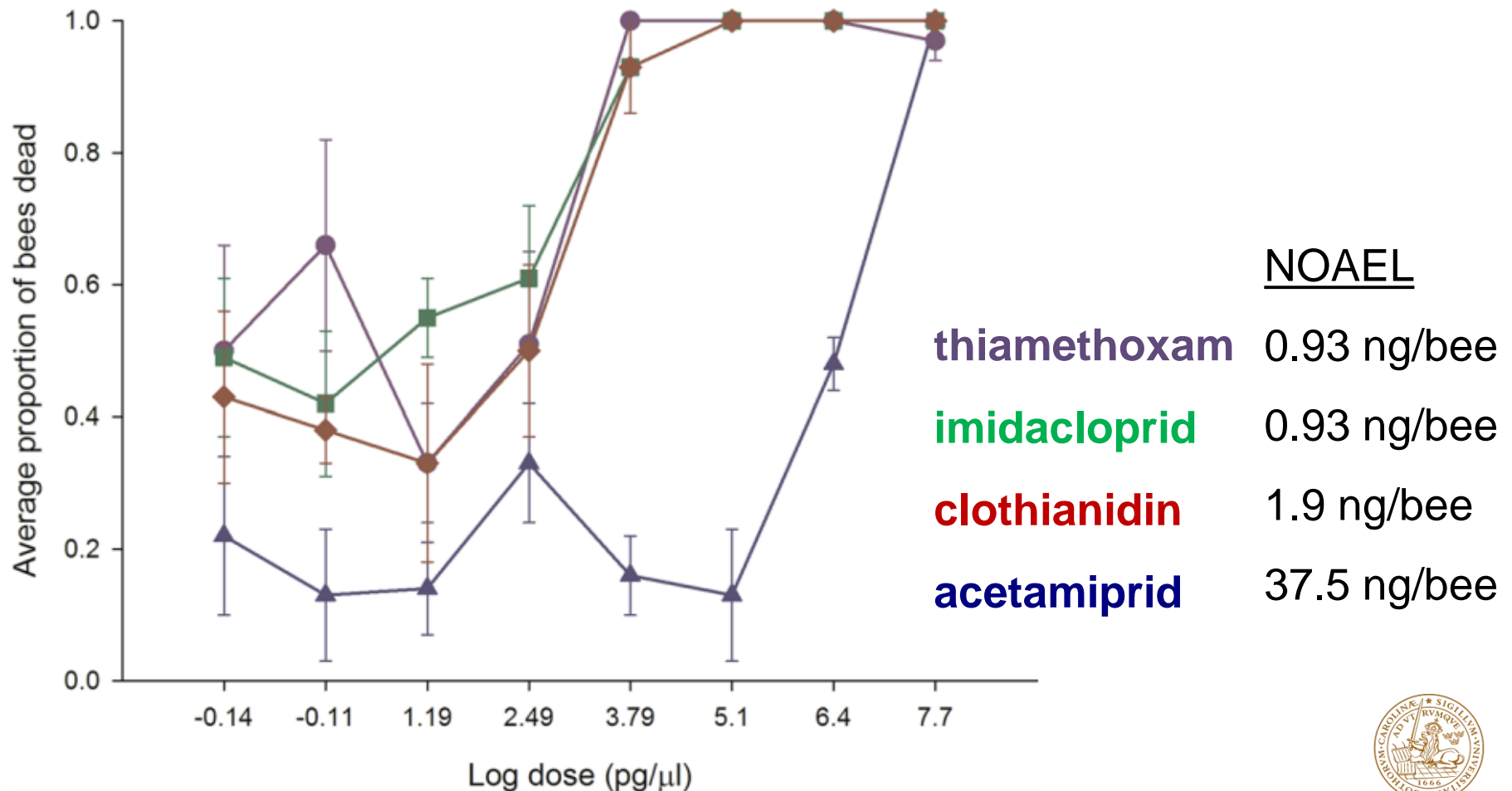


Photo: Hollis Woodard lab

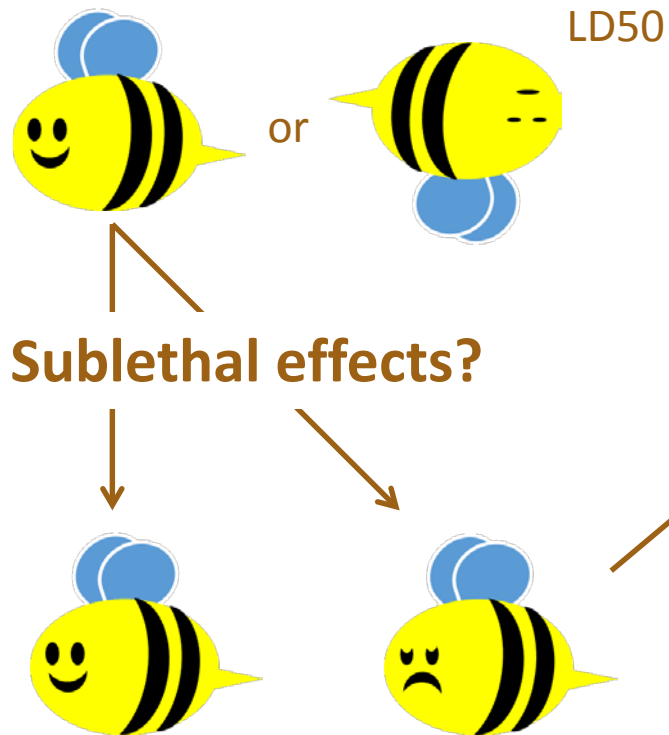


# 24 h exposure of bumble bees in cage trial

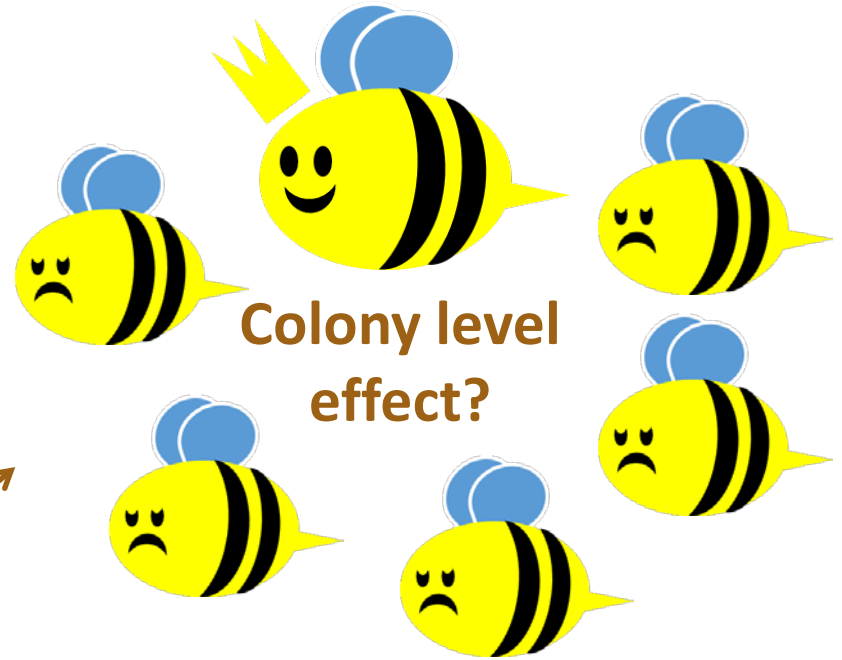


# Lethal and sublethal effects

## Individual level effect



## Colony level effect?



LETTER

# LETTER

## Combined pesticide exposure severely affects individual- and colony-level traits in bees

Oscar Ramos-Rodriguez<sup>1</sup> & Nigel E. Raine<sup>2</sup>

<sup>1</sup>Department of Biology, University of York, YO10 5DD, UK  
<sup>2</sup>Department of Biology, University of York, YO10 5DD, UK

**Abstract** Pesticides are used to protect crops from insect pests, but they can also harm beneficial insects, such as bees. Bees are important pollinators of many crops and wildflowers, and their decline is a major concern. Pesticides can affect bees in many ways, including by reducing their ability to learn, navigate, and communicate. In this study, we investigated the effects of combined exposure to two common pesticides, neonicotinoids and pyrethroids, on individual and colony-level traits in honeybees. We found that combined exposure to these pesticides significantly reduced individual bees' ability to learn and navigate, and also reduced the colony's overall foraging success. Our results suggest that the combined use of these pesticides may be particularly harmful to bees, and that efforts to reduce their use could help to protect these important pollinators.

**Key words:** bees, pesticides, individual-level traits, colony-level traits, foraging success, neonicotinoids, pyrethroids.

**Introduction** Bees are important pollinators of many crops and wildflowers, and their decline is a major concern. Pesticides can affect bees in many ways, including by reducing their ability to learn, navigate, and communicate. In this study, we investigated the effects of combined exposure to two common pesticides, neonicotinoids and pyrethroids, on individual and colony-level traits in honeybees. We found that combined exposure to these pesticides significantly reduced individual bees' ability to learn and navigate, and also reduced the colony's overall foraging success. Our results suggest that the combined use of these pesticides may be particularly harmful to bees, and that efforts to reduce their use could help to protect these important pollinators.

**Methods** We used a combination of individual-level and colony-level experiments to investigate the effects of combined exposure to neonicotinoids and pyrethroids on honeybees. Individual-level experiments measured bees' ability to learn and navigate, while colony-level experiments measured the colony's overall foraging success. We found that combined exposure to these pesticides significantly reduced individual bees' ability to learn and navigate, and also reduced the colony's overall foraging success.

**Results** We found that combined exposure to neonicotinoids and pyrethroids significantly reduced individual bees' ability to learn and navigate, and also reduced the colony's overall foraging success. Specifically, bees exposed to both pesticides showed significantly lower learning and navigation scores than bees exposed to either pesticide alone, and colonies exposed to both pesticides showed significantly lower foraging success than colonies exposed to either pesticide alone.

**Discussion** Our results suggest that the combined use of neonicotinoids and pyrethroids may be particularly harmful to bees, and that efforts to reduce their use could help to protect these important pollinators. We also found that individual-level effects of pesticides can have significant colony-level consequences, highlighting the importance of studying both levels of organization in future research.

**Conclusion** Our study provides evidence that combined exposure to neonicotinoids and pyrethroids severely affects individual and colony-level traits in honeybees. This has important implications for the health of bee populations and the ecosystems they support. We recommend that efforts be made to reduce the use of these pesticides, particularly in areas where bees are important pollinators.

**References** [1] Ramos-Rodriguez, O., & Raine, N. E. (2018). Combined pesticide exposure severely affects individual- and colony-level traits in bees. *Journal of Apiculture*, 12(3), 45-55. [2] Raine, N. E., & Ramos-Rodriguez, O. (2019). The effects of pesticides on bees: A review. *Journal of Apiculture*, 13(1), 1-10. [3] Raine, N. E., & Ramos-Rodriguez, O. (2020). The effects of pesticides on bees: A review. *Journal of Apiculture*, 14(2), 1-10. [4] Raine, N. E., & Ramos-Rodriguez, O. (2021). The effects of pesticides on bees: A review. *Journal of Apiculture*, 15(3), 1-10. [5] Raine, N. E., & Ramos-Rodriguez, O. (2022). The effects of pesticides on bees: A review. *Journal of Apiculture*, 16(4), 1-10.

**Correspondence** Oscar Ramos-Rodriguez, Department of Biology, University of York, YO10 5DD, UK. Email: oscar.ramos@york.ac.uk

**Conflict of interest** The authors declare no conflict of interest.

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Richard J. Gill<sup>1</sup>, Oscar Ramos-Rodriguez<sup>1</sup> & Nigel E. Raine<sup>2</sup>

combined – and colony-level – effects on individual – and colony-level – fitness. Richard J. Gill<sup>1</sup>, Oscar Ramos-Rodriguez<sup>2</sup> & Nigel E. Raine<sup>1</sup>

Reported widespread declines of wild and managed insect pollinators have serious consequences for global ecosystem services and agricultural production<sup>1–3</sup>. It is important to understand and mitigate insect pollination, so it is important to understand and mitigate the causes of current declines in bees. These declines, as exposure to insecticides, have implicated the role of pesticides in bee behaviour<sup>4–7</sup> and have implicated the role of pesticides in colony queen production<sup>8</sup>. However, the effects of pesticides on bees have been largely overlooked. Here, we show that pesticides have impacted bees in two ways: *in vivo* and reductions in colony queen production and the consequent impact on the colony level has not been shown. Social bees are dependent on the collective performance of many individuals, colonies depend on the collective performance of many individuals. Thus, although field-level pesticide concentrations can have subtle or sublethal effects on the colony level, further research is needed to determine whether bees are affected by pesticides in a severe cumulative effect on the colony level. Furthermore, the effects of pesticides on bees are not yet fully understood, but it is known that pesticides can have adverse effects on bees, yet the bees are exposed to numerous pesticides when foraging<sup>9–11</sup>, yet the bees are exposed to numerous pesticides when foraging<sup>9–11</sup>, yet the bees are exposed to numerous pesticides when foraging<sup>9–11</sup>, yet the bees are exposed to numerous pesticides when foraging<sup>9–11</sup>.

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[illegible]

2). Colonies were motivated to f

During colony survival (for example, brood care and production at the end of diapause) compared to colonies,  $t = 1.97$ ,  $z = 3.0$ ,  $p = 0.009$ . Linear mixed effects models gave  $t = -2.62$ ,  $p = 0.009$ . Colonies did not survive Supplemental I (see Supplemental I for details). These two colonies were not higher than other nests (0.029). These two colonies provide a conserved in a ment, 223 (21% of colonies), specifically in control (9% in  $t = 4.23$ ,  $p < 0.01$  in L2 and M control waste of your young in sample, for example, for Queen loss significantly

**Colonies to be examined**

**Green loess** significantly higher than green loess

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## A Common Pesticide Decreases Foraging Success and Survival in Honey Bees

Mickaël Henry,<sup>1\*</sup> Maxime Beguin,<sup>2</sup> Fabrice Requier,<sup>3,4</sup> Orianne Rollin,<sup>1,5</sup> Jean-François Pierrick Aupinel,<sup>4</sup> Jean Aptel,<sup>1</sup> Sylvie Tchamitchian,<sup>1</sup> Axel Decourtaye<sup>5</sup>

<sup>1</sup>INRA, UR406 Abeilles et Environnement, F-84914 Avignon, France. <sup>2</sup>Association pour le développement de l'apiculture provençale (ADAPI), F-13626 Aix-en-Provence, France. <sup>3</sup>Centre d'Etudes Biologiques, CNRS (USC-INRA 1339), UPR1934, F-79360 Beauvoir-sur-Niort, France. <sup>4</sup>INRA, IGEV, Entomologie, F-17700 Surgères, France. <sup>5</sup>ACTA, UMT PrADE, UR 406 Abeilles et Environnement, France.

\*To whom correspondence should be addressed. E-mail: mickael.henry@avignon.inra.fr

Non-lethal exposure of honey bees to thiamethoxam (neonicotinoid pesticide) causes high mortality due to homing failure at levels colony at risk of collapse. Simulated exposure events on free-labeled with an RFID tag suggest that homing is impaired by intoxication. These experiments offer new insights into the common neonicotinoid pesticides used worldwide.

Colony collapse disorder (CCD) is a recent, pervasive syndrome affecting honey bees (*Apis mellifera*) colonies in the Northern hemisphere which is characterized by a sudden disappearance of honey bees the hive (1). Multiple causes of CCD have been proposed, such as pesticides, pathogens, parasites, and natural habitat degradation (2-6), the relative contribution of those stressors in CCD ever unknown. Some scientists and beekeepers suspect pesticides as central place in colony weakening processes (1) or at least with other stressors (5, 6). In modern cereal farming systems are readily exposed to pesticides because they rely heavily on blooming crops, like oilseed rape (*Brassica napus*), sunflower (*Helianthus annuus*), that are now routine insect pests (3). Systemic pesticides, in particular, *o* the neonicotinoids as plant growth regulators, and especially clothianidin (7). Foraging bees are therefore directly exposed to the rest of the colony as returning foragers store nectar material with hive conspecifics (7, 8). The use of insecticides is of important concern and pesticide management to reduce non-intentional intoxications.



Fig. 1. Honey bee R. forager honey bee fitted with entrance equipped with RFID marked foragers.

Scienceexpress/ <http://www.sciencemag.org/content>

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Penelope R. Whitehorn,<sup>1</sup> Stephanie O'Connor,<sup>2</sup> and  
Poulson<sup>1\*</sup>

**See Pesticide Reduces Bee Colony Growth and**  
**Production**

Penelope R. Whitehorn,<sup>1</sup> Stephanie O'Connor,<sup>1</sup> Felix L. Wackers,<sup>2</sup> Dave Goulson<sup>1\*</sup>

<sup>1</sup>School Natural Sciences, University of Stirling, Stirling FK9 4LA, UK; <sup>2</sup>Lancaster University, Lancaster LA1 4YQ, UK

\*To whom correspondence should be addressed. E-mail: dave.goulson@stir.ac.uk

Bees in agroecosystems survive by feeding on wildflowers grown along field margins and patches of semi-natural habitat, supplementing the nectar and pollen provided by mass flowerings of crops. The loss of these floral resources, caused by the reduction of wildflower populations, has a considerable negative impact on wild bumble bee colonies. Given the scale of use of neonicotinoids, we suggest that the reduction of wildflower populations, and the consequent loss of floral resources, is a serious threat to wild bumble bee colonies. Treating colonies with neonicotinoids, therefore, allows them to survive in reduced quantities of floral resources, but at the expense of the negative impact on wild bumble bee colonies. Given the scale of use of neonicotinoids, we suggest that the reduction of wildflower populations, and the consequent loss of floral resources, is a serious threat to wild bumble bee colonies.

[illegible]

the control colonies (Fig. 1). linear mixed effect model;  $F(2, 558) = 3.39$ ,  $P < 0.001$  respectively). The weight gain in the low and high treatment colonies was 15% and 12% respectively than the control colonies. The weight gain in the high treatment colonies was 1.44,  $P = 0.151$ . The rate of colony growth was 1.44,  $P = 0.151$ . The rate of colony growth was not significantly different from the control colonies ( $F(2, 558) = 2.65$ ,  $P = 0.009$ ) respectively. The workforce for optimal development, reflecting the number of pupae cells at the end of the experiment, although the number of empty pupal cells was 18% and 30% lower, respectively, in low and high treatment compared to controls. The mean number of green produced by colonies in the control colony was 13.72 (7.70), whilst in the low and high treatments was 2.00 (1.13) and 1.4 (0.53) respectively (Fig. 2; Kruskal-Wallis test;  $H(2) = 9.57$ ,  $P = 0.008$ ). The drop in queen production is displayed in Table 1.

There is evidence foraging under natural conditions ( $Z$ ) is likely to have a larger success rate than no study. The results of the present study suggest that the honey bee colony under study is likely to have a larger success rate than no study. The results of the present study suggest that the honey bee colony under study is likely to have a larger success rate than no study.

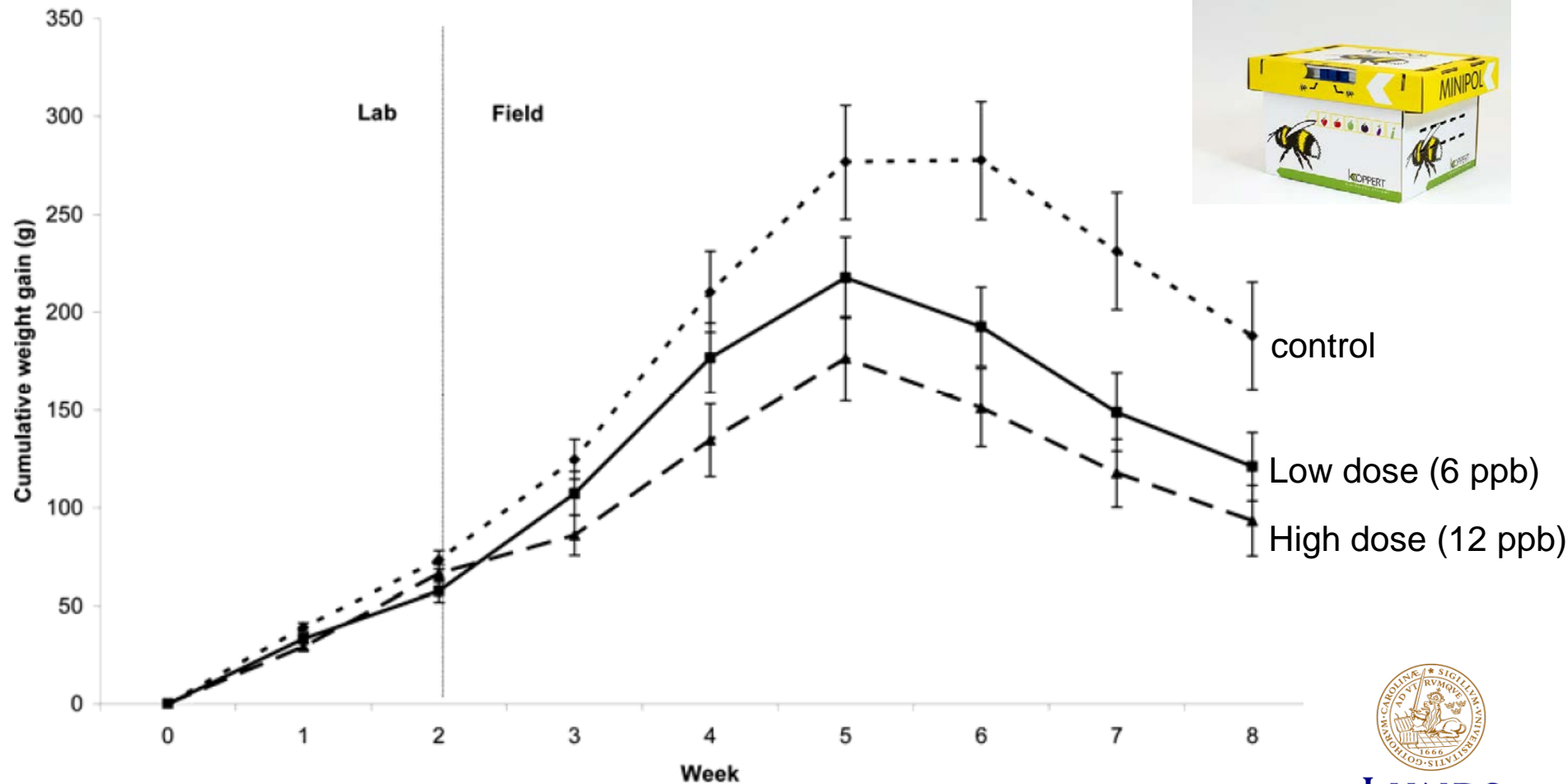
Table 1. Linear mixed effect model for colony weight. Degrees of freedom are given in parentheses. Parameter estimates are with reference to the control treatment. The mean number of queens produced by colonies in the low and high treatments was 13.72 (5.70) and 1.4 (0.53) respectively [(Fig. 2). Kruskal-Wallis test:  $H(2) = 9.57, P = 0.008$ ]. The drop in queen production is disproportionate to the drop in the number of colonies in the low treatment compared to controls.

Fixed effect	Value	SE	t value	P
(Intercept)	364.21	39.59	14.24 (>68)	<0.001
Treatment (high)	13.62	27.81	0.490 (71)	0.676
Treatment (low)	89.21	27.70	0.502 (71)	
Week*	-6.68	5.30	1.22 (568)	
Week*No. workers at week = 0	0.759	0.430	1.76 (568)	
Treatment (high)*Week	-13.42	1.92	15.22 (>68)	
Treatment (low)*Week	-9.95	2.40	16.52 (>68)	
Week*No. workers at week = 0	0.448	2.40	1.87 (568)	

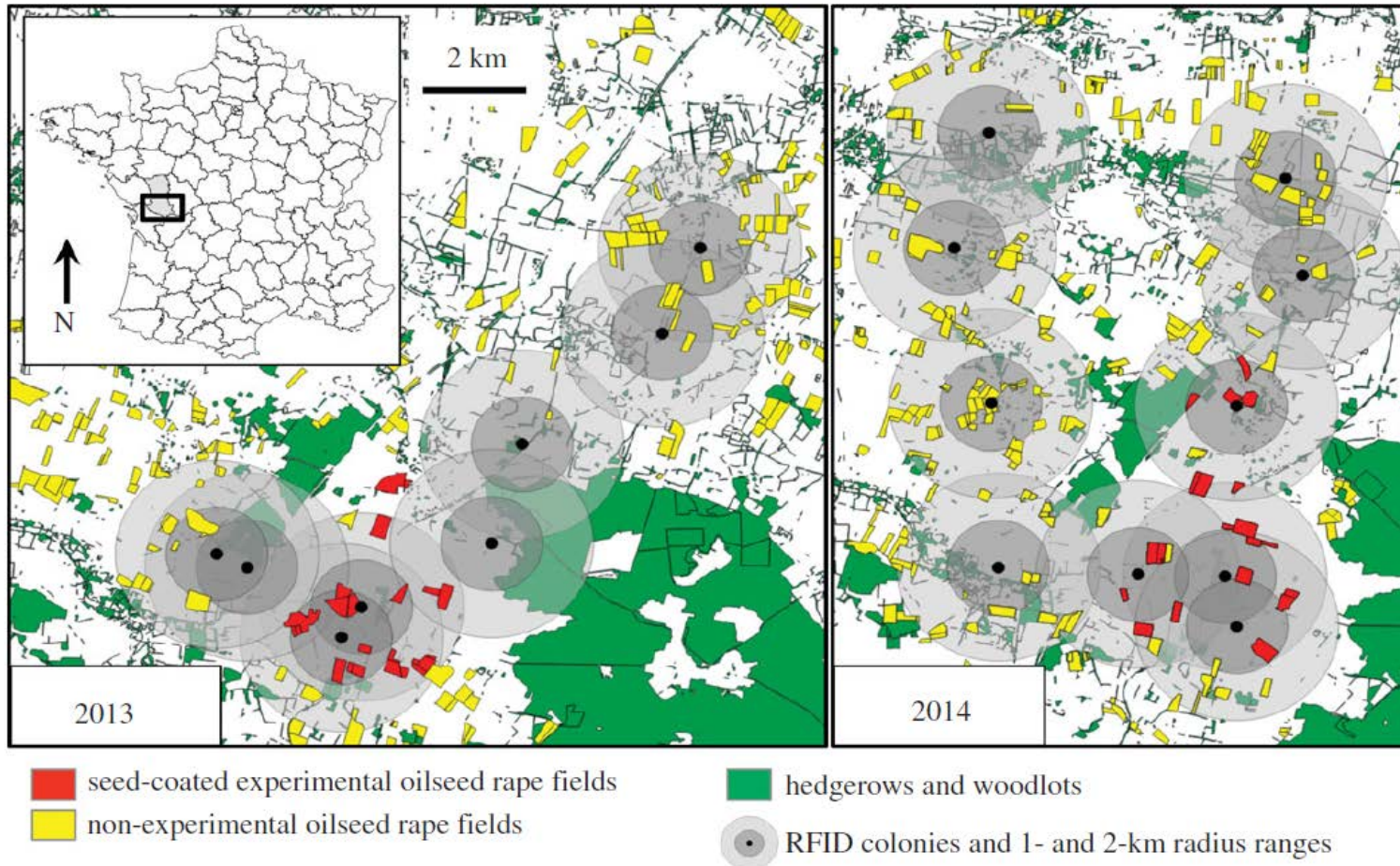
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# Semi-field study on bumble bee colonies

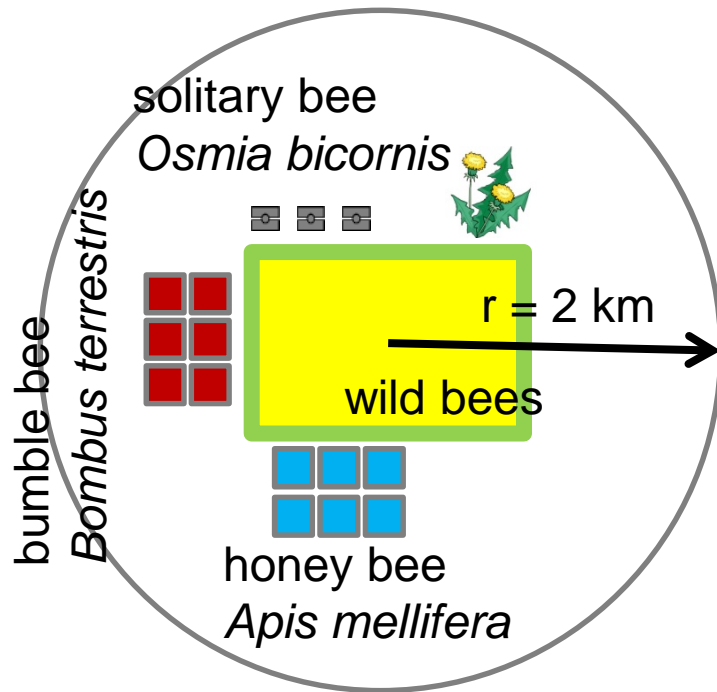


# Semi-field study on honey bee foraging

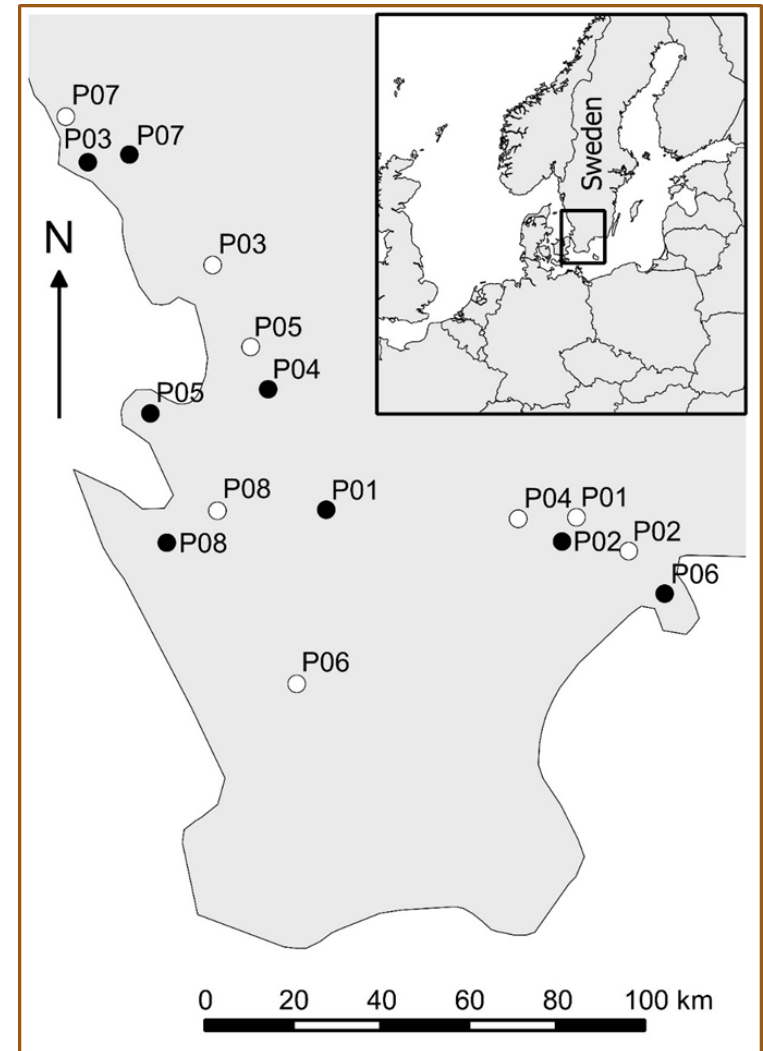


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# Landscape-scale experiment in 2013



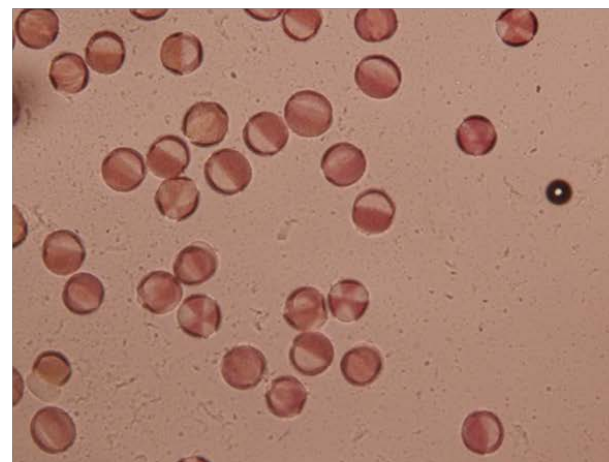
- 8 pairs of spring-sown canola fields and surrounding landscapes
- random assignment to treatment (clothianidin seed dressing) and control
- treatment blinded during field work





# Verifying exposure – oilseed rape pollen use and clothianidin residues

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$35 \pm 17\%$



$80 \pm 5\%$



$58 \pm 5\%$

**Table 1 | Clothianidin concentrations in bee-collected pollen ( $\text{ng g}^{-1}$ ) and nectar ( $\text{ng ml}^{-1}$ ), and field border differences between treatments (control or insecticide-coated seeds)**

	Control		Insecticide seed coating	
	Range	Mean $\pm$ s.e.m.	Range	Mean $\pm$ s.e.m.
Honeybee pollen	0	0	6.6–23	$13.9 \pm 1.8$
Honeybee nectar	0–0.61	$0.1 \pm 0.1$	6.7–16	$10.3 \pm 1.3$
Bumblebee nectar	0	0	1.4–14	$5.4 \pm 1.4$
Field border plants ( $\leq 2$ days after sowing)	0	0	0–5.9	$1.2 \pm 0.8$
Field border plants (2 weeks after sowing)	No material collected		0–6.5	$1.0 \pm 0.8$



# The neonic treatment had no significant influence on *Apis mellifera* colony strength

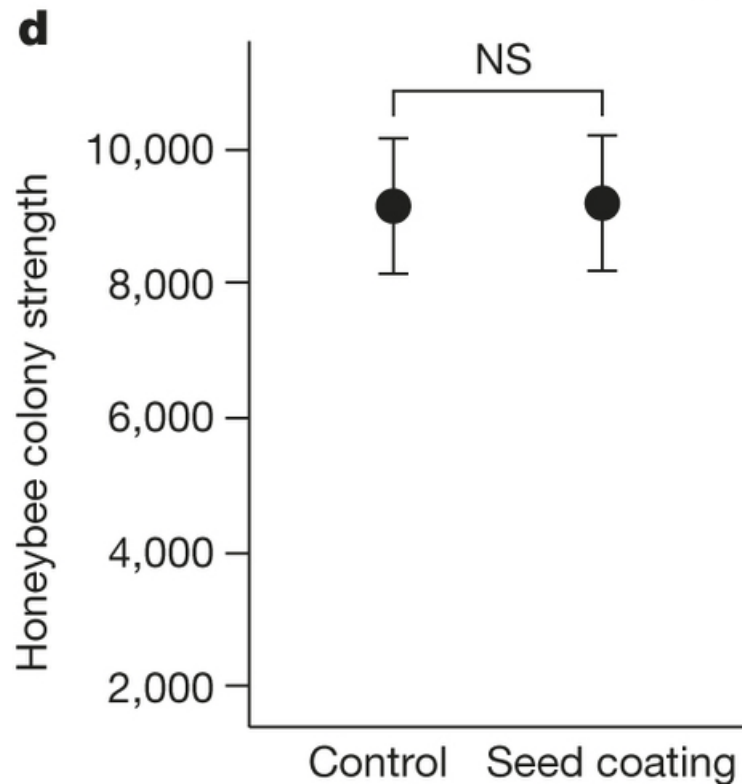
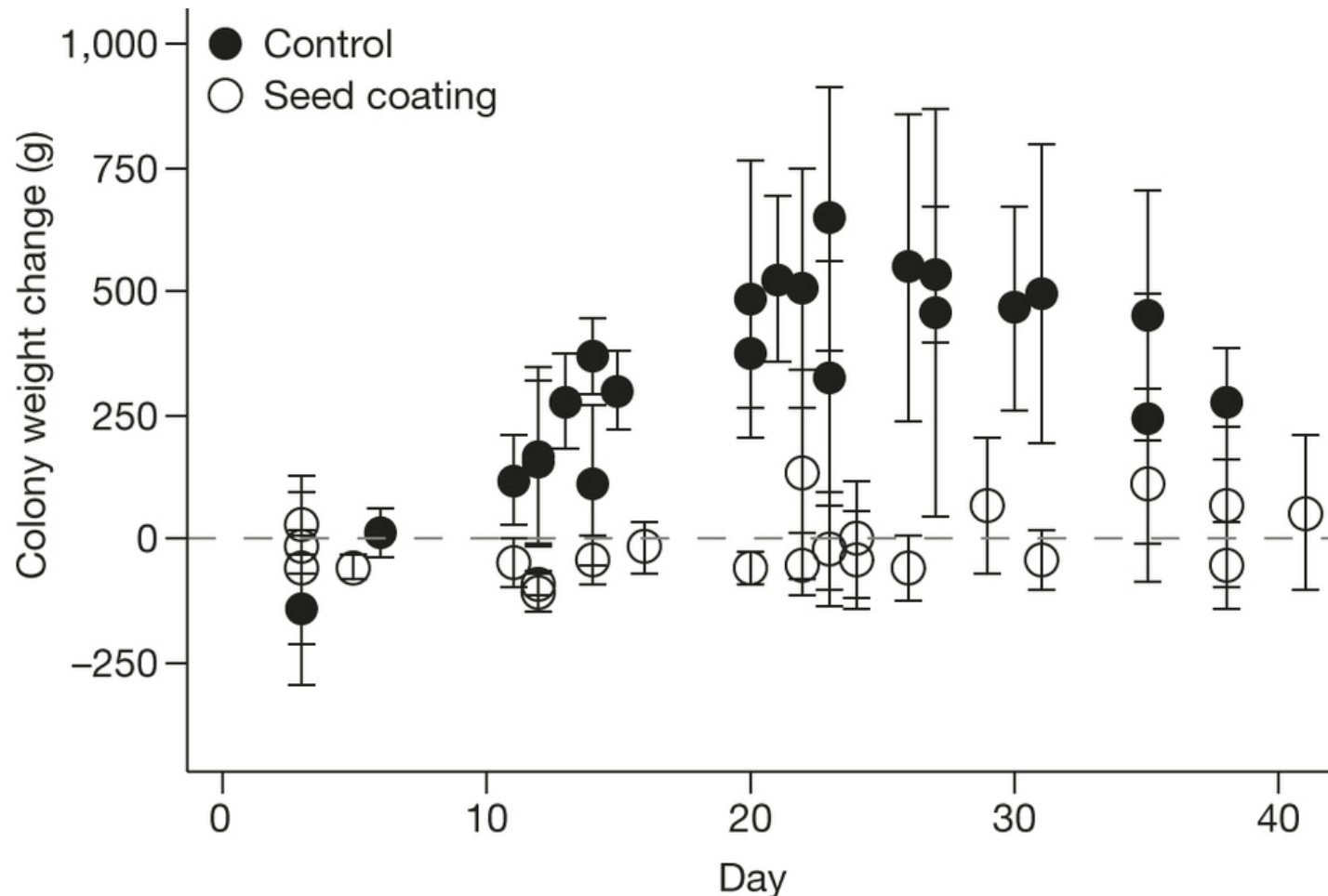


Photo: Albin Andersson



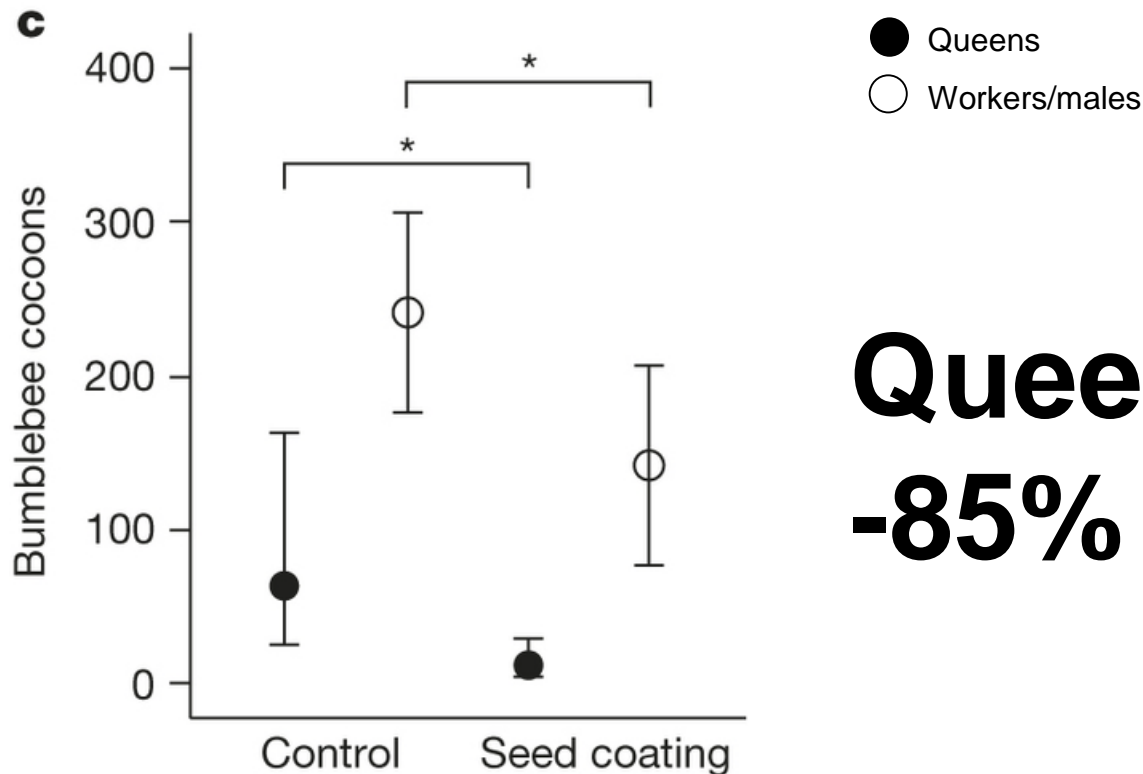
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# The neonic treatment was negatively related to *Bombus terrestris* colony growth





## ...and *Bombus terrestris* reproduction

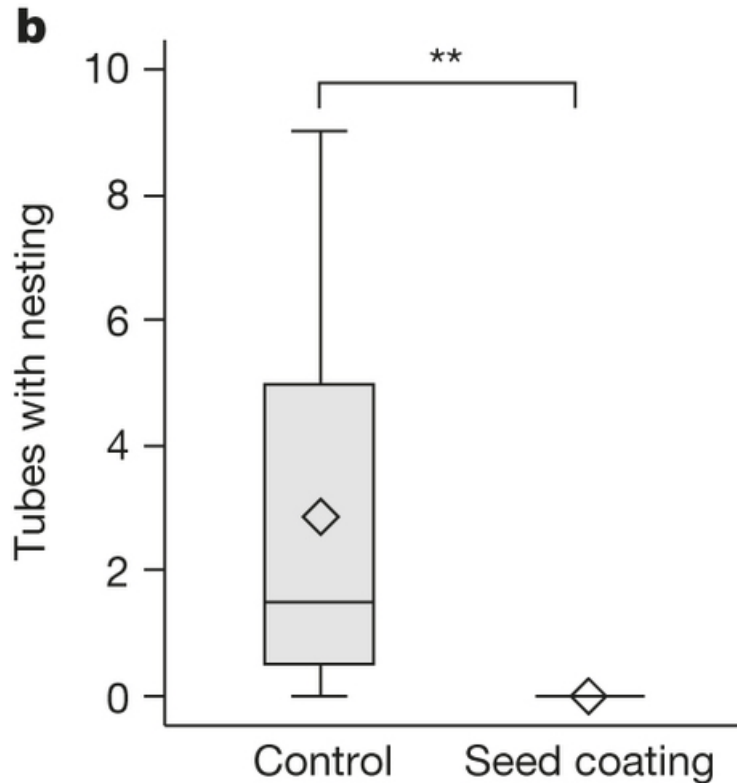


**Queens:  
-85%**



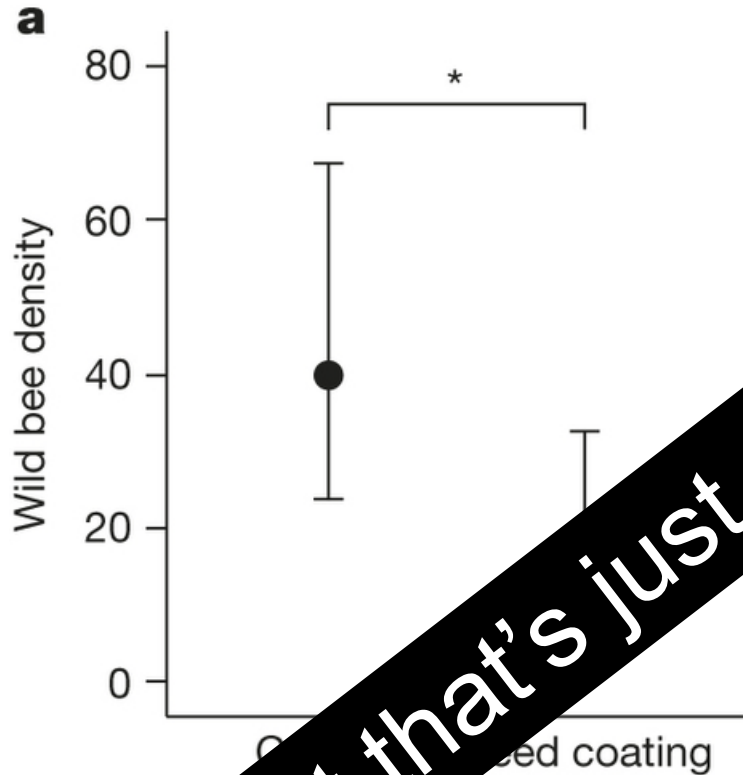
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# Relation between the neonic treatment and reduced nesting of *Osmia bicornis*



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# Reduced wild bee density in oilseed rape fields treated with the neonic



But that's just one crop/year/region...



Wild bees are in Sweden bumble bees and solitary bees



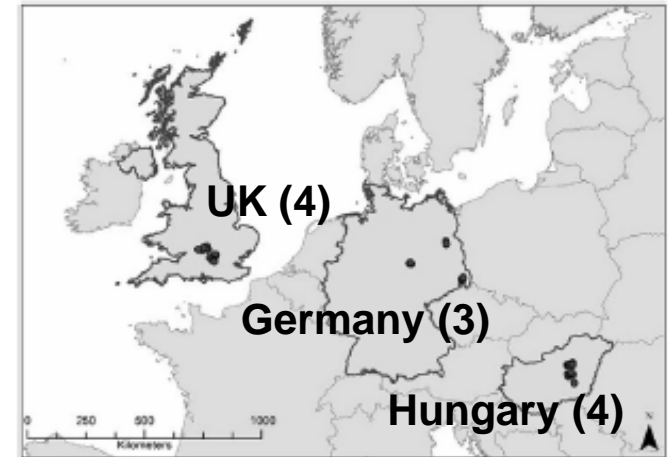
Photo: Morgan Boch



# Autumn sown canola in three countries

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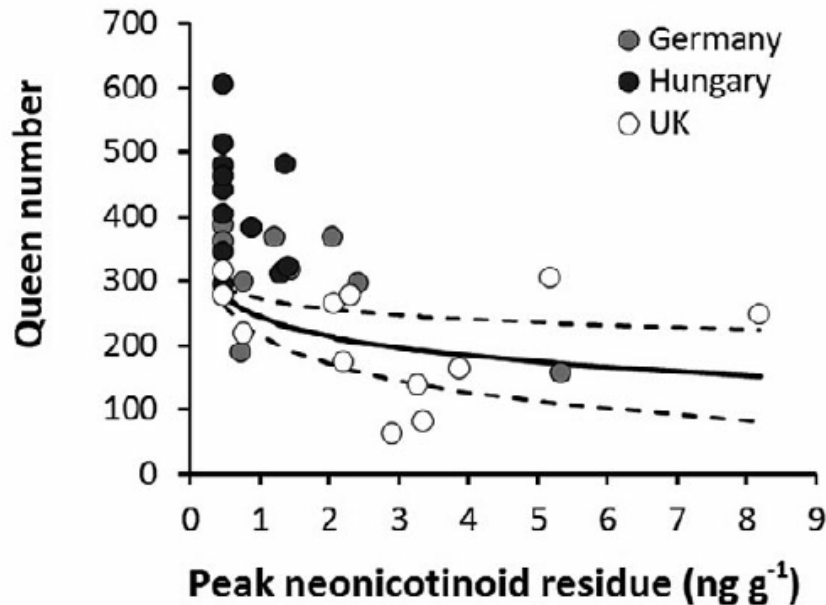
- Clothianidin treated canola expressed higher clothianidin residues than the control crop, but residues very low (LOD-2.21 ppb)
- No systematic differences in neonicotinoid (clothianidin + thiamethoxam + imidacloprid) residues between treated and control sites
- No systematic differences in (most) bee measures between treated and control sites



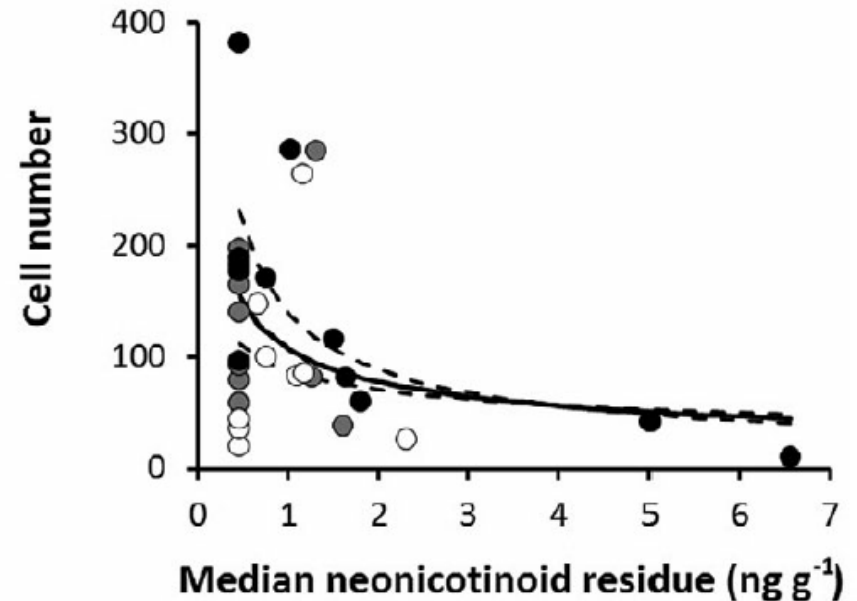


# Autumn sown canola in three countries

**A** *Bombus terrestris* queen production



**B** *Osmia bicornis* reproductive cells



# Correlative study links bee decline to neonics

## Neonicotinoids:

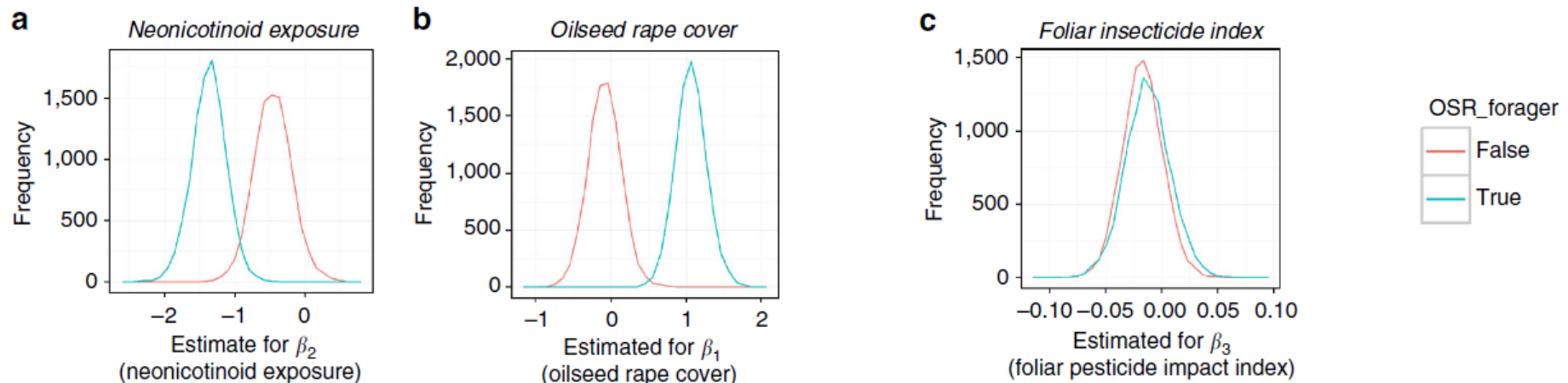
- canola foraging bees
- other bees

## Canola cover:

- + canola foraging bees
- other bees

## Foliar applied insecticides:

- canola foraging bees
- other bees



**Figure 2 | Posterior distributions for the effect sizes describing wild bee population persistence in England.**

# Effects on pollination

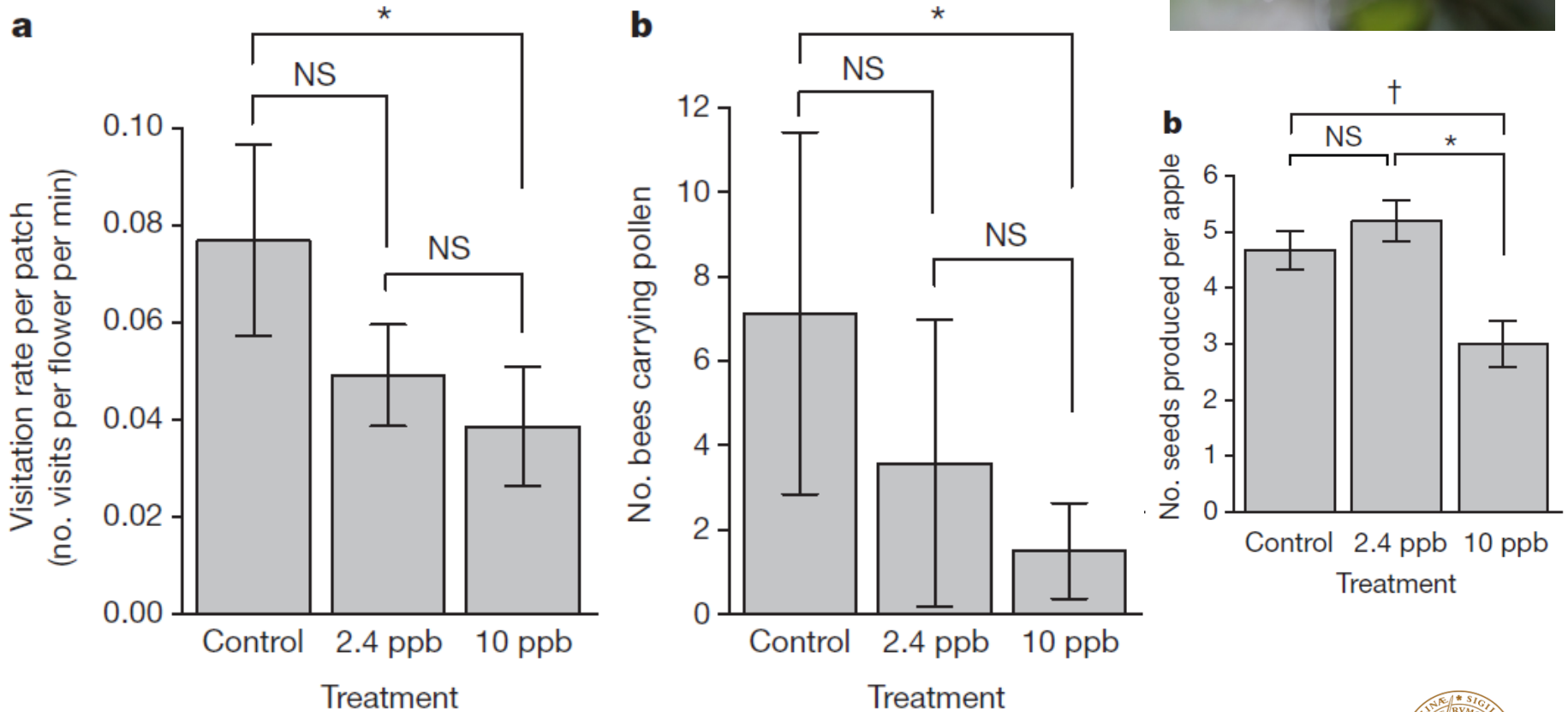
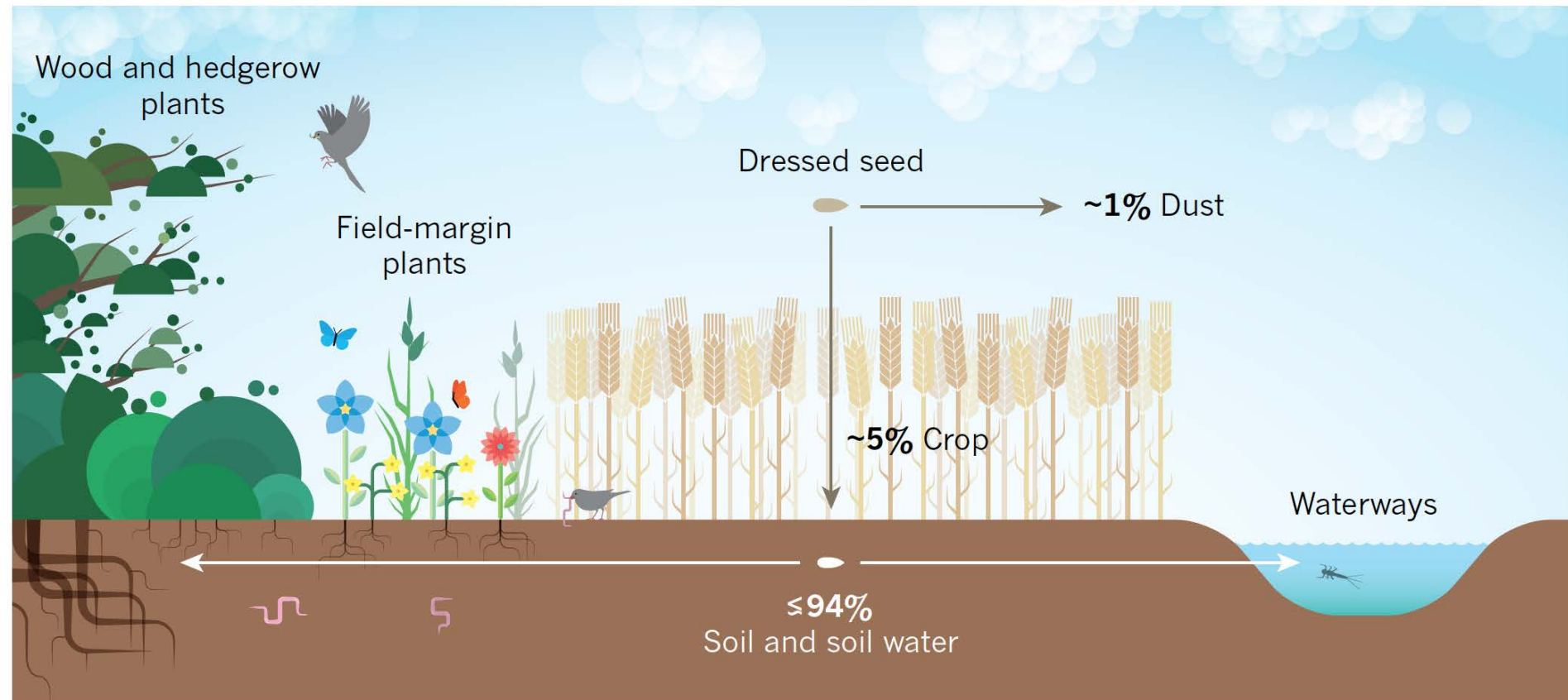


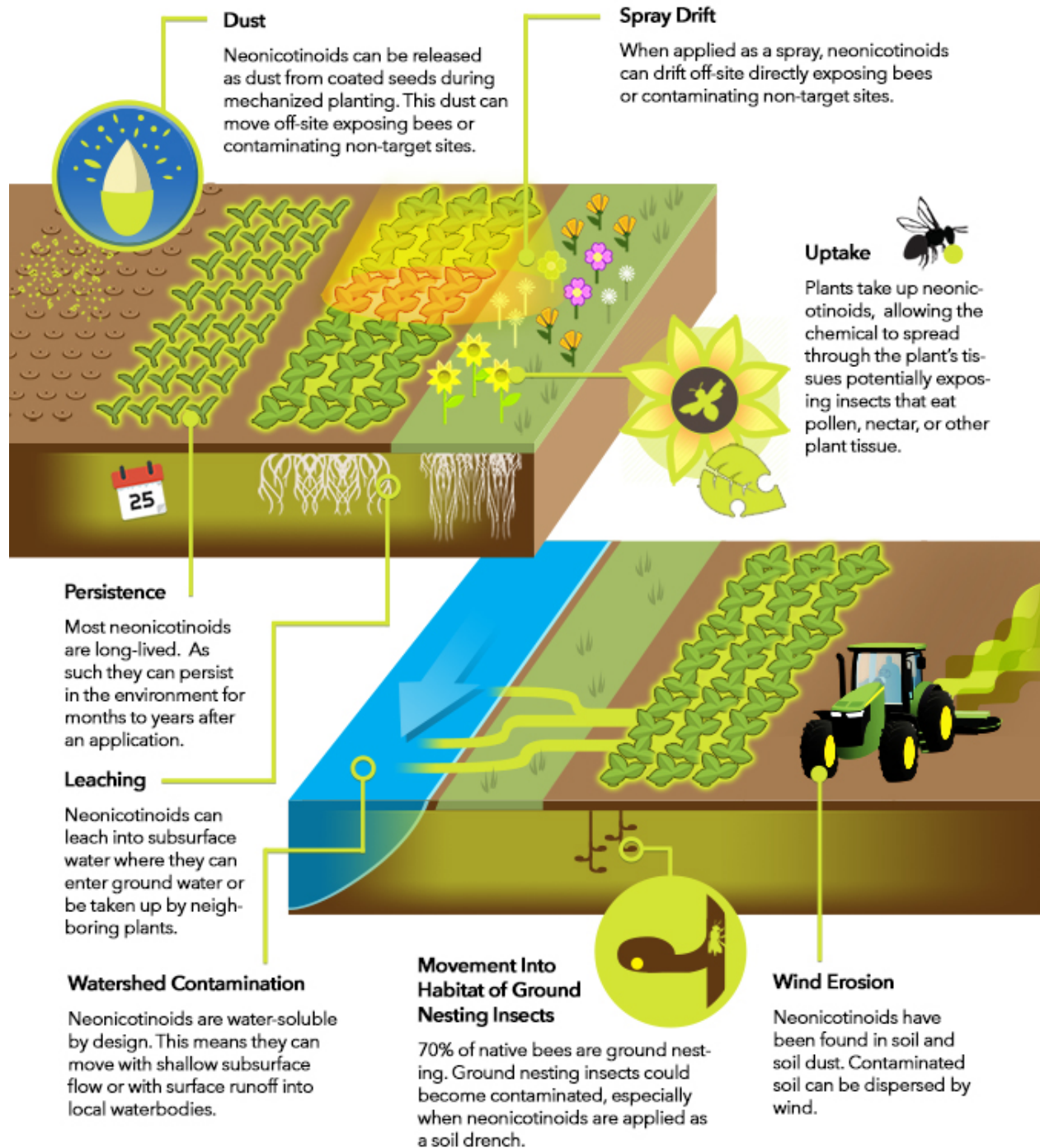
Figure 1 | Effects of pesticide treatment on colony-level behaviour.

# Routes of exposure



**Figure 1 | The environmental fate of neonicotinoids.** When neonicotinoids are applied as a seed





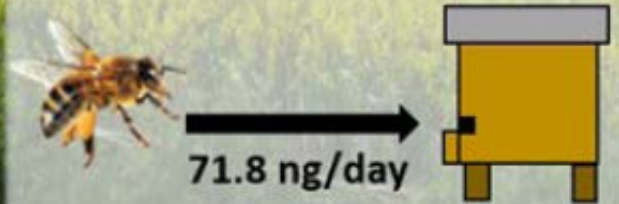
## DURING OILSEED RAPE BLOOMING

OSR pollen



7.2 ng/g

Neonicotinoid residues in pollen brought to the hives

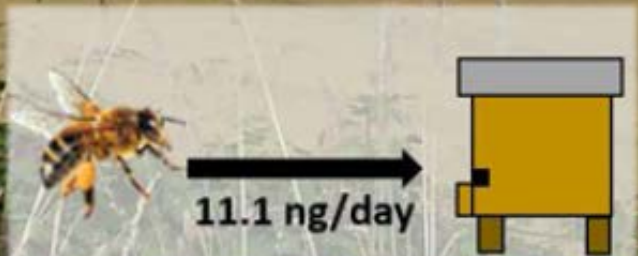


Wildflower pollen

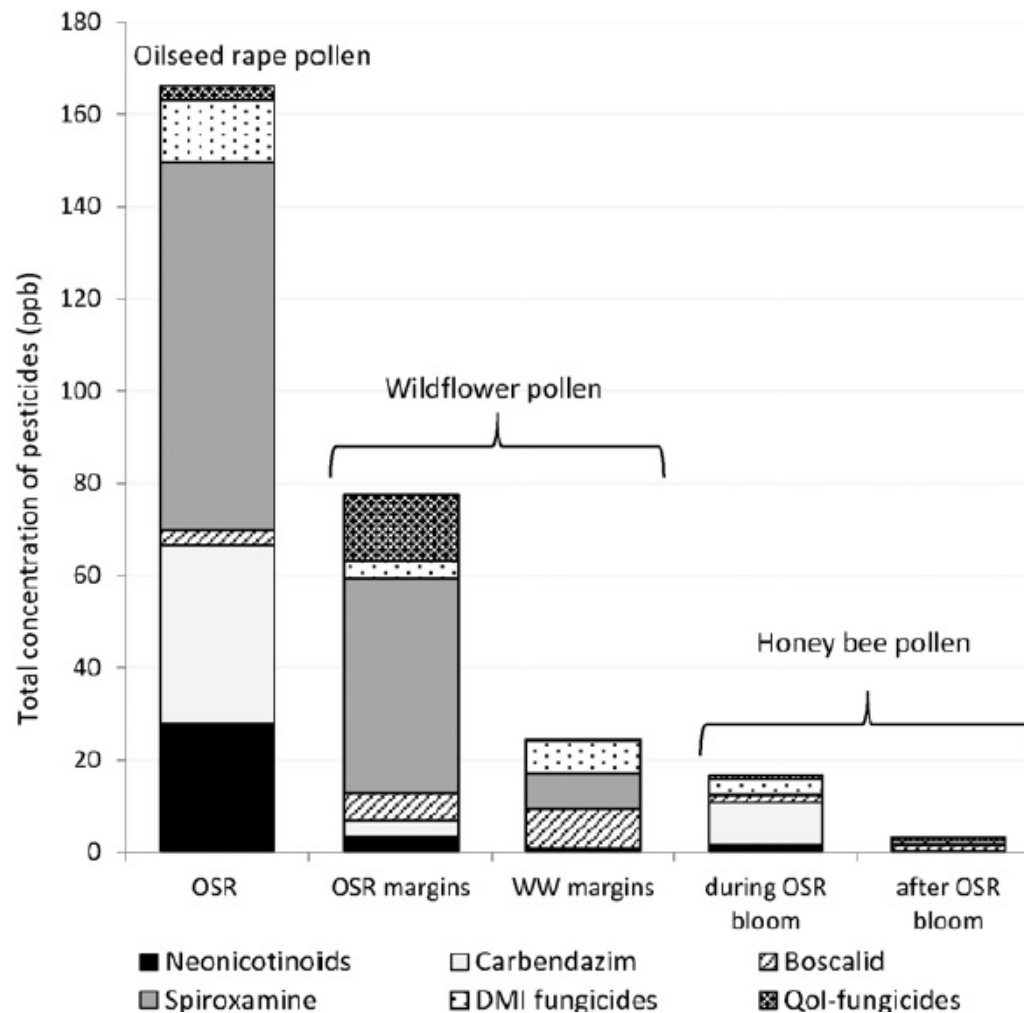


6.9 ng/g

## AFTER OILSEED RAPE BLOOMING

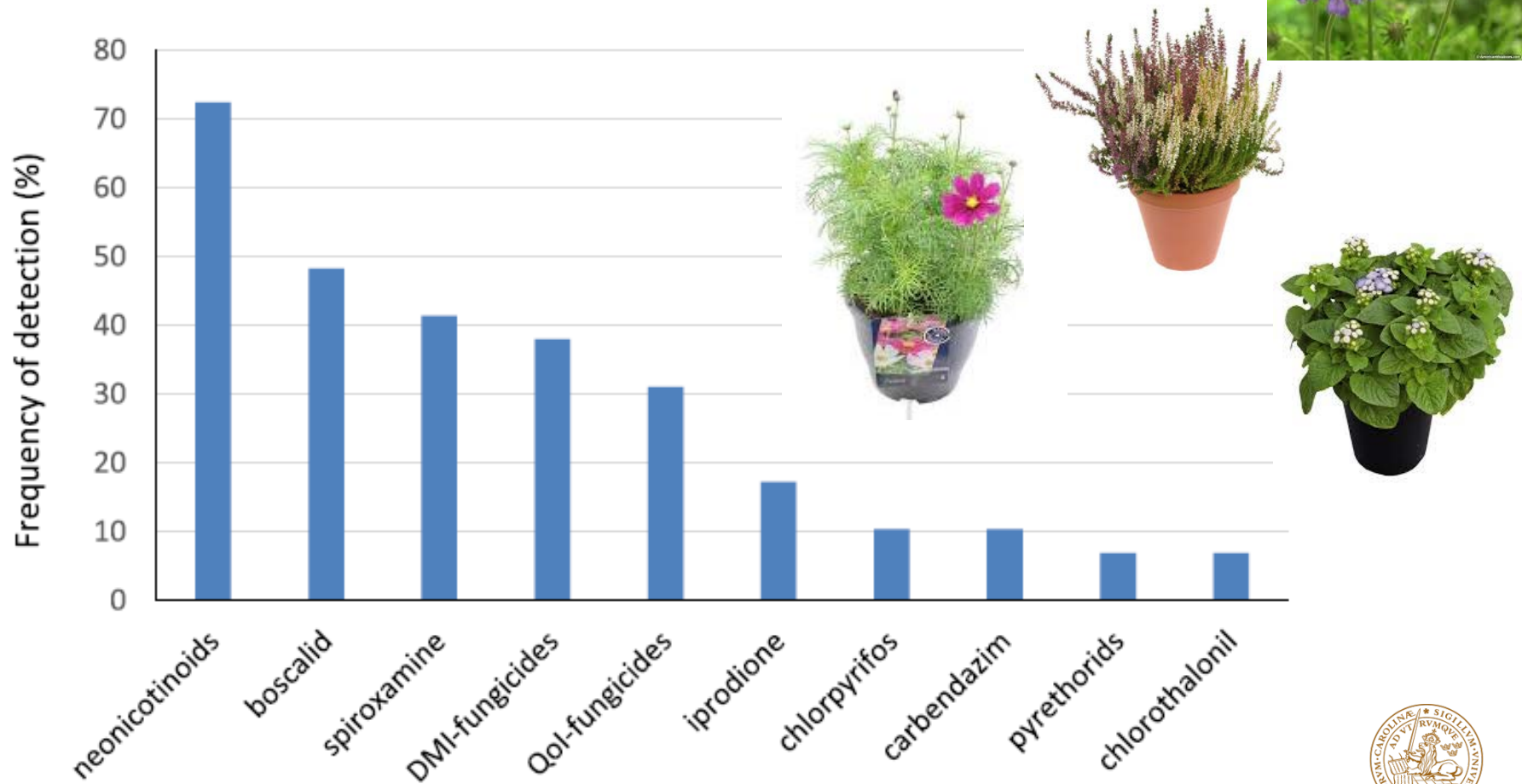


# Non-crop habitats emerge as exposure routes





# Neonicotinoids in “bee-friendly” ornamental plants







All but one of these garden insecticides contain neonicotinoids, and none of the labels indicate that they are poisonous to bees and adult butterflies. Photograph by Matthew Shepherd.

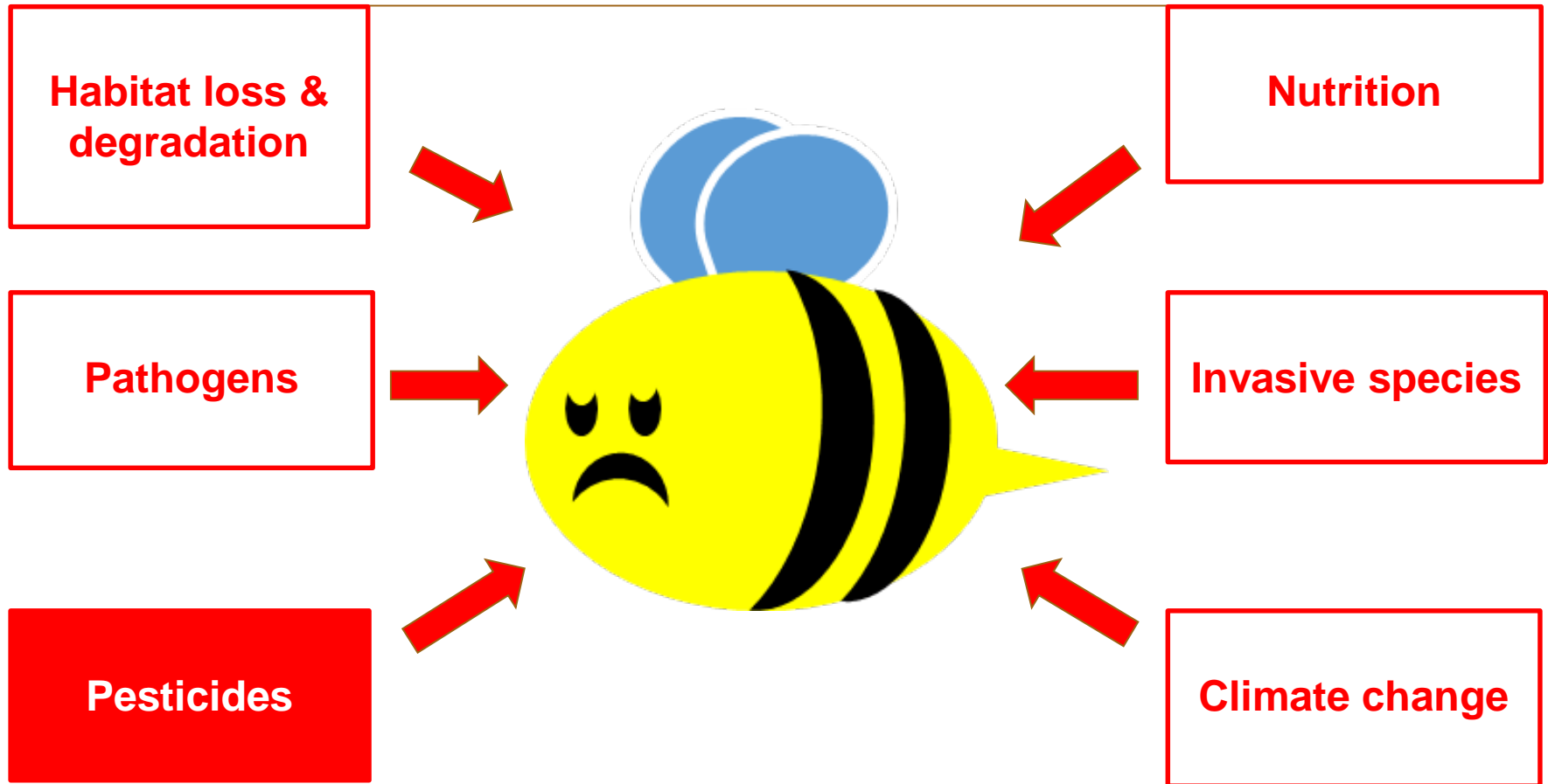
Hopwood & Shepherd (2012) Neonicotinoids in Your Garden. Xerces Society

Visit for more information: <http://xerces.org/neonicotinoids-and-bees/>



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# Drivers of bee decline



Interacting multiple factors!







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Centre for Animal Movement Research  
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# Questions?

[MAJ.RUNDLOF@BIOL.LU.SE](mailto:MAJ.RUNDLOF@BIOL.LU.SE)



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