A Brief History of Neonicotinoid and Bee Research

M. Rei Scampavia
PhD Candidate
Williams Lab and Lewis Lab
Department of Entomology and Nematology
University of California: Davis

Recent Pollinator Declines

Honeybee Declines

USA, Canada, + Europe- higher rates of colony losses

- 2012-2013: 49.4% average loss
- 2014-2015: 51.1 % average loss

Steinhauer et al. 2014, Lee et al. 2015

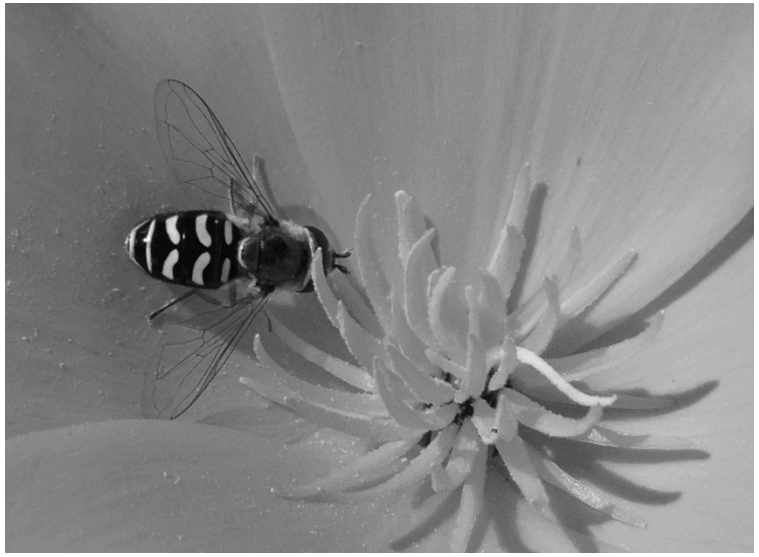
Bumblebee Declines

U.S.A.- 4/8 species

U.K. 6/16 species (3 extinct)

Cameron et al. 2011, Goulson et al. 2008

Other Pollinator Declines



Other Pollinator Declines(?)

Winfree et al. 2009

Potts et al. 2010

Causes of Decline

Habitat Loss & Fragmentation

Genetics

Nutrition

Invasive Species

Pathogens

Climate Change

Pesticides

Parasites

Overwintering and Pollination Stress

Causes of Decline

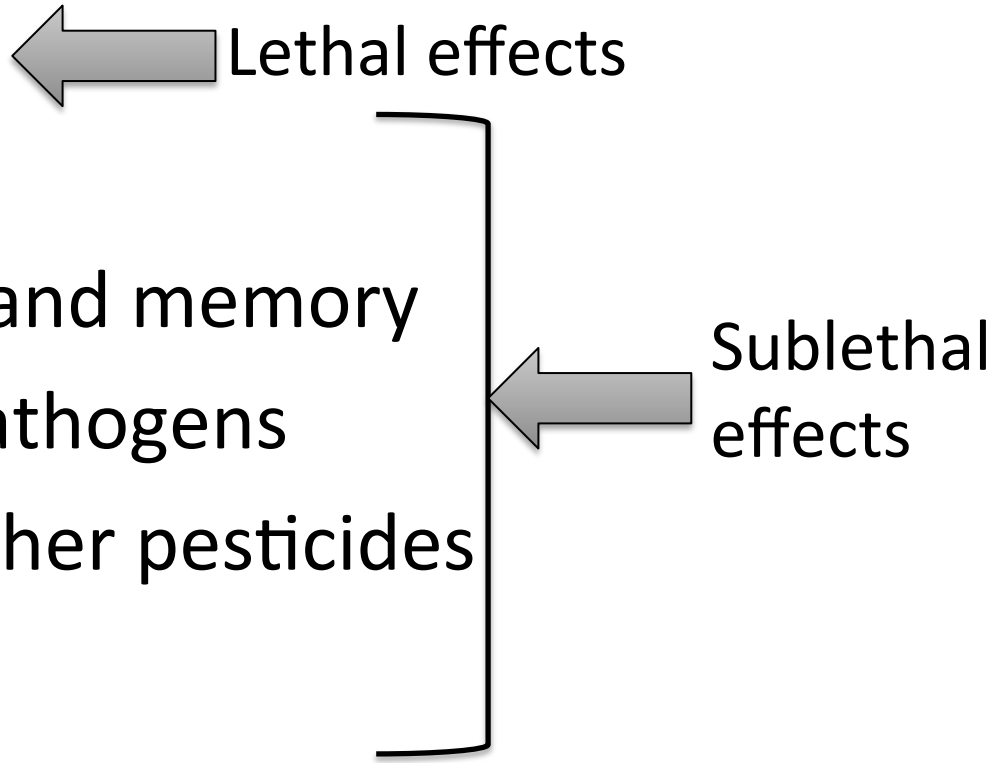
Pesticides
(neonicotinoids)

2013- European Commission Restricts Neonicotinoid Use

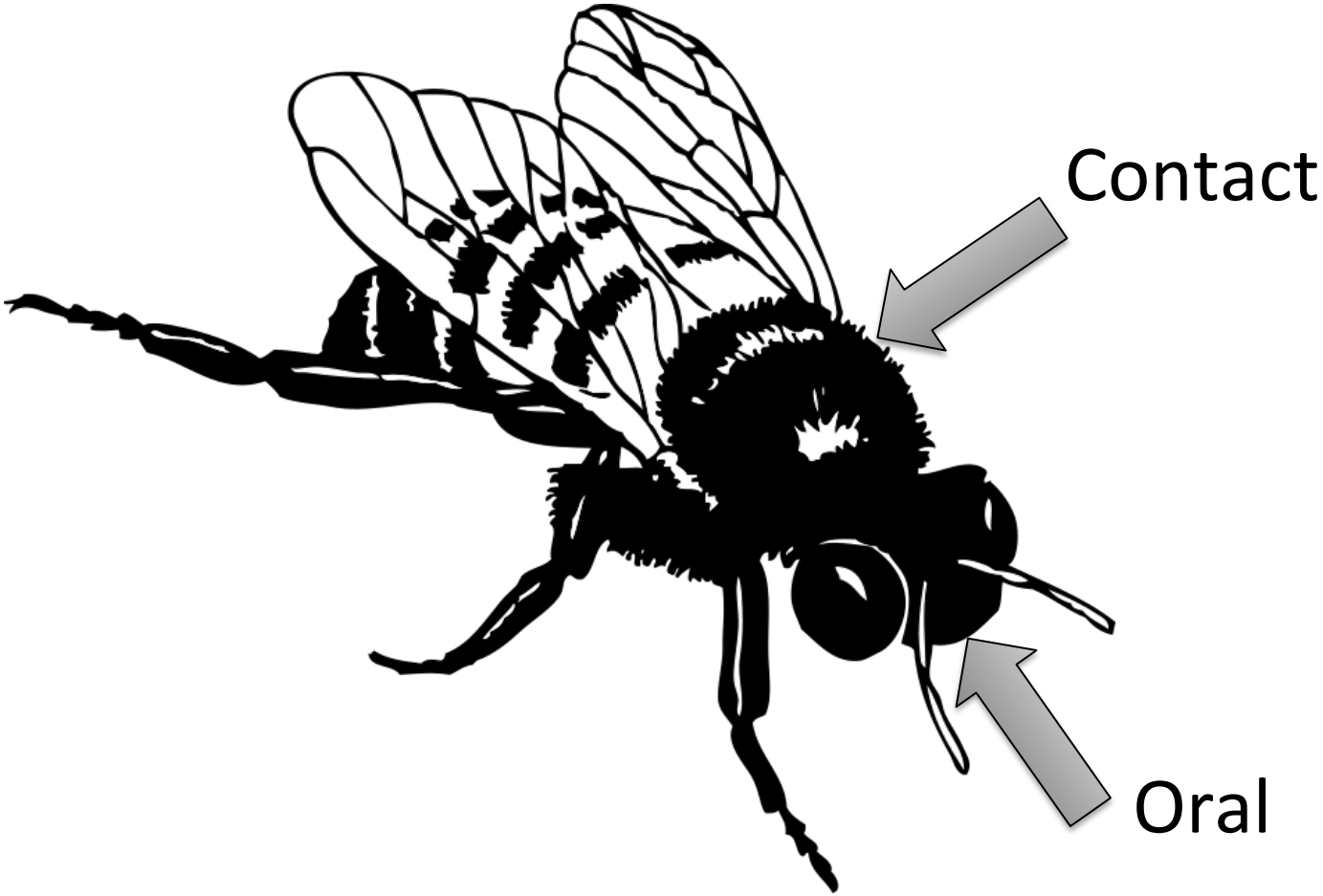
- 2 year restriction on certain applications of:
  - Clothianidin
  - Thiamethoxam
  - Imidacloprid
- Allow time for scientific research

Outline

- Routes of exposure
- Colony level effects
- Foraging, learning, and memory
- Interactions with pathogens
- Interactions with other pesticides
- Other pollinators?



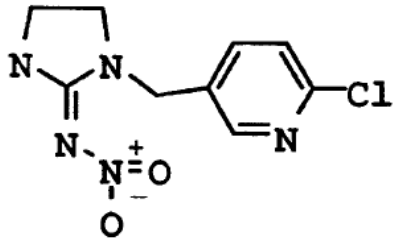
Routes of Exposure



Honey Bee Contact Toxicity (24 hr LD_{50})

- Imidacloprid (18 ng/bee)
- Clothianidin (22 ng/bee)
- Thiamethoxam (30 ng/bee)
- Dinotefuran (75 ng/bee)
- Nitenpyram (138 ng/bee)

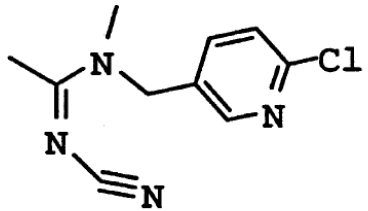
Nitro-group



imidacloprid

- Acetamiprid (7000 ng/bee)
- Thiacloprid (15000 ng/bee)

Cyano-group



acetamiprid

Iwasa et al. 2004

Honey Bee Contact Toxicity (24 hr LD_{50})

- **Imidacloprid (18 ng/bee)** ⟸ 78% of studies
- Clothianidin (22 ng/bee)
- Thiamethoxam (30 ng/bee)
- Dinotefuran (75 ng/bee)
- Nitenpyram (138 ng/bee)
- Acetamiprid (7000 ng/bee)
- Thiacloprid (15000 ng/bee)

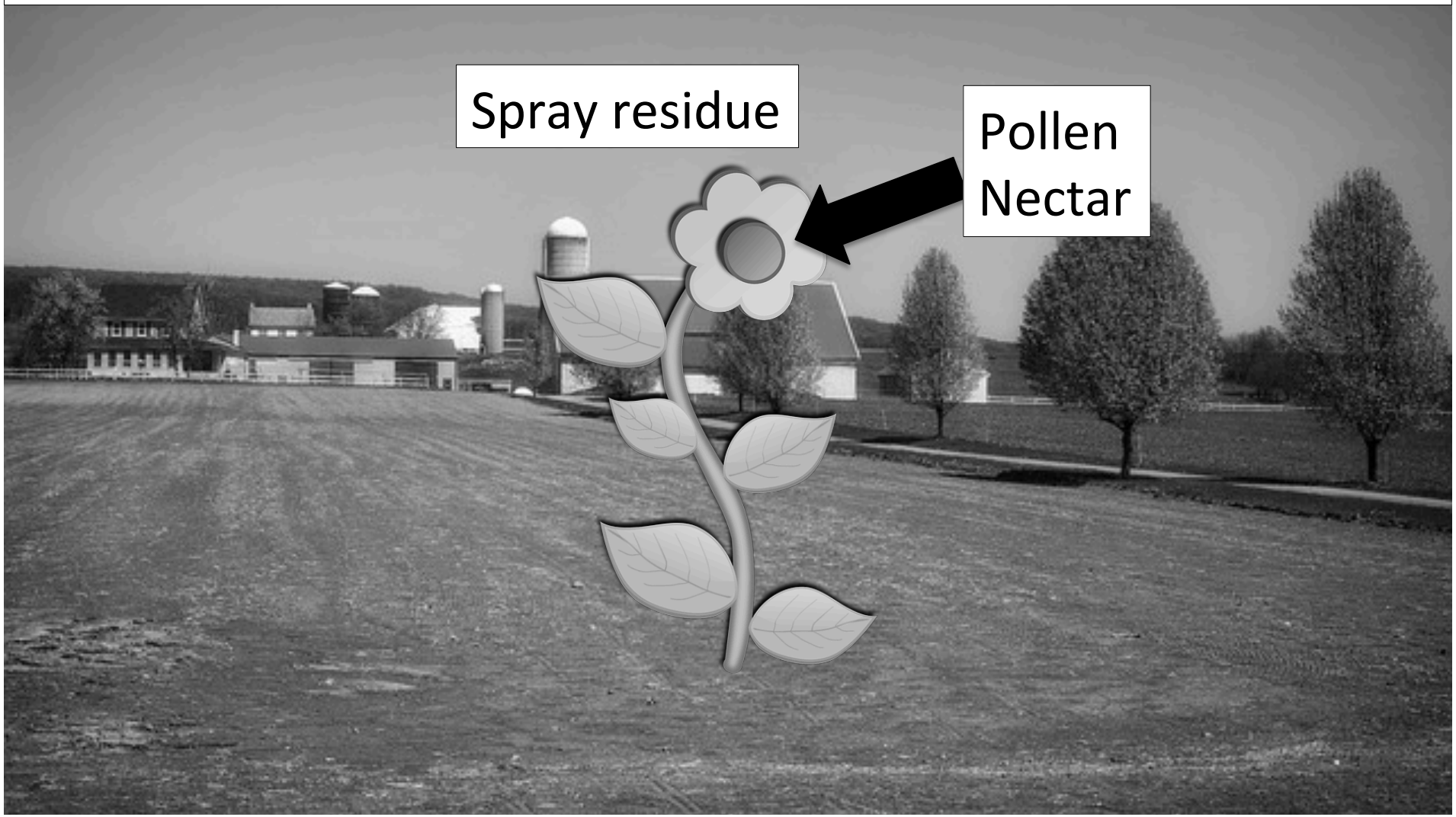
Iwasa et al. 2004, Lundin et al. 2015

Oral Toxicity

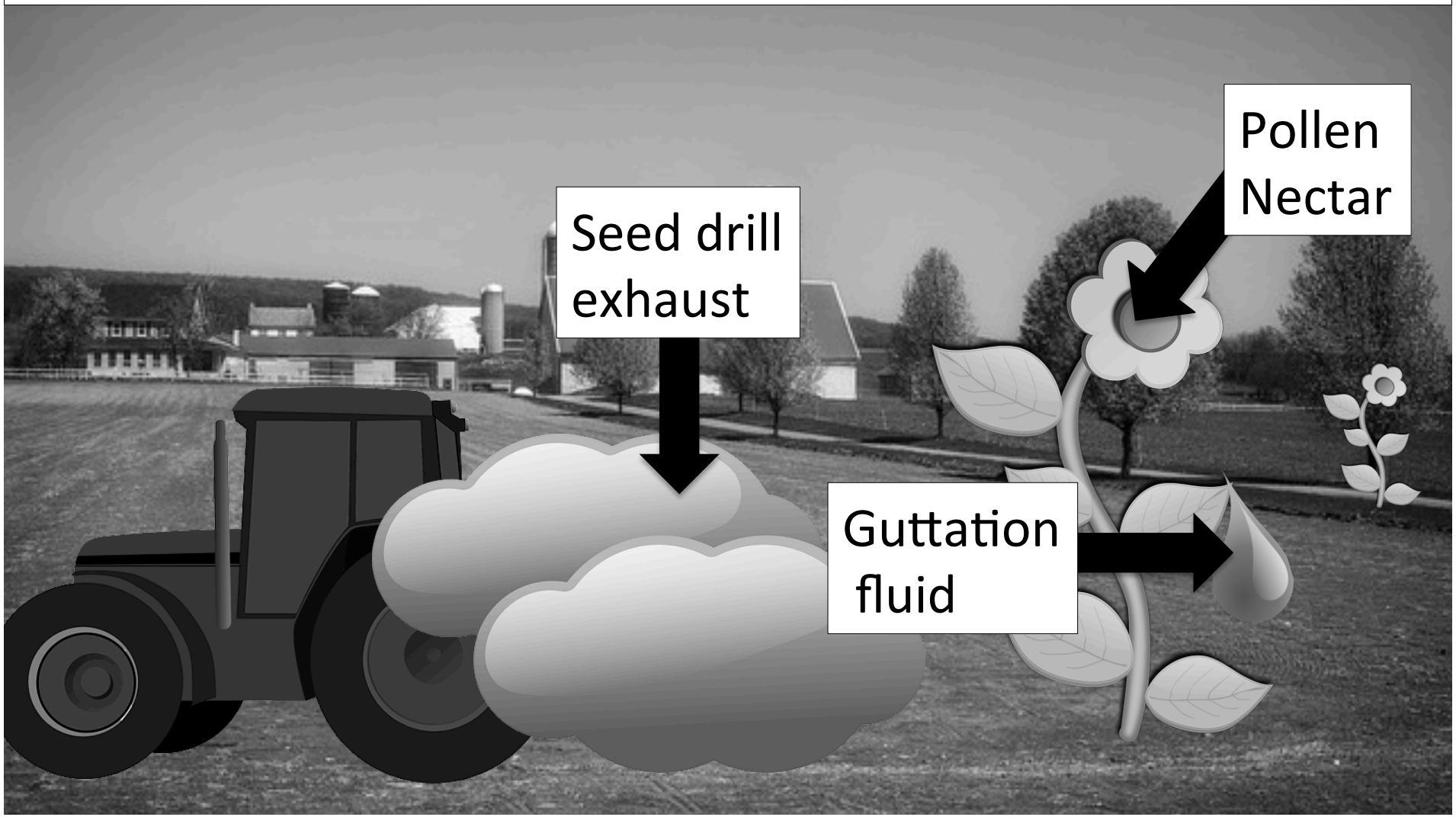
High variability between studies

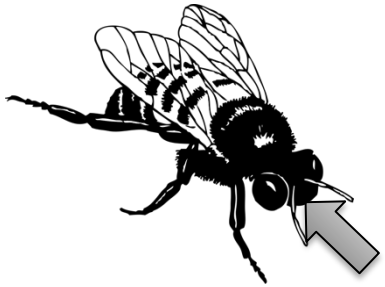
Blacquiere et al. 2012

Pesticide Exposure (Foliar Application)



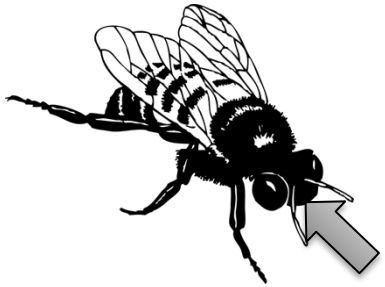
Pesticide Exposure (Seed Treatment)



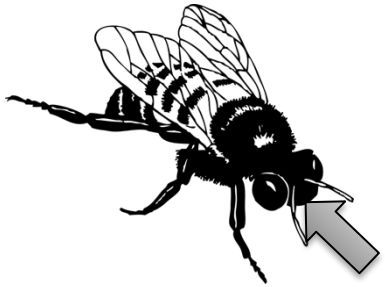


Pollen and Nectar

- Field-realistic range of imidacloprid in nectar 0.7-10 ug/L (Cresswell 2011)
- Average maximum of 6.1 ug / kg in pollen, 1.9 ug/L in nectar (Godfray et al. 2014)
- Well below acute and chronic toxicity levels



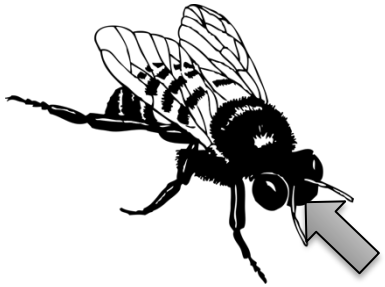
Guttation Fluid



Guttation Fluid

- Fed honey bees guttation fluid from seed-treated corn seedlings
- Very high peak concentrations
  - nearing concentration foliar spray
  - >200,000 ug /L imidacloprid

Girolami et al. 2009

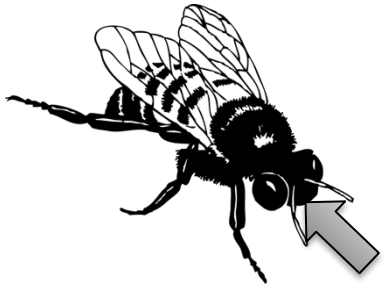


Guttation Fluid

- Fed honey bees guttation fluid from seed-treated corn seedlings
- Very high peak concentrations
  - nearing concentration foliar spray
  - >200,000 ug /L imidacloprid

Nectar concentration:
0.7-10 ug / L
(Cresswell 2011)

Girolami et al. 2009

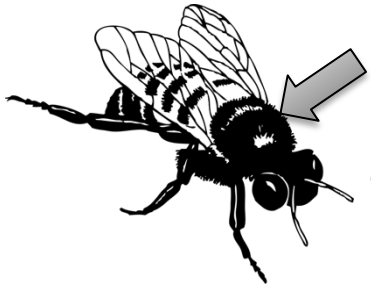


Guttation Fluid

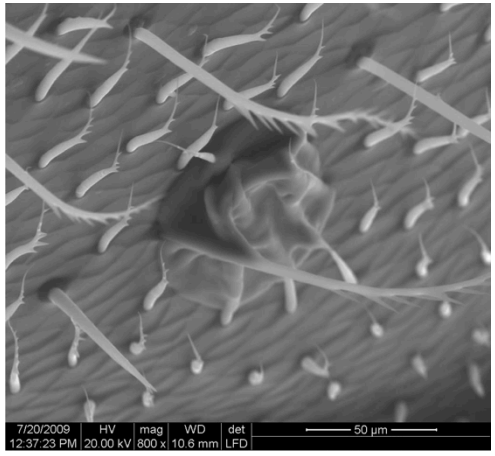
- Fed honey bees guttation fluid from seed-treated corn seedlings
- Very high peak concentrations
- High mortality in treatment groups
- No mortality in negative controls

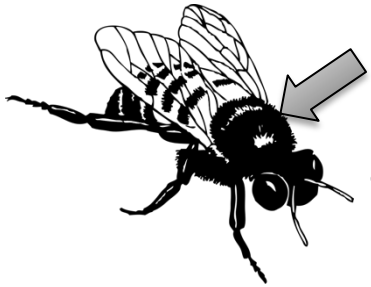
Girolami et al. 2009

Girolami et al. 2013, Tapparo et al. 2012



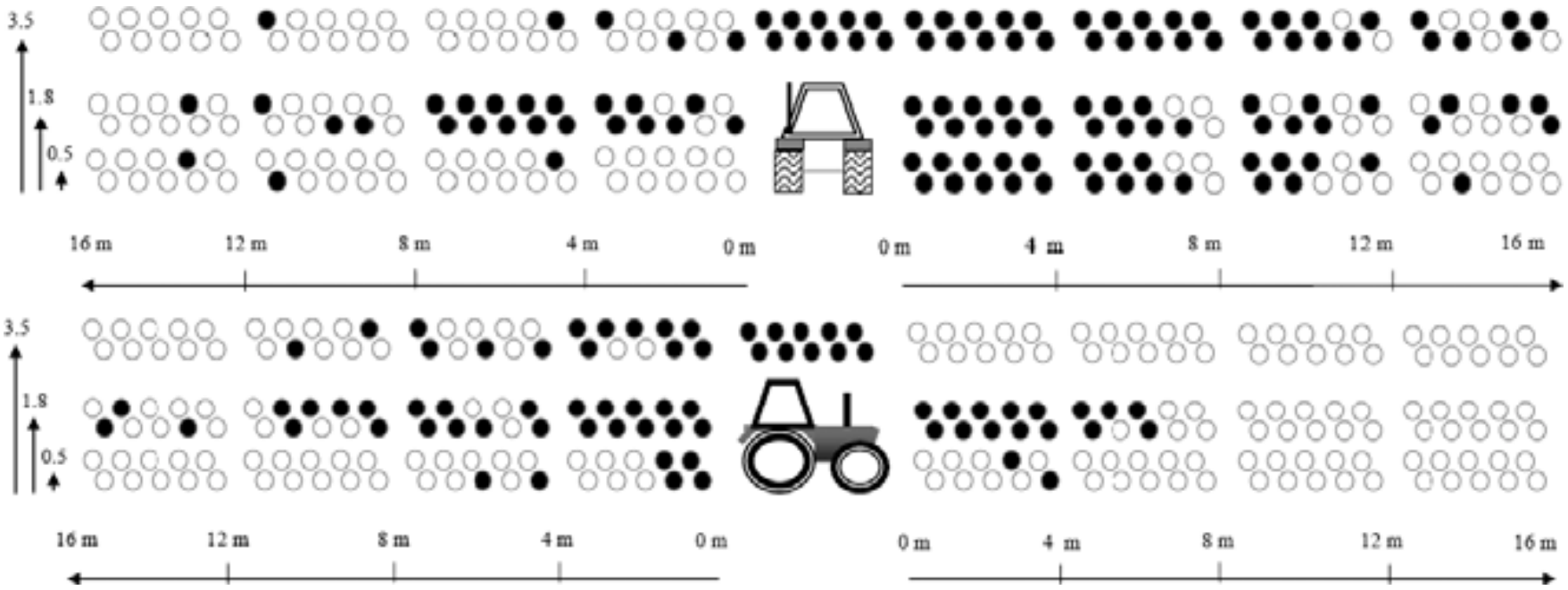
Seed Drilling Particulates



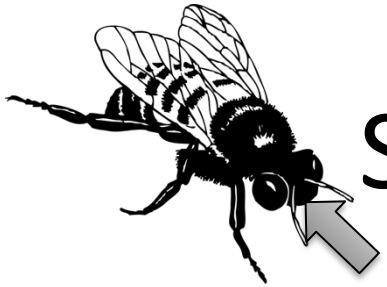


Seed Drilling Particulates

Bee deaths after a single rapid pass (clothianidin seed treatment):



Girolami et al. 2013



Seed Drilling Particulates

- Exhaust drift to weedy field margins
- Thiamethoxam, clothianidin detected on flowers in field margins

Clothianidin concentration: 1.1-9.4 ug/L

Imidacloprid nectar concentration: 0.7-10 ug / L (Cresswell 2011)

Krupke et al. 2012

Conclusions- Routes of Exposure

Neonicotinoid seed treatments present novel mechanisms of exposure to bees (seed drilling dust, guttation fluids)

- Depends on seed treatment formulation, type of seed drill used
- Due to types of crops and times of year present, bees unlikely to consume contaminated guttation fluid

Godfray et al. 2014

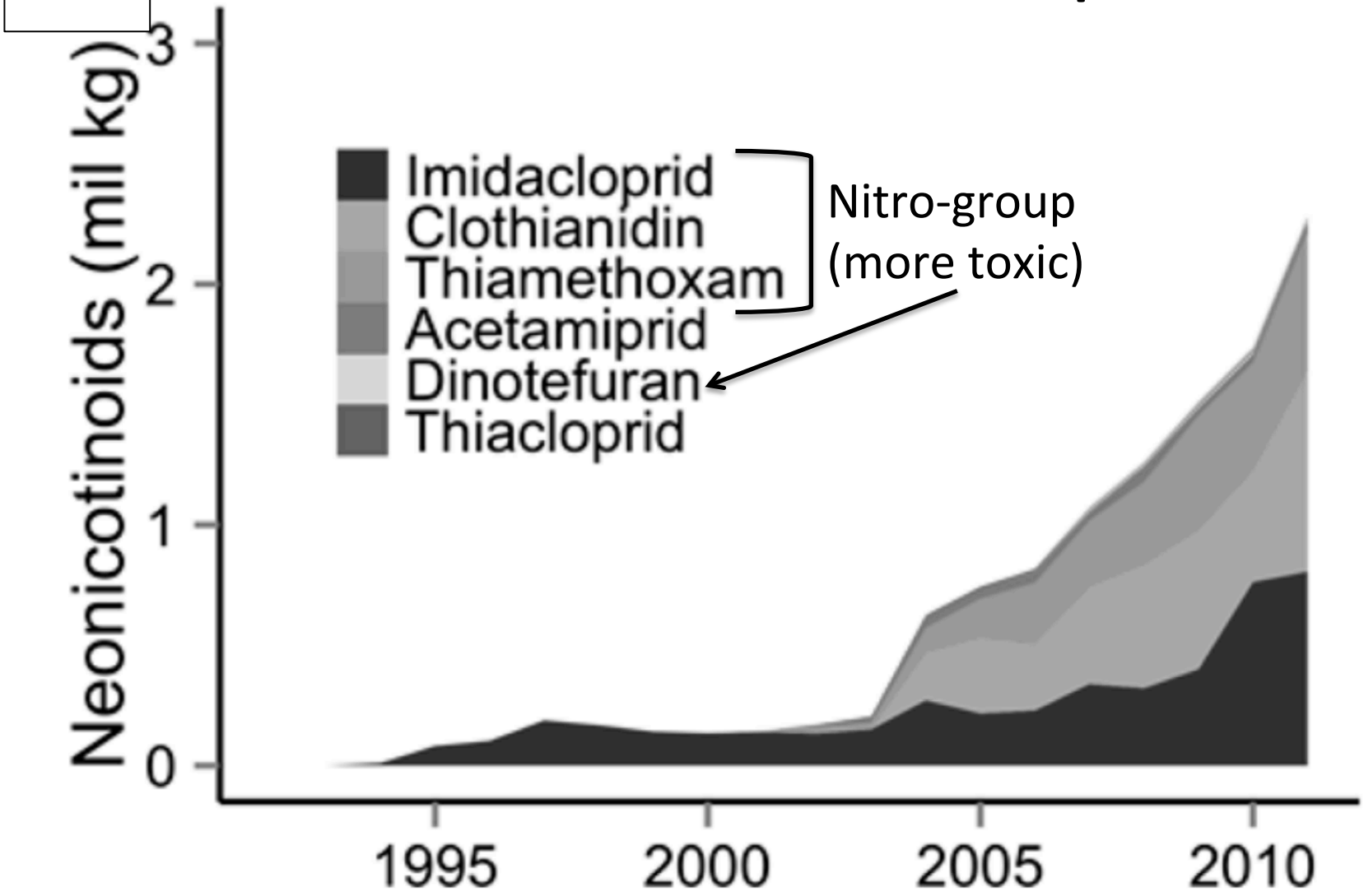
Conclusions- Routes of Exposure

Neonicotinoid seed treatments present novel mechanisms of exposure to bees (seed drilling dust, guttation fluids)

Levels of neonicotinoids to which bees are exposed are unlikely to be lethal

Godfray et al. 2014

Conclusions- Routes of Exposure



Douglas and Tooker 2015

Lethal vs. Sublethal effects

- **Lethal effect**- increased rate of mortality
- **Sublethal effect**- modified individual or colony performance (growth, fecundity, longevity, or behavior)

Cresswell 2011

Outline

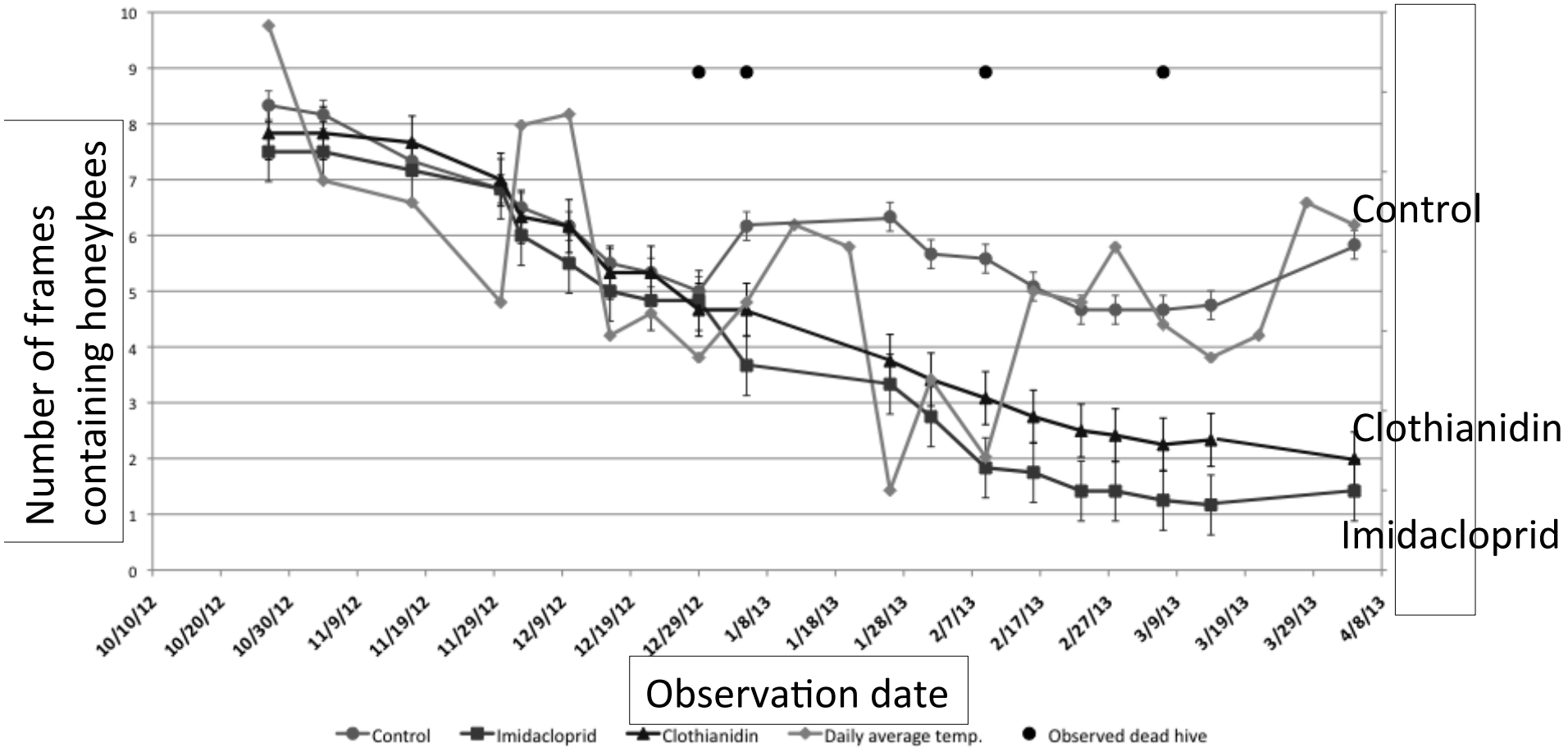
- Routes of exposure
- Colony level effects
- Foraging, learning, and memory
- Interactions with pathogens
- Interactions with other pesticides
- Other pollinators?

Honey bee overwintering

Could imidacloprid in high fructose corn syrup fed to overwintering bees lead to CCD-like symptoms?

Lu et al. 2012

Honey bee overwintering



Lu et al. 2014

Honey bee overwintering

Concentrations of imidacloprid in high fructose corn syrup: 20 – 400 ug/L

Nectar concentration: 0.7-10 ug/L (Cresswell 2011)

Cresswell 2011

Bumble bee colony growth, reproduction

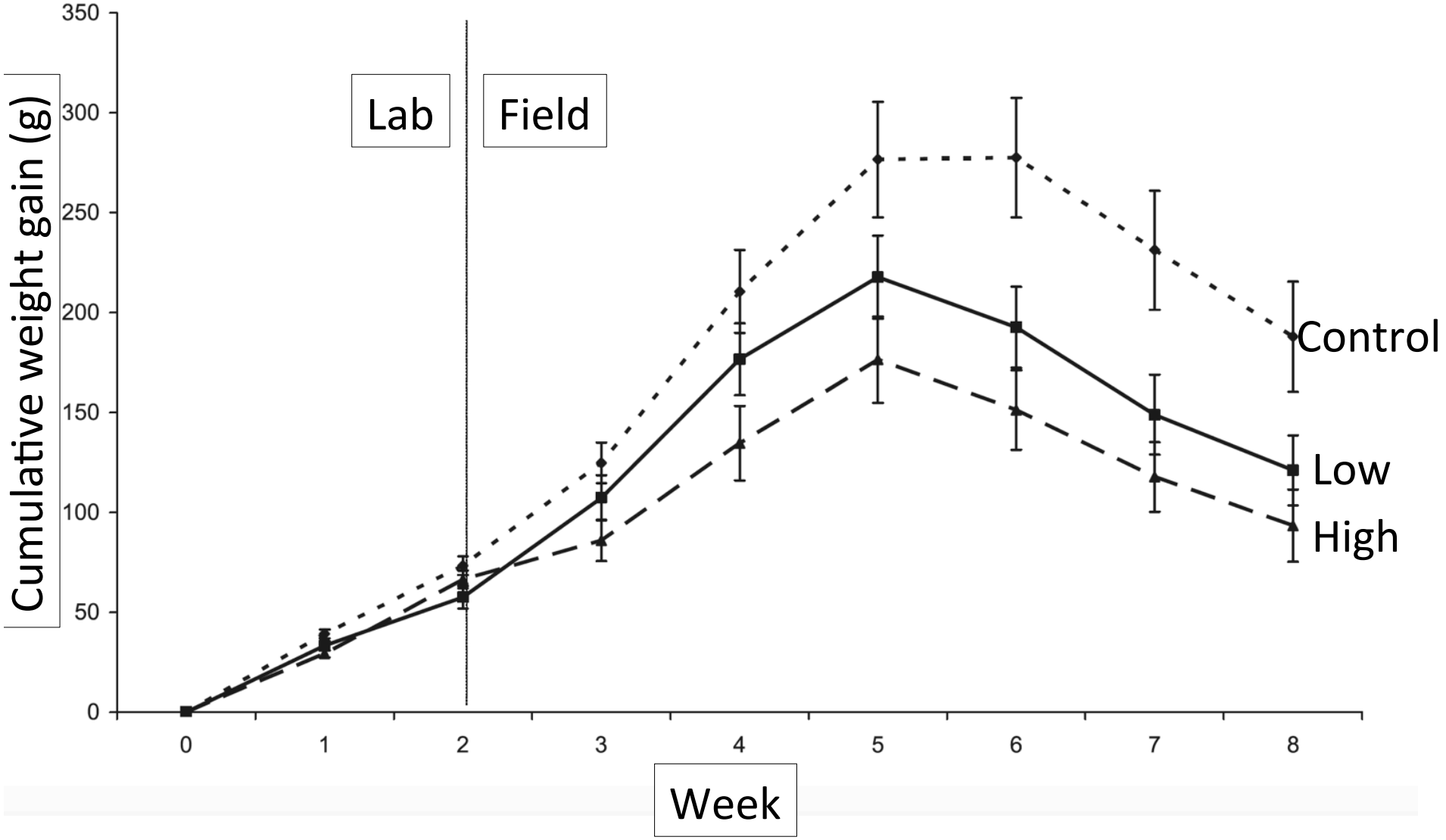
Can trace amounts of dietary imidacloprid contribute to observed bumble bee declines?

- "Low" treatment
  - 6 ug/kg imidacloprid in pollen
  - 0.7 ug/L imidacloprid in nectar
- "High" treatment: double the "low" dose

Nectar concentration: 0.7-10 ug/L (Cresswell 2011)

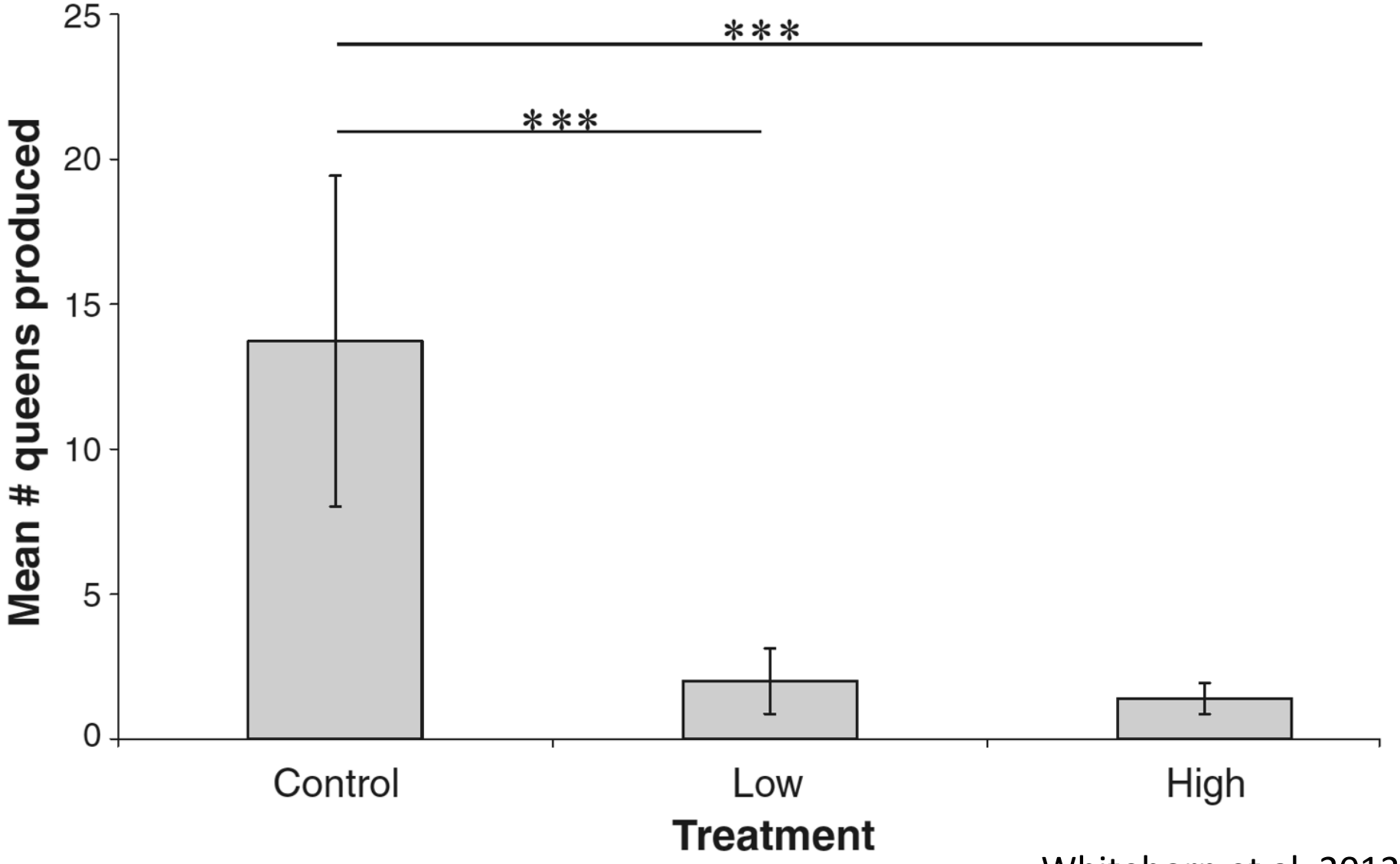
Average maximum pollen concentration: 6.1 ug/kg (Godfray 2014)

Bumble bee colony growth



Whitehorn et al. 2012

Bumble bee queen production



Whitehorn et al. 2012

Outline

- Routes of exposure
- Colony level effects
- Foraging, learning, and memory
- Interactions with pathogens
- Interactions with other pesticides
- Other pollinators?

Honey bee laboratory studies

- Single acute dose imidacloprid can impair
  - Learning (Lambin et al. 2001; Guez et al. 2001)
  - Motor activity (Lambin et al. 2001; Medzrycki et al. 2003)
  - Memory (Decourtye et al. 2004)
- Chronic sublethal doses imidacloprid can impair
  - Learning
  - Foraging (Decourtye et al. 2003, Han et al. 2010)
- Higher than "field-realistic" doses

A Common Pesticide Decreases Foraging Success and Survival in Honey Bees

Mickaël Henry,[1,2]* Maxime Béguin,[2,3] Fabrice Requier,[4,5] Orianne Rollin,[2,6] Jean-François Odoux,[5] Pierrick Aupinel,[5] Jean Aptel,[1,2] Sylvie Tchamitchian,[1,2] Axel Decourtye[2,6]

Can sublethal quantities of thiamethoxam increase hive death rate through homing failure in foraging bees?

Henry et al. 2012

Honey bee foraging

- Fed a single high dose of thiamethoxam
  - 1.34 ng
  - 67 ug/L solution

Average maximum nectar concentration: 1.9 ug/L (Godfray 2014)

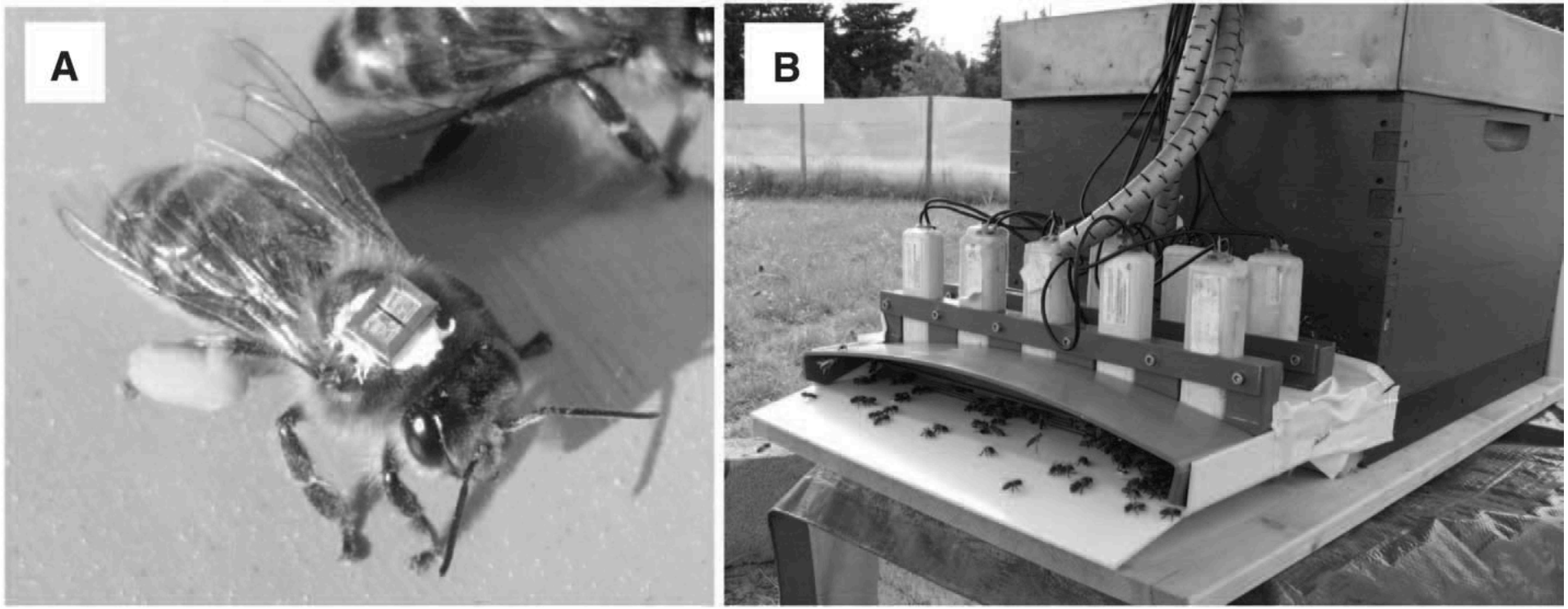
Henry et al. 2012

Honey bee foraging

- Fed a single high dose of thiamethoxam
  - 1.34 ng
  - 67 ug/L solution
- Probability of returning to hive monitored after release in
  - Familiar foraging location
  - Random location

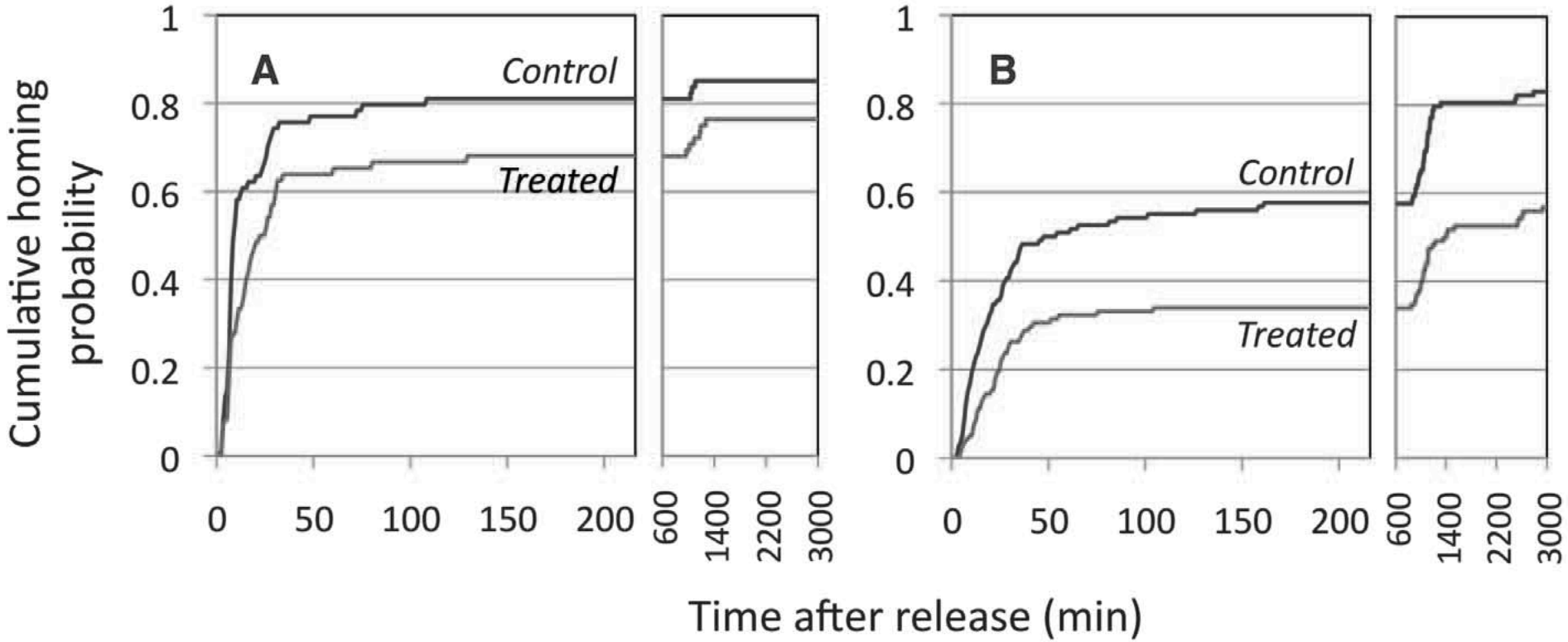
Henry et al. 2012

Honey bee foraging



Henry et al. 2012

Honey bee foraging



Henry et al. 2012

Outline

- Routes of exposure
- Colony level effects
- Foraging, learning, and memory
- Interactions with pathogens
- Interactions with other pesticides
- Other pollinators?

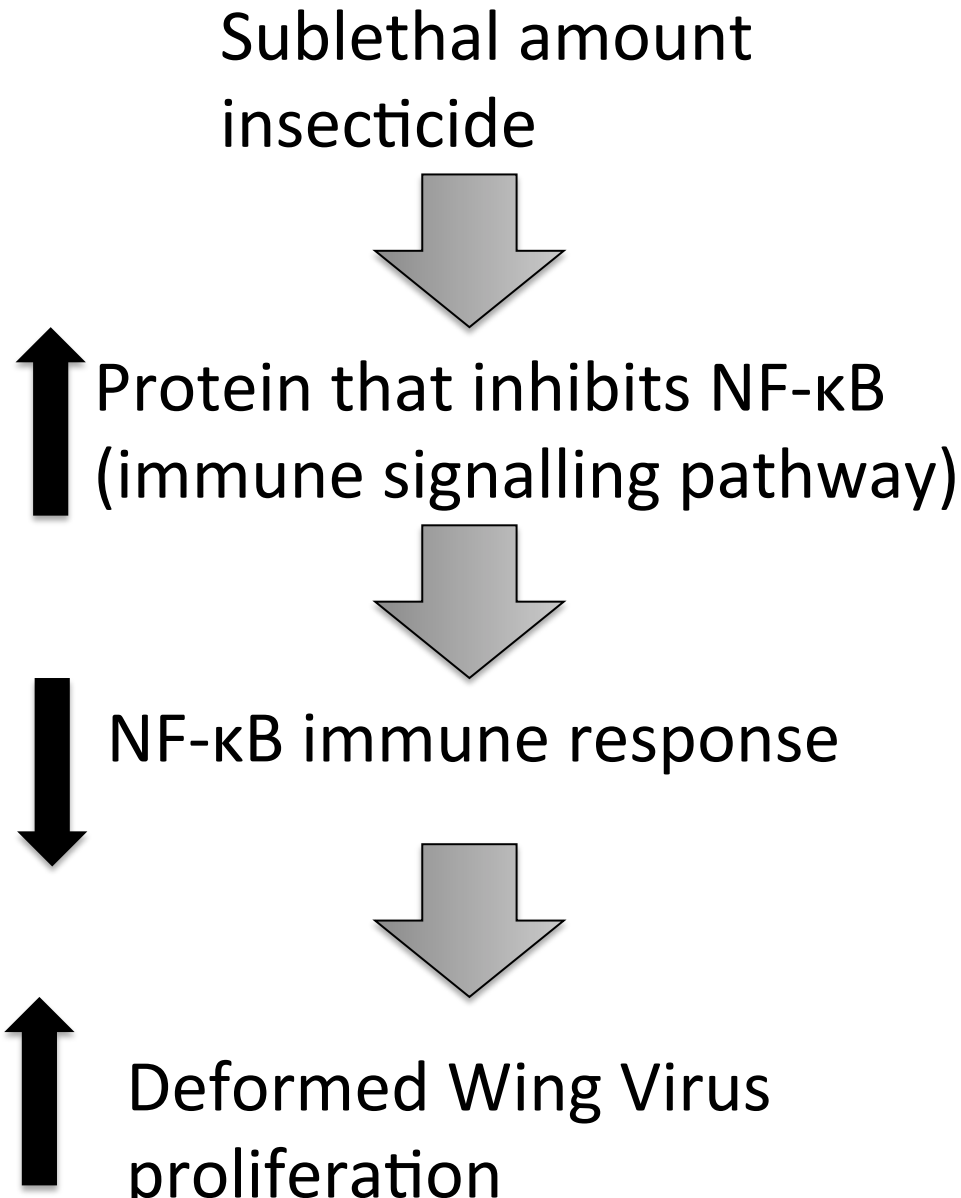
PNAS

Neonicotinoid clothianidin adversely affects insect immunity and promotes replication of a viral pathogen in honey bees

Gennaro Di Prisco[a], Valeria Cavaliere[b], Desiderato Annoscia[c], Paola Varricchio[a], Emilio Caprio[a], Francesco Nazzi[c], Giuseppe Gargiulo[b], and Francesco Pennacchio[a,1]

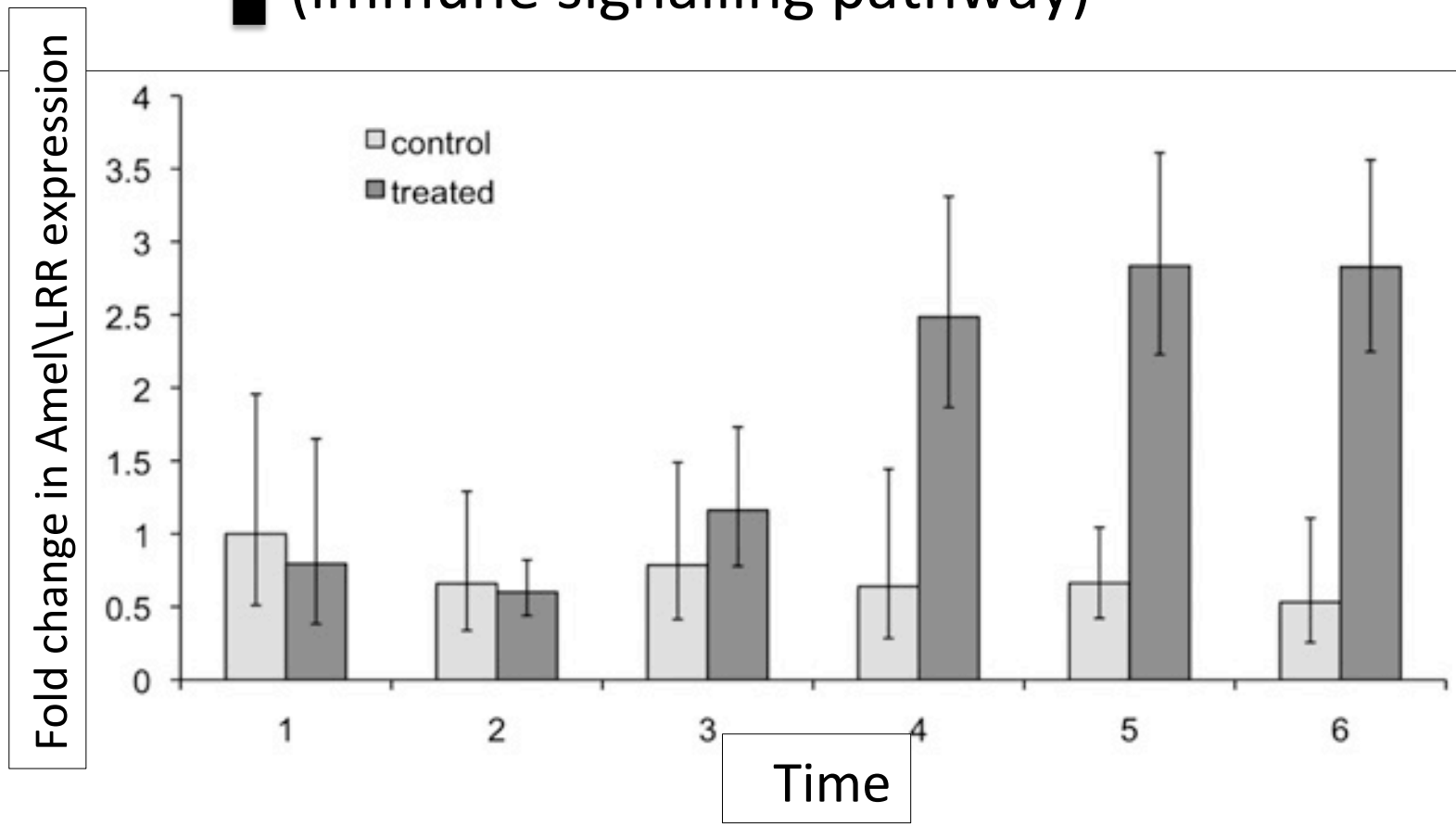
[a]Dipartimento di Agraria, Laboratorio di Entomologia E. Tremblay, Università degli Studi di Napoli Federico II, I-80055 Portici, Italy; [b]Dipartimento di Farmacia e Biotecnologie, Università di Bologna, I-40126 Bologna, Italy; and [c]Dipartimento di Scienze Agrarie e Ambientali, Università degli Studi di Udine, I-33100 Udine, Italy

Di Prisco et al. 2013


Sublethal amount insecticide
Protein that inhibits NF-κB (immune signalling pathway)
NF-κB immune response
Deformed Wing Virus proliferation

Change in immunity-inhibiting protein

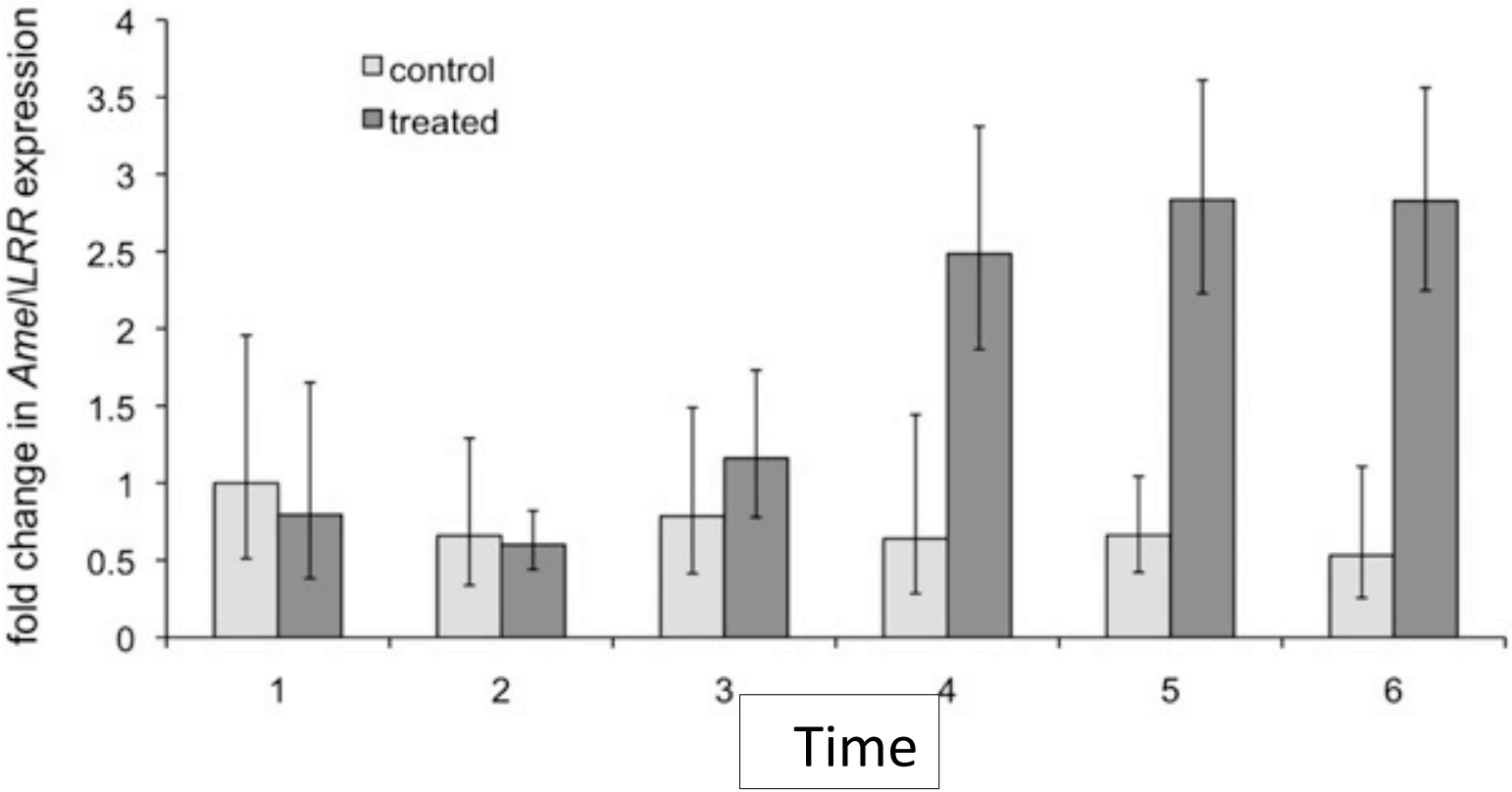
Protein that inhibits NF-κB
(immune signalling pathway)



Di Prisco et al. 2013

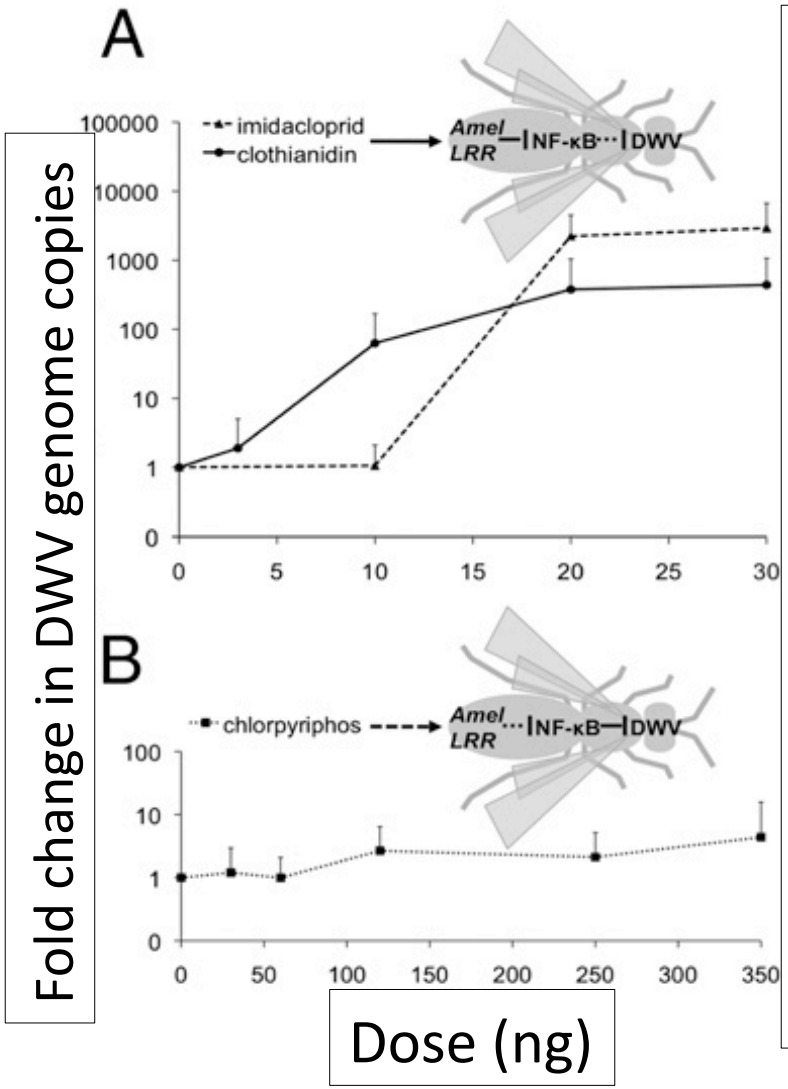
Change in immunity-inhibiting protein

- Clothianidin and imidacloprid altered gene expression
- Chlorpyrifos (an organophosphate) did not



Di Prisco et al. 2013

Increase in Deformed Wing Virus



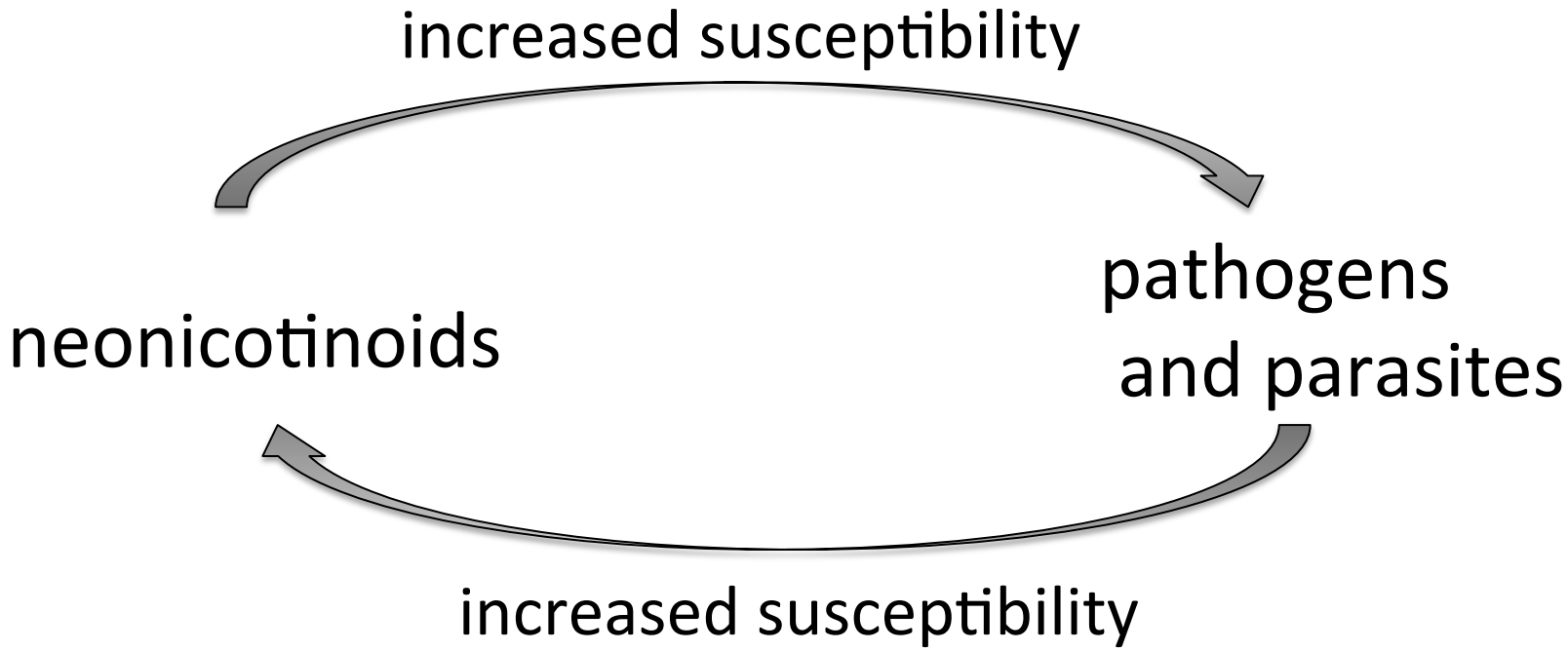
imidacloprid

clothianidin

chlorpyrifos

Di Prisco et al. 2013

Conclusions- Pathogens and Parasites



Data mostly limited to honey bee studies

Godfray et al. 2014

Outline

- Routes of exposure
- Colony level effects
- Foraging, learning, and memory
- Interactions with pathogens
- Interactions with other pesticides
- Other pollinators?

Synergy with DMI-Fungicide Pretreatment

Neonicotinoid	**Fungicide**	**LD_{50}(µg/bee)**
Imidacloprid		0.0179
Imidacloprid	Triflumizole	0.0097
Acetamiprid		7.07
Acetamiprid	Triflumizole	0.029
Thiacloprid		14.6
Thiacloprid	Triflumizole	0.0128

Nitro-group (more toxic)

Cyano-group (less toxic)

Honey bee study

Iwasa et al. 2004

Synergy with DMI-Fungicide Pretreatment

Neonicotinoid	**Fungicide**	**LD_{50}(µg/bee)**
Imidacloprid		0.0179
Imidacloprid	Triflumizole	0.0097
Acetamiprid		7.07
Acetamiprid	Triflumizole	0.029
Thiacloprid		14.6
Thiacloprid	Triflumizole	0.0128

Nitro-group (more toxic)

Cyano-group (less toxic)

>1,000 x more toxic

Honey bee study

Iwasa et al. 2004

Combined effects on bumble bee foraging

Over 4 week period, exposed *Bombus terrestris* colonies to

- 10 ug/L imidacloprid (fed in sucrose)

Nectar concentration: 0.7-10 ug/L (Cresswell 2011)

Gill et al. 2012

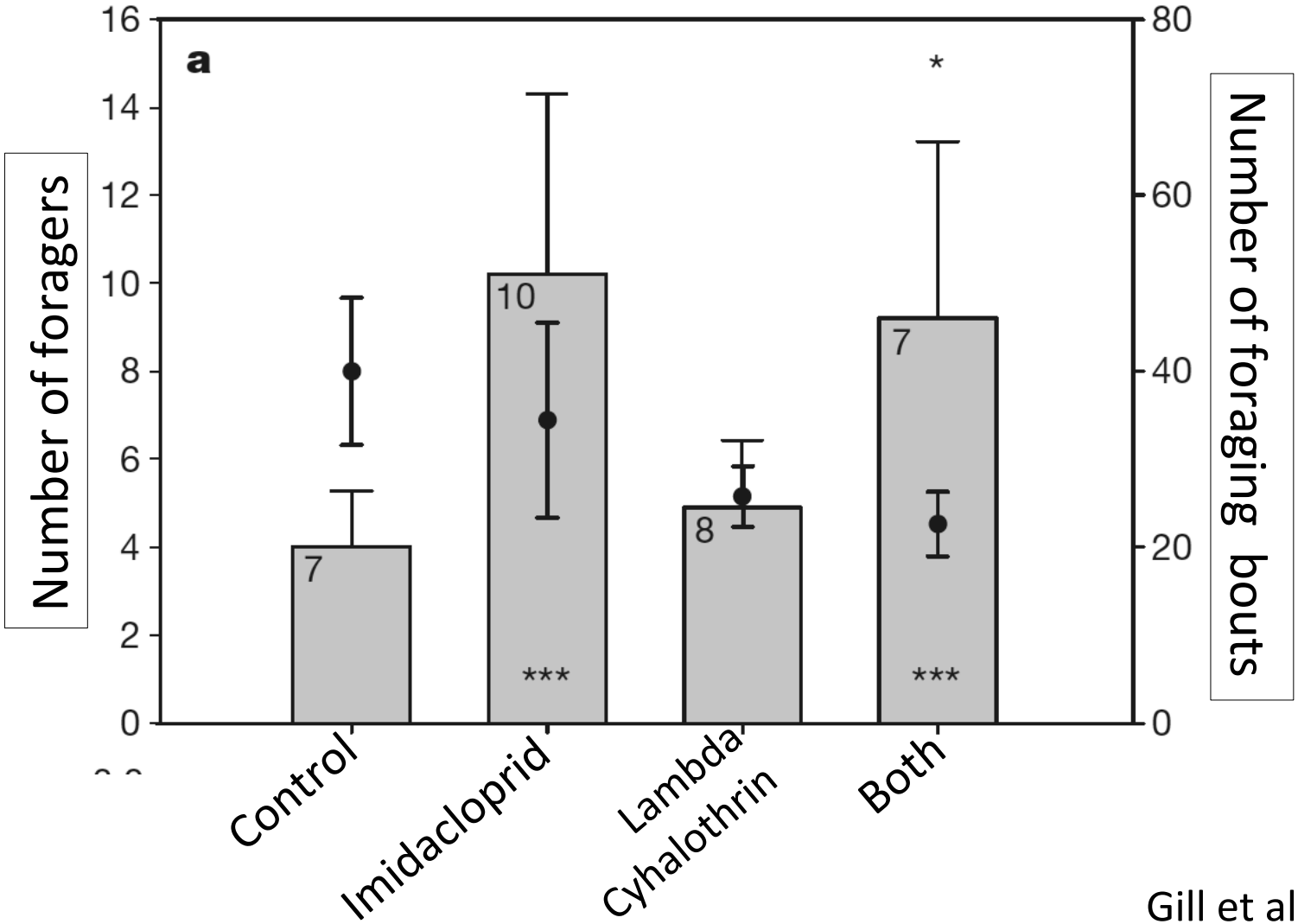
Combined effects on bumble bee foraging

Over 4 week period, exposed *Bombus terrestris* colonies to

- 10 ug/L imidacloprid (fed in sucrose)
- Lambda-cyhalothrin (pyrethroid) sprayed on flowering crops (pollen)
- Both imidacloprid and pyrethroid

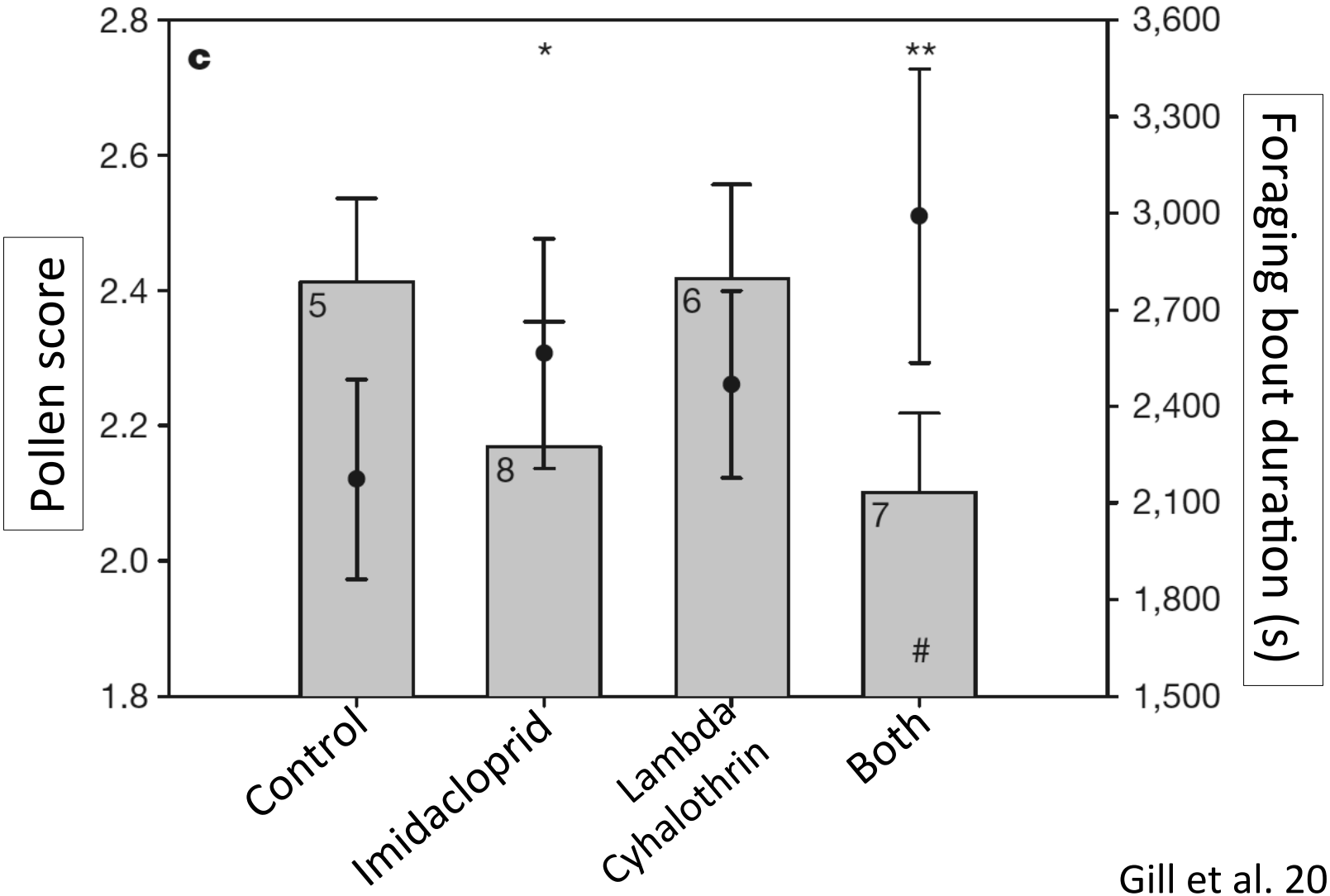
Gill et al. 2012

Increased number of foragers



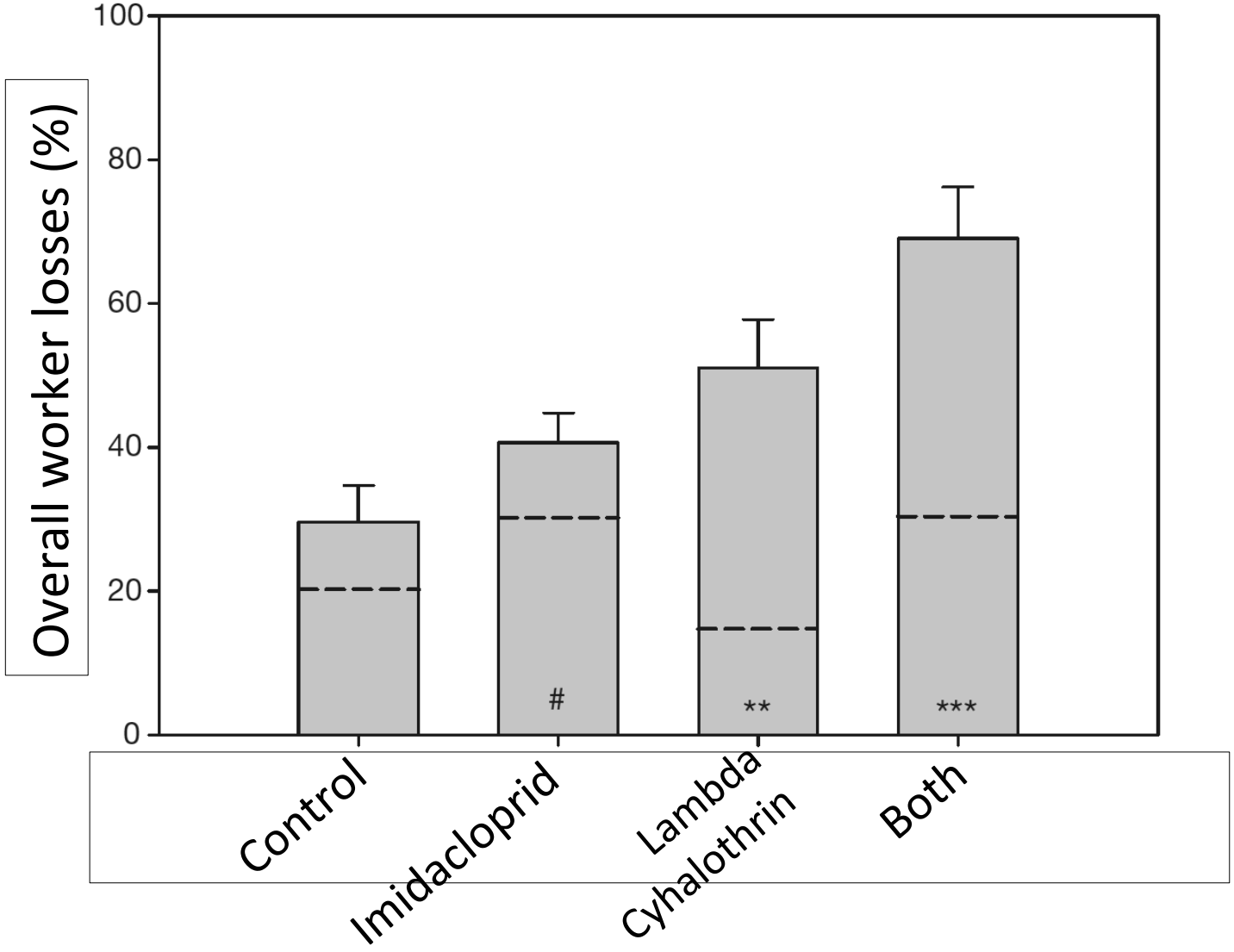
Gill et al. 2012

Decreased pollen loads



Gill et al. 2012

Increased worker loss

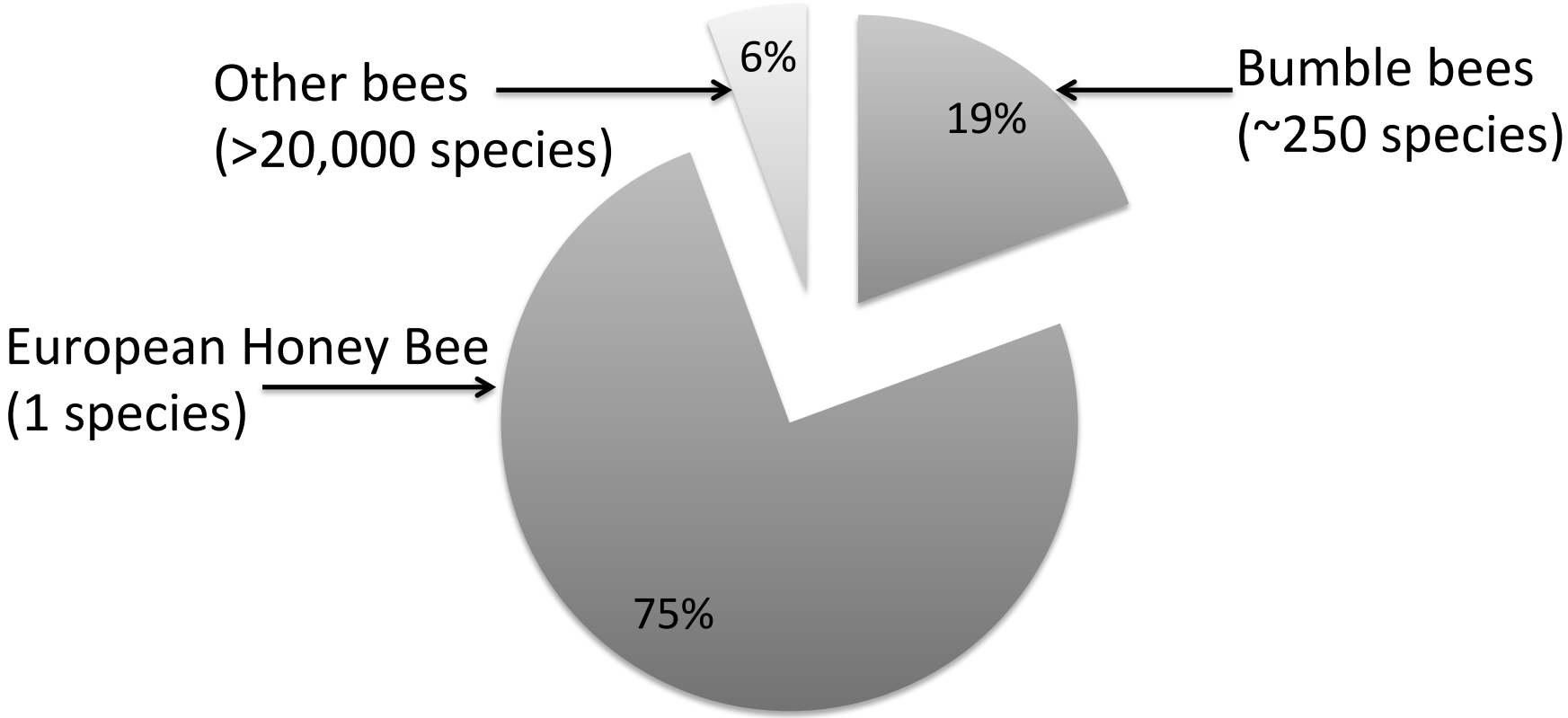


Outline

- Routes of exposure
- Colony level effects
- Foraging, learning, and memory
- Interactions with pathogens
- Interactions with other pesticides
- Other pollinators?

Limited Information

% of studies of effects of neonicotinoids on pollinators (by taxon):



Lundin et al. 2015

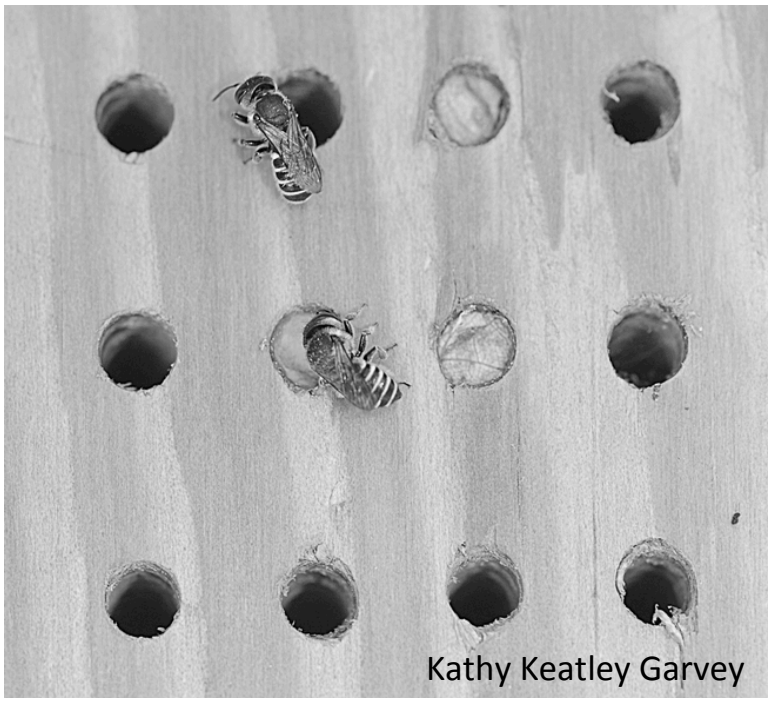
Diversity of Wild, Native Pollinators

- Differences in susceptibility to different neonicotinoids
  - Imidacloprid more toxic than clothianidin to blue orchard bees
  - Clothianidin more toxic than imidacloprid to alfalfa leafcutter bees

Scott-Dupree et al. 2009

Diversity of Wild, Native Pollinators

- Differences in susceptibility to different neonicotinoids
- Differences in nesting behavior



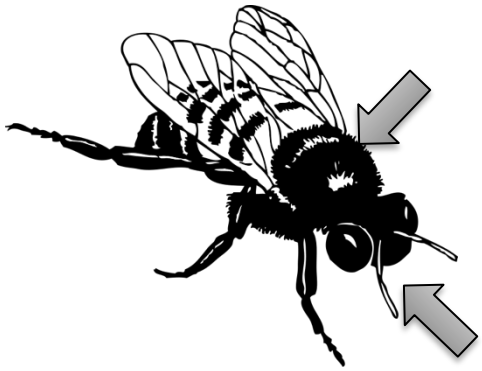
Diversity of Wild, Native Pollinators

- Differences in susceptibility to different neonicotinoids
- Differences in nesting behavior
- Differences in sociality

Conclusions

The effects of neonicotinoids on pollinators will depend on:

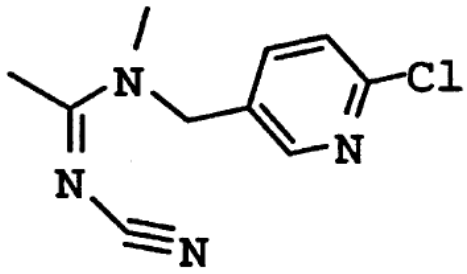
- Route of exposure



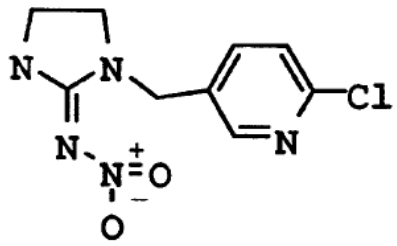
Conclusions

The effects of neonicotinoids on pollinators will depend on:

- Route of exposure
- type



acetamiprid

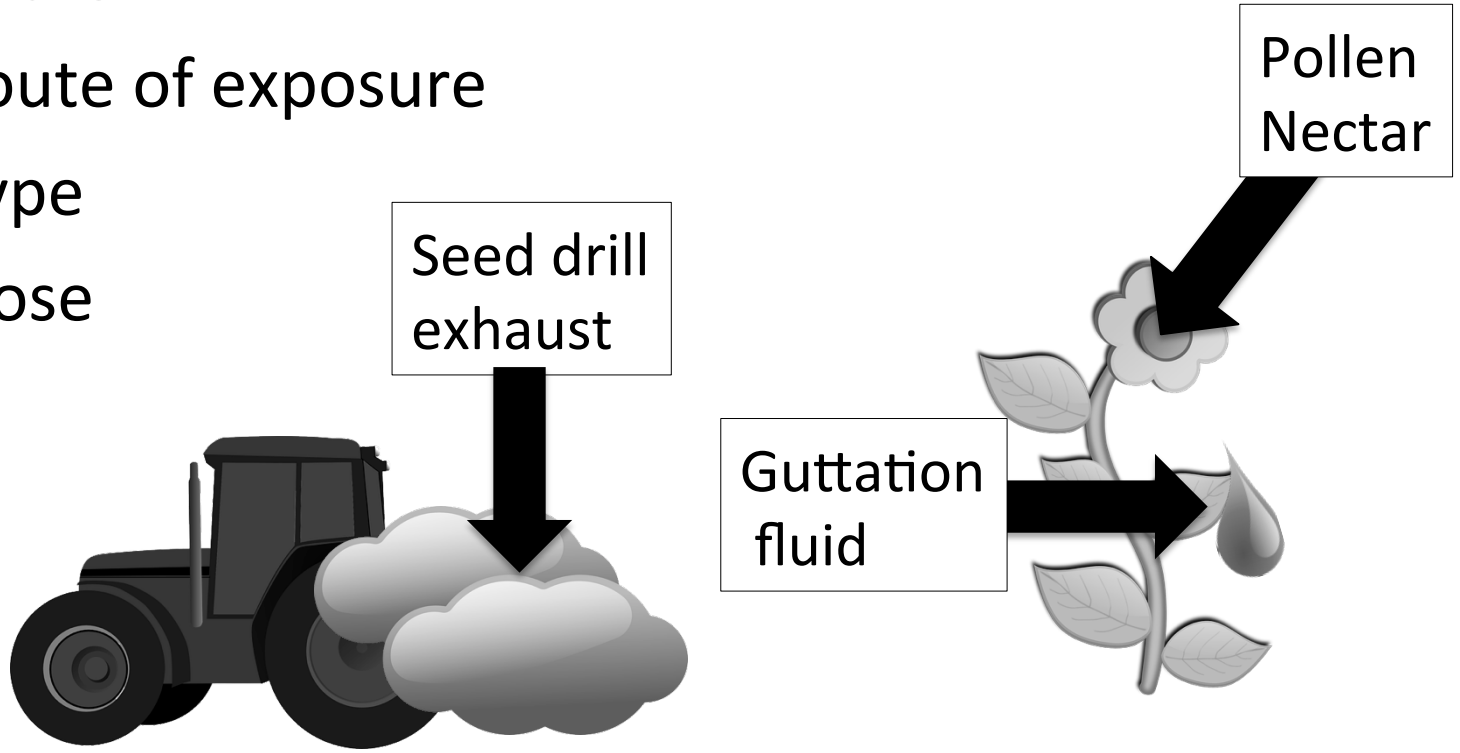


imidacloprid

Conclusions

The effects of neonicotinoids on pollinators will depend on:

- route of exposure
- type
- dose



Conclusions

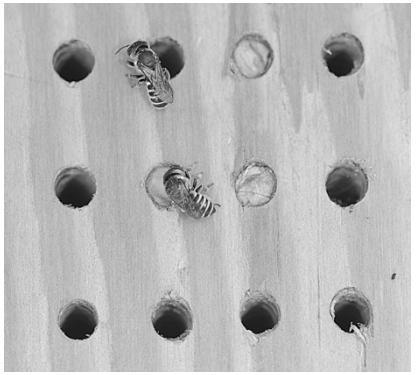
The effects of neonicotinoids on pollinators will depend on:

- route of exposure
- type
- dose
- Interactions
  - Parasites and pathogens
  - Other pesticides

Conclusions

The effects of neonicotinoids on pollinators will depend on:

- route of exposure
- type
- dose
- Interactions
- pollinator species



Conclusions

Pollinators are not likely to experience lethal effects at field-realistic levels of exposure

Sublethal effects have been demonstrated at exposure levels on the higher end of field-realistic

Conclusions

Pollinators are not likely to experience lethal effects at field-realistic levels of exposure

Sublethal effects influence

- Overwintering of honey bees
- Colony growth and reproduction
- Foraging ability
- Immune response

Thank You!