Maine Board of Pesticides Control

Miscellaneous Pesticides Articles
December 2015

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Article published Nov 25, 2015

Meeting seeks alternatives to rail herbicide

By Gina Conn

STAFF WRITER

MONTPELIER — Long-term alternatives to the use of herbicides for clearing train tracks in Montpelier of problem vegetation were the topic of discussion at a recent meeting of the Vermont Pesticide Advisory Council.

Meeting at the Department of Fish and Wildlife offices Nov. 12 at the National Life complex, the council also announced that a new herbicide alert system will be operating next summer.

The meeting came on the heels of a well-attended gathering in June at Montpelier City Hall at which residents expressed outrage that the chemical herbicide glyphosate would be sprayed on the 2-mile stretch of track that runs through the city. The June meeting was organized by Mayor John Hollar.

Vermont Rail System, which did the spraying, says weeds can get stuck in the wheels of rail cars. The herbicide spraying has been done annually since 1999 with the exception of last year.

In July a compromise was reached with the city agreeing to pay for the rental of weed whackers and their use to clear a portion of the tracks in the heavily populated area between Main Street and Granite Street. The remainder of the 2-mile stretch was sprayed with the herbicide.

"It didn't cost very much," said City Manager William Fraser in an interview Tuesday, estimating the rental and labor bill was around $3,000. To City Councilor Anne Watson, that was a price well worth paying.

"That was shockingly low," Watson said Tuesday about the cost. "That's pretty reasonable, and if it helps ease people's minds about it then it feels like money well spent to me."

Watson added, however, that there could be other options for the future, including cost sharing with the railroad.

According to Watson, weed whacking has been good for now but won't be sustainable for the long run.

"The weed whacking doesn't necessarily get up the roots," she said.

That's where the discussion of longer-term solutions picked up this month at the Vermont Pesticide Advisory Council meeting. Options discussed included applying vinegar and salt grind to the railway vegetation, having goats graze the area, and exploring safer chemicals to do the job.

"The city would like to find an arrangement where we will not have to pay anything," said Watson, who attended the meeting. In the short term, she added, "I think we would consider paying again if there was a plan where we can get off of that."

Gary Giguere, agrichemical management section chief for the state Agency of Agriculture, Food and Markets, was also present to hear the discussion and suggestions from the public. He said he is still open to hearing more suggestions for alternatives.

"I'll take any idea anyone has at any time, until it's final," he said. "There's not a specific time period ... where we are closed to ideas."

He said the pesticide council will be getting information from both the city and the general public and will at some point make a recommendation.

"Ultimately because these meetings started at the request of the mayor, we'll go back to him with a final plan," Giguere said.

The pesticide council plans to schedule another meeting to continue the discussion.

With Watson noting that the railroad is required to notify the public when any herbicide spraying is planned, the council also announced that the Vermont Emergency Alert System will soon include herbicide spraying alerts, much as it transmits weather advisories and Amber Alerts. Residents will be able to sign up at vtalert.gov to receive notifications on planned sprayings.

The herbicide alert system is being developed now, according to Giguere, and will be in place for next year's spraying season.

"You'll be able to sign up to be alerted when the (herbicide spraying) permits get activated," he said.

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ISIS Report 02/12/15

Declaration of Physicians in Crop-sprayed Towns in Argentina at 3rd National Congress

Faculty of Medicine, University of Buenos Aires, Buenos Aires, 17 October 2015

Original Publication: http://www.reduas.com.ar/declaration-of-the-3rd-national-congress-of-physicians-in-the-crop-sprayed-towns/#more-1541

Sign the Independent Scientists Manifesto on Glyphosate here:
http://www.i-sis.org.uk/Independent_Scientists_Manifesto_on_Glyphosate.php

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Five years after the first meeting at the Faculty of Medical Sciences of Córdoba, we - scientists, doctors and members of health teams from sprayed villages of Argentina -gathered in the Aula Magna of the Faculty of Medicine of the University of Buenos Aires (UBA), to verify that what we said then is emphatically true and getting worse by the day. The current system of agricultural production in the country pollutes the environment and our food, sickening and killing human populations in agricultural areas.

In the last 25 years, the consumption of pesticides increased by 983 % (from 38 to 370 million kilos), while the cultivated area increased by 50 % (from 20 million ha to 30 million ha). A production system based on the systematic application of agricultural poisons means, inevitably, that nature responds by adapting, forcing farmers to apply greater quantities of pesticides in the field to achieve the same objectives. Over the years a system has been created by and for sellers of pesticides, who every year increase their net sales (in 2015 the increase was 9%) while our patients, too, year after year are being exposed to this pesticide pollution more and more.

There is no doubt that the massive and growing exposure to pesticides changed the disease profile of Argentina's rural populations and that cancer is the leading cause of death among them (and the worst way to die).

Research presented at the congress show studies at different scales, which highlight a consistent pattern of toxicity. From small towns to larger populations at the provincial level (as in Chaco and Córdoba) or national level, different levels of exposure to glyphosate or

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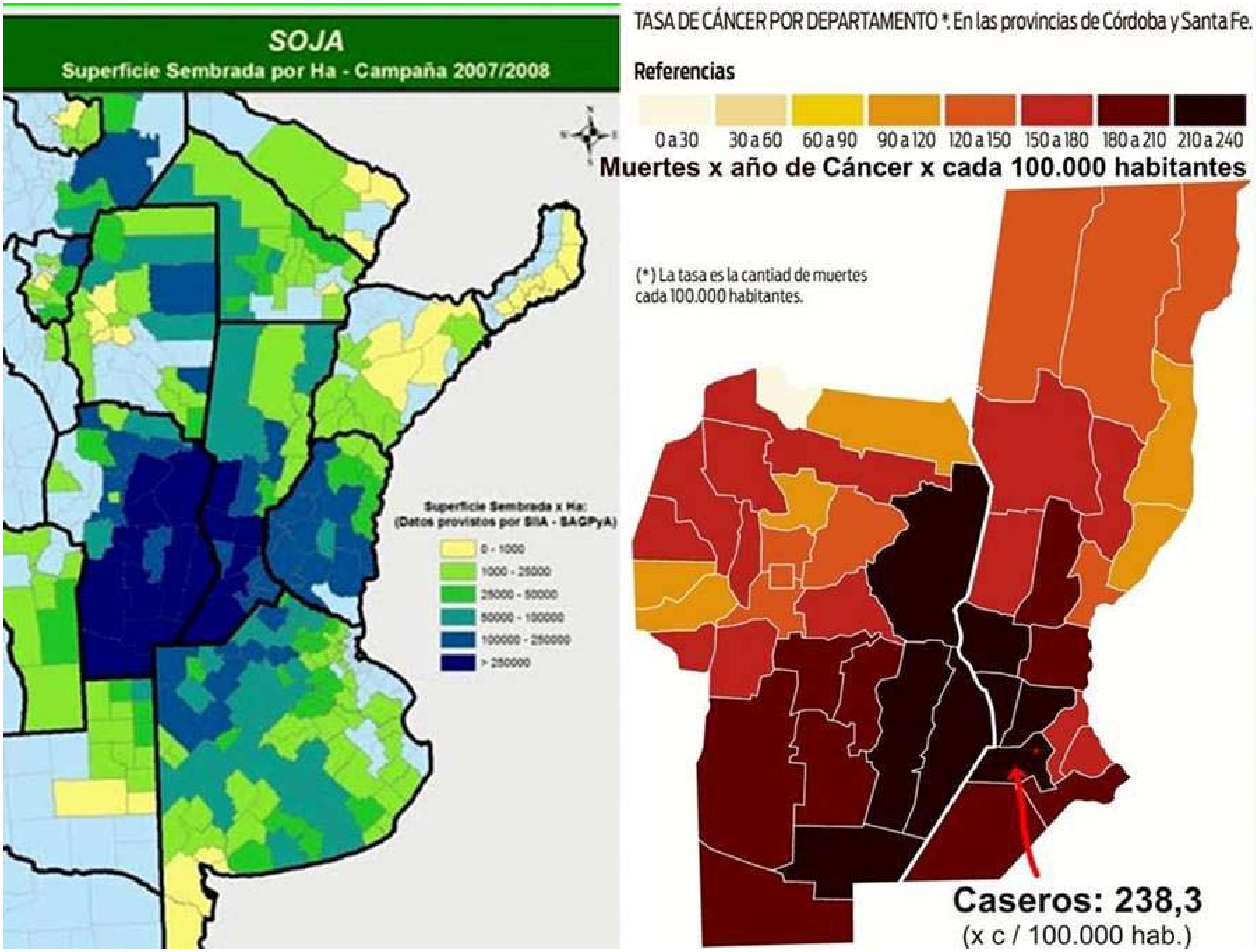
agricultural poisons in general are compared, showing that reproductive health is affected by increases in spontaneous abortions and birth defects. Also increased are endocrine disorders such as hypothyroidism, neurological disorders or cognitive development problems and soaring of cancer rates - a tripling of incidence, prevalence and mortality - which are directly related to pesticide exposure. In parallel, data from studies in experimental models show that the genotoxicity of glyphosate and other pesticides is an underlying biological mechanism that explains its relationship with disease that doctors have found in our patients. Furthermore, genotoxicity has been verified in agricultural populations (adults and children) exposed to pesticides, while being absent in populations that are not fumigated.



Distribution of soya planted left and distribution of cancer mortality in Cordoba and Santa Fe, according Minagria and provincial Ministry of

Health

During 2015, the International Agency for Research on Cancer (IARC WHO) recognized the human carcinogenicity of several pesticides, including glyphosate. This is the most widely used pesticide in the world and Argentina consumed 240 million kilos in the last year generating a potential average exposure of 6 kilos per person per year, the highest in the world. Glyphosate is bought and stored anywhere and is applied without any restriction over schools, neighbourhoods, streets and villages, subjecting people to indiscriminate and unnecessary exposure.

Environmental pollution with toxic chemicals and even carcinogens in food we bring to cities is increasing. For example, it was found that one serving of a common salad contains about 600 μg of agrochemicals; and now we know that even cotton swabs, gauze, panty liners and tampons marketed in our country contain glyphosate. There are no maximum residue limits for chemicals that are safe when they cause cancer, its absolute absence should be guaranteed.

The system of producing food in our society (field crops with poisons and industrial manufacturing) results in the destruction of native forests, land desertification, depletion and pollution of soil, water from streams and rivers, expulsion and eviction of indigenous populations, peasants and family farmers, exacerbates climate change and sprays hundreds of schools with children inside. It is strongly promulgated in the production and consumption of highly processed food including salt, sugar, fats and compounds such as soy lecithin, corn syrup, high fructose, dyes, flavourings and others that today international agencies state as responsible for chronic, non-communicable diseases as obesity, diabetes and Alzheimer's disease. These fill the supermarkets, offered in an eye-catching way geared especially to vulnerable populations and especially children, in violation of food safety.

All these elements in the field of public health are a warning to the toxic nature of agriculture in general and GM agriculture in particular, they have grown in our country as a result of the immense influence of large multinational pesticide companies like Monsanto, Bayer Syngenta, Down, Dupont, etc., who are just looking to increase their sales regardless of the damage to environmental and public health from this system.

Our diagnosis of socio-environmental health is complemented by crucial immediate and long-term action. We demand the authorities of the national and provincial state recognize the requests made in previous Congresses and in the "Yes to Life No to Glyphosate Campaign" of the Federation of Health Professionals and the Andres Carrasco Collective.

To defend the human right to life, a healthy life and a healthy environment we demand:

1. Comprehensive ban on aerial spraying in the country with any kind of agrochemicals. The levels of pollution generated is unacceptable for the environment and human health.

2. Prohibition of all pesticides IARC-WHO recognized as human carcinogens grades 1, 2A and 2B, especially glyphosate. There is no need to justify the risk of generating cancer in people exposed environmentally or through contaminated food.

3. While the near total ban on glyphosate term is reached, it is urgent to get a reclassification to red tag (currently green label) and immediately prevent its free commercialization and application in and near populated areas and schools.

4. Prohibition of all "highly hazardous pesticides," according to WHO and FAO, many are already banned in their countries of origin but are marketed in ours.

5. Ban on any spraying around 1 000 meters from villages and schools, the presence and movement of machines to spray (mosquitoes) in urban areas and the existence of deposits of pesticides within towns and neighbourhoods of cities.

6. Generating public policies that discourage the use of poisons in farming and food production, recognizing the toxic nature thereof. It is necessary to question the current model of agroindustrial and transgenic production, and instead look for systems that allow for social and cultural integration and defence and reproduction of ecological conditions of our environment. It is possible through state action to decrease the levels pesticide use in our country as demonstrated by experiences in other countries, to promote agro-ecology, local food consumption and defence of food security.

Government officials over the years have continued trying to hide the "side effects" of the agricultural production model, demonstrating its complicity and alignment with the interests of ethically questionable multinational companies. This situation led us to require the Inter-American Commission on Human Rights of the Organisation of American States in the request for an injunction to protect the right to health and life of the population environmentally exposed to pesticides, especially their children.

This is not only an Argentine problem, identical situations exist in other countries with similar results in Brazil, Uruguay, Central America, Paraguay, etc. Everywhere there is growing resistance to toxic agriculture and honest doctors and scientists support these struggles with their diagnoses and providing technical studies.

Struggles that seek to prioritize values such as health and the environment over economic and commercial interests of large biotech companies and sowing pools [a type of speculative investment fund for large-scale production of cereals in Argentina] in defence of human rights violated by heavily extractive productivist policies that destroy the environment into a collective health crisis.

UBA:
Universidad
de Buenos Aires

Dr. Medardo Avila-Vazquez , Lic. Miryam Gorban; Presidents of National Congress Of Physicians of Crop -Sprayed Towns; Prof. Sergio Provenzano, Dean of Faculty of Medicine UBA

Translated by Dr Eva Sirinathsinghji

There are 3 comments on this article so far. Add your comment

Helene Wilkie Comment left 3rd December 2015 08:08:38
I would hope that those readers who may have been unsympathetic toward Hugo Chavez, for one reason or another, could now appreciate why he was totally against the importation and use of GMOs and their necessary chemicals. He was not to be fooled. Hats off to him.

dhinds Comment left 3rd December 2015 08:08:25
If Monsanto et. al is allowed to achieve their goals, the quality of life on this planet will plummet to unendurable levels and the legacy of homo sapiens will be the destruction of the biosphere and it's life support systems. Their goals can be achieved only if they are able to continue subverting governments and successfully manipulating public policy creation. This means that the current crop of corrupt politicians mas be defeated and environmentally and socially responsible legislators must take their place. This is what each and everyone of us must do in order to change the course of history, preserve the Earth for beneficial organisms and assure that life is worth living.

Rory Short Comment left 3rd December 2015 11:11:57
When a society lets profits have priority over everything else then that society inevitably self-destructs.

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From: cleanearth@tds.net [mailto:cleanearth@tds.net]
Sent: Thursday, December 03, 2015 1:49 PM
To: Jennings, Henry
Subject: homedepot-neonics

Henry – Please print this out for the Board, including my words here. Thank you.

The Board ought to ban neonicotinoids right now......it's clearly immoral not to do so. Should have done this years ago; other countries have done so.

The Board needs to, each and every one, take PERSONAL RESPONSIBILITY for their decisions to allow the poisoning of Maine's land, waters, and all life forms. It's all about money combined with a studied indifference to the harm they've wrought and continue to wreak on Maine's flora and fauna.

The Board needs to be replaced with non-users of pesticides, regular Maine people who care about our health and the health of Maine's woods, waters, wildlife, fisheries, humans, and all other life forms.
- Nancy Oden

Friends of the Earth

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Home Depot to phase out bee-killing pesticides

Posted Dec. 3, 2015 / Posted by: Brian Salamanca

Coalition presses for all retailers to make commitment to protect bees

WASHINGTON, D.C. — Home Depot (NYSE: HD), the world's largest home-improvement chain, has announced (http://www.ecooptions.homedepot.com/healthy-home/organic-gardening/) that it has removed neonicotinoid pesticides, a leading driver of global bee declines, from 80 percent of its flowering plants and that it will complete its phase-out in plants by 2018. This announcement follows an ongoing campaign and letter (http://webiva-downton.s3.amazonaws.com/877/89/8/6922/Home_Depot_follow-up_letter_Nov_2015_final.pdf) by Friends of the Earth and allies urging Home Depot to stop selling plants treated with neonicotinoids and remove neonic pesticides from store shelves.

"Home Depot's progress in removing neonics shows it is listening to consumer concerns and to the growing body of science telling us we need to move away from bee-toxic pesticides," said **Lisa Archer, Food and Technology program director** at Friends of the Earth U.S. (http://www.foe.org/about-us) "However, we know that Home Depot and other retailers can do even more to address the bee crisis. Along with allies, we will continue to challenge retailers to engage in a race to the top to move bee-toxic pesticides off their shelves and out of garden plants as soon as possible. Bees are the canary in the coal mine for our food system and everyone, including the business community, must act quickly to protect them."

A study released by Friends of the Earth and Pesticide Research Institute, Gardeners Beware 2014 (http://www.foe.org/news/news-releases/2014-06-new-tests-find-bee-killing-pesticides-in-51-percent-of-bee-friendly-plants), showed that 51 percent of garden plants purchased at **Lowe's (NYSE: LOW), Home Depot (NYSE: HD) and Walmart (NYSE: WMT)** in 18 cities in the United States and Canada contained neonicotinoid pesticides at levels that could harm or even kill bees. Following the release of this report, Home Depot announced it would require its suppliers to label all plants treated with neonicotinoid pesticides, which have been shown to harm and kill bees, by the fourth quarter of 2014. It also committed to "find alternative insecticides for protecting live goods and bees."

Friends of the Earth and allies have called on (http://webiva-downton.s3.amazonaws.com/877/89/8/6922/Home_Depot_follow-up_letter_Nov_2015_final.pdf) Home Depot to strengthen its existing commitments to protecting bees and other pollinators and nursery workers by immediately disclosing the progress it has made to date in phasing out neonicotinoid pesticides in all of its plants and off-the-shelf products. The coalition also called on the retailer to make a public commitment to complete its phase-out of neonicotinoids in all plants and off-the-shelf products, while transitioning to least-toxic alternatives that are benign to human health and the environment, by December 2016.

"Home Depot's public commitment will better position the company to meet the demands of an increasingly environmentally-conscious consumer base. And, it sends an important market signal that restricting the use of bee-harming pesticides is essential to stemming chronic bee declines," said **Susan Baker, Vice President of** Trillium Asset Management (http://www.trilliuminvest.com/). Trillium and partners in the Investor Environmental Health Network (http://www.iehn.org/home.php), Domini Social Investments (http://www.domini.com/why-domini/about-domini) and the Sustainability Group of

Loring, Wolcott and Coolidge (http://www.sustainabilitygroup.com/), have been in active dialogue with management on this issue.

"Home Depot's progress in removing neonicotinoids from the majority of its flowering plants shows how fast a corporation can move when it needs to respond to consumer pressure and science," **said Beatrice Olivastri, CEO**, Friends of the Earth Canada (http://foecanada.org/en/about/). "We expect all garden retailers, big and small, to be specifying right now to their suppliers to stop use of neonics for 2016 flowering plants."

"We welcome Home Depot's announcement that it has removed 80% of bee-killing pesticides from its plants. Together, over 750,000 SumOfUs members told Home Depot to stand up for the bees, and together we will be watching closely to make sure that Home Depot phases out these bee-killing pesticides as quickly as possible," **said Angus Wong, campaigner,** SumOfUs (http://sumofus.org/).

"It's important that retailers like Home Depot begin to make the switch towards safer products for bees, butterflies, and other beneficial insects. By phasing out neonicotinoid products, Home Depot is helping consumers break away from a dependency on the use of toxic pesticides in their homes and gardens," **said Jay Feldman, executive director,** Beyond Pesticides (http://www.beyondpesticides.org/).

In the past year, more than thirty nurseries (http://www.foe.org/beeaction/retailers), landscaping companies and retailers have taken steps to eliminate bee-killing pesticides from their stores. A growing body of scientific evidence has continued to mount that neonicotinoids are a major contributor to both wild bee and honey bee declines and that they are contaminating the environment (http://toxics.usgs.gov/highlights/2015-08-18-national_neonics.html), harming a variety of other organisms (http://www.tfsp.info/worldwide-integrated-assessment/) essential to healthy ecosystems and sustainable food production.

"Even though Home Depot has taken these steps in the right direction, it's important for gardeners to be aware that many plants in stores today still contain neonicotinoids. We look forward to the day when we can all buy home garden plants without worrying about harming pollinators. In the meantime, gardeners should choose organic and neonic-free starts, seeds and soil," said **Katherine Paul, associate director,** Organic Consumers Association (https://www.organicconsumers.org/about-oca).

"It's time for other retailers, such as Ace and True Value, to take a stand against toxic, bee-killing neonicotinoids by making a full-fledged, public commitment to eliminate bee-killing pesticides from store shelves," said **Laurel Hopwood**, Sierra Club's (http://www.sierraclub.org/about?gclid=CJ7t8fy5u8kCFZBcfgodCQwOMw) **pollinator protection program coordinator.**

Earlier in 2015, Friends of the Earth and Pesticide Research Institute surveyed nurseries and released the report Growing Bee Friendly Garden Plants: Profiles in Innovation (http://www.foe.org/news/archives/2015-05-new-report-highlights-strategies-to-move-garden-industry-in-bee-safe-direction), to find out how growers and retail stores were working to meet consumer demand for neonicotinoid-free plants.

"The survey showed that many growers are stepping up to the plate to ensure that their plants are safe for pollinators," said **Dr. Susan Kegley, principal scientist at** Pesticide Research Institute (https://www.pesticideresearch.com/site/?page_id=504). "These growers are using innovative approaches to control pests such as application of beneficial insects or fungi that eat or disable pest insects, as well as tried and true common-sense pest prevention methods like proper sanitation, frequent monitoring for pests, and selection of pest-resistant plants. Their success shows that harmful systemic insecticides are not necessary to grow bee-friendly plants."

Greenhouse Grower magazine surveyed the one hundred largest greenhouse growers in the industry, and found 31 percent of the growers surveyed are not using neonicotinoids at all, and 38 percent have eliminated neonicotinoid use for some of their plant products.

Last April, the EPA placed a moratorium on new and expanded uses of neonicotinoids. In September, the 9th Circuit Court suspended the EPA's approval of sulfoxaflor, a neonicotinoid.

In November, the U.S. Geological Survey released a reconnaissance study demonstrating native bees collected in an agricultural landscape are exposed to multiple pesticides and of the bees tested, 70 percent contained pesticides, including neonicotinoids.

***Organizations partnering with Friends of the Earth U.S. in the** campaign (http://www.foe.org/projects/food-and-technology/beeaction) **to urge garden retailers including Home Depot to phase out the use and sale of neonicotinoids include:** American Bird Conservancy, Atlanta Audubon Society, Beyond Pesticides, Beyond Toxics, Center for Biological Diversity, Center for Environmental Health, Center for Food Safety, CREDO Action, Ecology Center, Endangered Species Coalition, Environment New York, Environment Texas, Environmental Youth Council, Farmworker Association of Florida, Friends of the Earth Canada, Georgia Organics, GMO Inside, Green America, Maine Organic Farmers and Gardeners Association, Maryland Pesticide Network, Mercola.com, Natural Resources Defense Council, Northwest Center for Alternatives to Pesticides, Olympia Beekeepers Association, Organic Consumers Association, Pesticide Action Network North America, Planet Rehab, Save our Environment, Sierra Club, Smart on Pesticides Maryland, SumOfUs, Toxics Action Center, Toxic Free North Carolina, Turner Environmental Law Clinic and The Xerces Society for Invertebrate Conservation.

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LETTER

doi:10.1038/nature16167

Neonicotinoid pesticide exposure impairs crop pollination services provided by bumblebees

Dara A. Stanley[1], Michael P. D. Garratt[2], Jennifer B. Wickens[2], Victoria J. Wickens[2], Simon G. Potts[2] & Nigel E. Raine[1,3]

Recent concern over global pollinator declines has led to considerable research on the effects of pesticides on bees[1–5]. Although pesticides are typically not encountered at lethal levels in the field, there is growing evidence indicating that exposure to field-realistic levels can have sublethal effects on bees, affecting their foraging behaviour[1,6,7], homing ability[8,9] and reproductive success[2,5]. Bees are essential for the pollination of a wide variety of crops and the majority of wild flowering plants[10–12], but until now research on pesticide effects has been limited to direct effects on bees themselves and not on the pollination services they provide. Here we show the first evidence to our knowledge that pesticide exposure can reduce the pollination services bumblebees deliver to apples, a crop of global economic importance. Bumblebee colonies exposed to a neonicotinoid pesticide provided lower visitation rates to apple trees and collected pollen less often. Most importantly, these pesticide-exposed colonies produced apples containing fewer seeds, demonstrating a reduced delivery of pollination services. Our results also indicate that reduced pollination service delivery is not due to pesticide-induced changes in individual bee behaviour, but most likely due to effects at the colony level. These findings show that pesticide exposure can impair the ability of bees to provide pollination services, with important implications for both the sustained delivery of stable crop yields and the functioning of natural ecosystems.

Biotic pollination is required by a large proportion of crops worldwide[10], disproportionately including those with economically high values and nutritional content[13]. The contribution of pollination services to global agriculture has been steadily increasing and was estimated at US$361 billion in 2009 (ref. 14). In addition, animal-vectored pollination is required by an estimated 87.5% of all angiosperms to reproduce[11], making this process fundamental to the functioning of natural ecosystems. Therefore, any threats to the delivery of pollination services could have serious consequences for both food security and wider ecosystem function. Neonicotinoid pesticides, the most widely used group of insecticides worldwide[15], are implicated as one of the contributing factors in the global declines of bee pollinators[3,16]. Although previous work has shown that bumblebee foraging activity, colony growth and reproduction can be altered by sublethal exposure to neonicotinoid pesticides[1,2,5–7], all research on pesticide effects has focused on bees as the service providers, but has not assessed the pollination service itself. Therefore it is unknown whether pesticide exposure actually results in changes to the delivery of pollination services to crops and wild plants (for a discussion of potential mechanisms see ref. 17). This information is essential to assess the severity of pesticide effects on ecosystem services, and to inform actions to mitigate negative effects.

Apples are an important global crop, with 75 million tonnes harvested from 95 countries in 2012 and an estimated export value of US$71 billion (Food and Agriculture Organisation statistics, http://faostat3.fao.org). Apple crops benefit from insect pollination with seed number, fruit set, fruit size and shape all improved with increased pollination services[18]. Bumblebees are major pollinators of apples[19] and many other crops across the world[12], and are exposed to low levels of pesticides when foraging in agricultural areas. Here we investigated how exposure to low, field-realistic levels of a widely used neonicotinoid insecticide (thiamethoxam) could affect the ability of bumblebees to pollinate apple trees. We pre-exposed colonies to 2.4 parts per billion (ppb) thiamethoxam, 10 ppb thiamethoxam or control solutions (containing no pesticide; rationale for selecting pesticide concentrations and relevance of results are outlined in Methods and Supplementary Information) in their nectar source (artificial sugar water) for a period of 13 days (8 colonies per treatment, that is, 24 colonies in total). Subsequently, colonies were brought to the field and allowed access to virgin apple trees of a dessert (Scrumptious) variety, along with trees of a polliniser (Everest) variety, in pollinator exclusion cages in which we observed both individual- and colony-level behaviour. At the end of the season, apples from tested trees were collected to assess pollination service delivery in terms of fruit and seed set.

When whole colonies were given access to apple trees we found an effect of insecticide treatment on visitation rates to apple flowers ($F_{2,86} = 3.1$, $P = 0.05$); colonies exposed to 10 ppb pesticide provided lower visitation rates to apple flowers than controls (Fig. 1a; Extended Data Table 1). We also found an effect of treatment on the number of foraging trips from which bees returned carrying pollen ($\chi^2 = 9.65$, degrees of freedom (df) = 2, $P = 0.008$), with fewer bees from colonies exposed to 10 ppb pesticide returning with pollen than workers from control colonies (Fig. 1b). Apple abortion rate was affected by treatment ($\chi^2 = 5.94$, df = 2, $P = 0.05$), with trees pollinated by

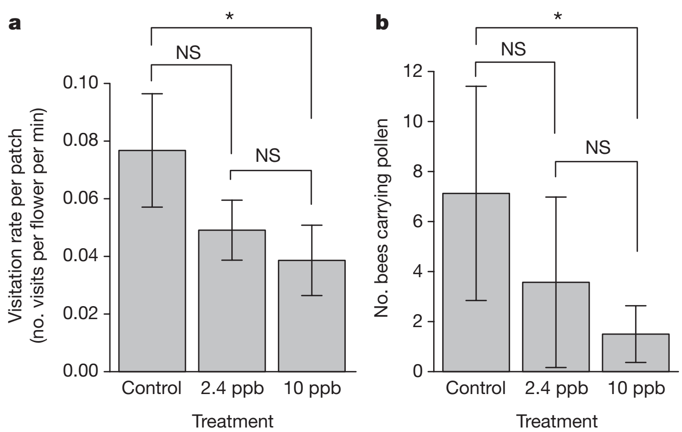

Figure 1 | Effects of pesticide treatment on colony-level behaviour. **a**, **b**, Visitation rates provided by colonies to Scrumptious apple flowers (number of visits per flower per minute) (**a**) and number of foraging trips from which bees returned carrying pollen (**b**), from colonies exposed to different pesticide treatments. Eight colonies were observed per treatment group, and means ± s.e.m. are shown, $*P < 0.05$. NS, not significant. Results from statistical models are given in Extended Data Table 1.

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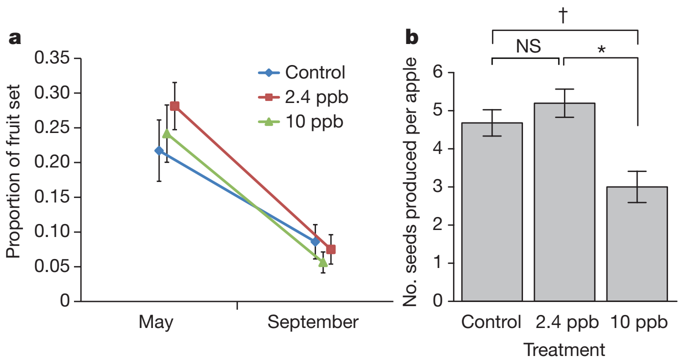

Figure 2 | Effects of pesticide treatment on fruit and seed set. **a**, **b**, The change in proportion of fruit set for trees (48 trees in total, 16 per treatment) pollinated by colonies exposed to different pesticide treatments measured early (May) and late (September), which represents fruit abortion level (**a**), and number of seeds produced per apple (134 apples in total; 53 in control, 46 in 2.4 ppb and 35 in 10 ppb pesticide treatments) pollinated by colonies exposed to different pesticide treatments (**b**). Eight colonies were observed per treatment group, and means ± s.e.m. are shown, $*P < 0.05$, † indicates a difference of $P = 0.06$ between control and 10 ppb. NS, not significant. Results from statistical models are given in Extended Data Table 1.

2.4 ppb pesticide-exposed colonies aborting more fruit than controls (Fig. 2a), although overall levels of fruit set did not differ ($\chi^2 = 4.1$, df = 2, $P = 0.13$) and there was no difference in the proportion of trees that produced fruit among treatments ($\chi^2 = 1.2$, df = 2, $P = 0.55$). However, we found a significant effect of treatment on the number of seeds produced per apple, an indicator of fruit quality, ($\chi^2 = 8.27$, df = 2, $P = 0.02$); flowers pollinated by colonies exposed to 10 ppb pesticide produced significantly fewer seeds than those pollinated by 2.4 ppb colonies (Fig. 2b). These results show that colonies exposed to pesticide can deliver reduced pollination services to apple crops.

These colony-level effects could be explained by several mechanisms, including individual behavioural changes. Individual bees exposed to 10 ppb pesticide spent longer foraging ($F_{2,57} = 3.72$, $P = 0.03$; Fig. 3a), visited more Scrumptious flowers ($\chi^2 = 12.79$, df = 2, $P = 0.002$) and switched more frequently between varieties during each trip ($\chi^2 = 11.32$, df = 2, $P = 0.003$: Fig. 3b; Extended Data Table 2), which suggests a modification of their floral preferences[7]. Neonicotinoids target neurotransmitter receptors in insects and, as well as causing neuronal inactivation[20], some have been shown to be

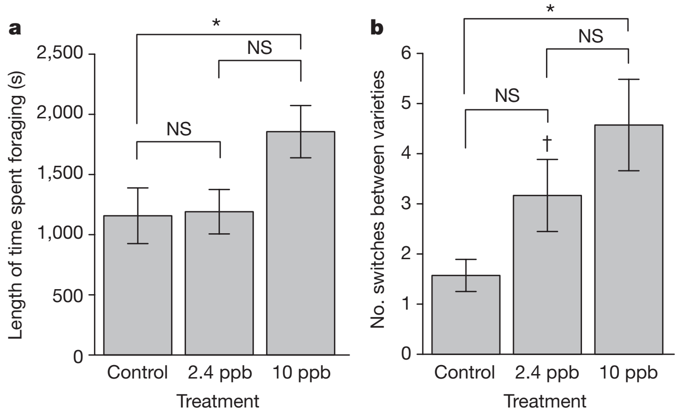

Figure 3 | Effects of pesticide treatment on individual bee behaviour. **a**, **b**, Time spent foraging per foraging trip (seconds; $n = 68$ bees) (**a**) and number of switches between Scrumptious and Everest apple varieties ($n = 93$ bees) (**b**) for individual bees exposed to different pesticide treatments. Means ± s.e.m. are shown, $*P < 0.05$, † indicates a difference of $P = 0.06$ between control and 2.4 ppb. NS, not significant. Results from statistical models are given in Extended Data Table 2.

partial neuronal agonists[21]; therefore increases in individual foraging activity may be explained by acute increases in neuronal activity causing hormesis (a biphasic response in which low levels of an otherwise toxic compound can result in stimulation of a biological process[22]). However, we found no effect of treatment on whether flowers visited by these individual bees produced apples ($\chi^2 = 0.88$, df = 2, $P = 0.64$), showed higher rates of fruit abortion ($\chi^2 = 0.42$, df = 2, $P = 0.81$) or different levels of seed set ($\chi^2 = 0.11$, df = 2, $P = 0.95$). This suggests that bees exposed to pesticide must somehow be behaving differently on flowers, in a way that was not readily observable in our experiment (for example, changes in stigmatic contact[23]), such that increased visit frequency did not result in better pollination service delivery at the individual level.

Our results suggest that effects on pollination service delivery are not due to individual behavioural modification, but instead are most likely due to changes in colony activity levels as evidenced by reduced floral visitation rates and pollen collection. Bees collecting pollen may be more effective pollinators as they can deposit more pollen on plant stigmas[24]; therefore if pesticide-exposed colonies are collecting less pollen they are also likely to be depositing less on stigmas than bees from control colonies. While individual bees exposed to pesticides visited more flowers, overall pesticide-exposed colonies provided lower visitation rates and collected less pollen, thus explaining why reduced pollination services were delivered. Gill & Raine[7] found that control (untreated) bees improved their pollen foraging performance over time, whereas imidacloprid-treated bees became less successful foragers; foragers in our colony-level experiment may have carried out multiple trips and become more experienced foragers, potentially explaining why we find effects on pollen collection here but not in the individual-level experiment. Interestingly, for almost all parameters measured in this study we found significant effects on both individual behaviour and colony-level function following 10 ppb thiamethoxam exposure, but not at the 2.4 ppb level. This suggests that there are dose-dependent effects that lie between these two exposure levels. Both these exposure levels are highly relevant as they are within the range measured in the field, but further work is necessary to elucidate the lowest level at which these effects become significant (for further discussion of rationale for exposure and relevance of results, see Methods and Supplementary Information).

A 36% reduction in the number of seeds produced in apples pollinated by colonies exposed to 10 ppb pesticide in comparison to control colonies has important agronomic implications for crop production. The number of seeds in apples is closely linked to fruit crop quality in most, but not all, varieties[18,25] and the enhancement of fruit quality, particularly the proportion of Class 1 fruit, underpins the economic value of UK orchards[26]: growers must typically thin out their apple crops making the quality of each fruit very important. Therefore impacts on seed set and fruit quality have direct implications for apple production value, and as seed set and fruit set are positively linked in many varieties, reduced seed set can have direct negative implications for fruit set and total crop yield[26,27]. As certain apple varieties in the UK currently experience pollination deficits[19,26], mitigating the effects of pesticides on bumblebee pollinators could improve pollination service delivery. Apple crops are visited by a wide variety of pollinator groups, and neonicotinoid pesticides differentially affect insect taxa[4,28]. Apart from bumblebees, one of the other main pollinator groups that visit apple flowers are solitary bees[19], and it has been suggested that pesticide sensitivity of solitary bees is likely to be higher than for larger, social species like bumblebees[4,5,17,29]. Therefore, apple pollination in a field setting could be more vulnerable to pesticide exposure than measured here.

Bumblebees are essential pollinators of many important crops other than apples, including field beans, berries, tomatoes and oilseed rape[12,26]. If exposure to pesticides alters pollination services to apple crops, it is likely that these other bee-pollinated crops would also be affected. Most importantly, the majority of wild plant species benefit from insect pollination services[11]. Therefore reduced pollination by pesticide-affected colonies, as evidenced by reduced seed set, also has significant implications for pollination in wild systems. Many wild plant species are both self-incompatible and pollen limited[30], so any reduction in the delivery of pollination services could have substantial effects on wild plant communities and therefore wider ecosystem function.

Concerns over global bee declines are strongly driven by the need for the essential pollination services they provide to both crops and wild plants. The use of neonicotinoid pesticides presents a potential threat to bee health and, although the evidence base reporting sublethal (behavioural) effects of pesticides on bees is mounting[3], we have shown for the first time that there is also an important effect of pesticide exposure on the pollination services bees provide. This information provides a new perspective when trying to fully understand the trade-offs involved when using insecticides, showing that both the potential benefits and the true costs of pest control options need to be considered.

Online Content Methods, along with any additional Extended Data display items and Source Data, are available in the online version of the paper; references unique to these sections appear only in the online paper.

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Supplementary Information is available in the online version of the paper.

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Author Contributions D.A.S. and N.E.R. conceived the project, D.A.S., N.E.R. and M.P.D.G. designed the research, D.A.S., J.B.W and V.J.W. carried out the research, D.A.S., N.E.R., M.P.D.G. and S.G.P. contributed equipment for the research, D.A.S. analysed the data, all authors were involved in writing the manuscript.

Author Information Reprints and permissions information is available at www.nature.com/reprints. The authors declare no competing financial interests. Readers are welcome to comment on the online version of the paper. Correspondence and requests for materials should be addressed to D.A.S. (darastanley@gmail.com) or N.E.R. (nraine@uoguelph.ca).

METHODS

Pesticide preparation. A stock pesticide solution was made by dissolving 100 mg thiamethoxam (PESTANAL, Analytical Standard, Sigma Aldrich) in 100 ml acetone ($1\,mg\,ml^{-1}$). Aliquots of stock solution were added to 40% sucrose to create treatment solutions of $10\,\mu g\,l^{-1}$ (10 ppb) and $2.4\,\mu g\,l^{-1}$ (2.4 ppb) thiamethoxam. These concentrations were chosen as field-realistic; the lower concentration (2.4 ppb) was based on thiamethoxam concentrations found in nectar pots of bumblebee colonies foraging in agricultural areas in the UK[31] and in pollen collected by honeybees[32], and the higher concentration (10 ppb) is within the range measured in pollen and nectar and of a variety of treated crops[33–35] and contaminated wild flowers[35–37], and has been used in previous studies examining effects of another neonicotinoid (imidacloprid) on bumblebee behaviour[1,7]. A control solution was also made by repeating the process outlined above but using an aliquot of 10 ppb acetone only (that is, no pesticide).

Experimental setup. Twenty-four commercially reared *Bombus terrestris audax* colonies were obtained from Biobest (Westerlo, Belgium) at the start of April 2014, each containing a queen and an average of 99 workers (range 57–133). Colonies were weighed on arrival to estimate the overall colony size, and each assigned sequentially to one of three treatment groups (2.4 ppb thiamethoxam, 10 ppb thiamethoxam and control) based on decreasing mass (but randomly assigned within block). Each day, three colonies (one from each treatment) were assigned to treatment groups, until after 7 days all colonies were receiving treated sucrose (16 colonies exposed to thiamethoxam and 8 to control solution). We chose this sequential exposure regime to mimic subsequent field testing and ensure all colonies had comparable durations of exposure to their treatment. Colonies were fed treated sucrose solution from a gravity feeder inserted at the base of the nest box. Feeders were initially refilled every 2–3 days, and then every 1–2 days when the colonies had grown significantly. Untreated, defrosted honeybee-collected pollen was provided to colonies every 2–3 days. Colonies were exposed to treatments for an average of 13 days (range 12–15) before field testing. Before being moved to the field, colonies had access to a feeder containing sucrose (40%) in a laboratory flight arena for 48 h to become accustomed to leaving the nest to forage. There was no difference in colony weights at the start (ANOVA: $F_{2,21} = 0.091$, $P = 0.91$) or end (ANOVA: $F_{2,21} = 0.88$, $P = 0.43$) of the experimental period, indicating no treatment effect on colony size.

Field testing. Cage experiments were carried out at Sonning Farm, University of Reading, UK. 100 apple trees of a commercial dessert apple (Scrumptious variety) were moved into holding pollinator exclusion cages in mid-March 2014 before flowering to prevent insect visitation. Field experiments began when trees were entering full flower in mid-April. Each day, one colony from each treatment was taken from the laboratory, placed individually in one of the three test cages and observed simultaneously (with one observer per cage) in a randomized block design (see below for details of observations). Each day a different treatment was assigned to each observer. Cages were $4.8 \times 2.1 \times 2.1$ m frames covered in polyethylene mesh (gauge size = 1.33 mm, Extended Data Fig. 1). Observations were carried out on 8 dry, bright days from 16–26 April 2014 spanning the peak flowering of apples (daily means: maximum temperature 16 °C, rainfall 2.5 mm). This flowering period limited the number of days on which testing could be carried out, and therefore the number of colonies that could be tested; as a result no statistical methods were used to predetermine sample size. The investigators were not blinded to allocation during experiments and outcome assessment.

Individual-level measurements. Each morning, three cages were populated with two virgin Scrumptious trees each from the holding cages (mean ± s.e.m. = 130 ± 8.5 flowers per tree) as well as two polliniser trees (Everest variety, mean ± s.e.m. = 305 ± 15 flowers per tree, Extended Data Fig. 1). The number of flowers of each variety was standardized across cages to ensure equal floral density each day, and 40 open and receptive flowers were marked with cable ties on each Scrumptious tree for subsequent estimation of pollination services (fewer flowers were marked on the last day of observations as there were no longer 40 full-bloom flowers—flower numbers on these days were noted). The nest boxes in each cage were then opened to allow a single worker to exit. This bee was observed for the duration of its foraging trip (until it attempted to return to the nest), or until 60 min had elapsed (Extended Data Fig. 2). The duration of the foraging trip, the number of flowers of each apple variety visited, and the handling time for each flower visit was recorded using Etholog software (EthoLog: Behavioural observation transcription tool, University of Sao Paulo, Brazil, 2011). If the individual bee did not visit any flowers within the first 20 min, it was assumed not to be a forager and was captured, returned to the colony and another bee released. All bees that foraged were paint-marked before they were returned to the colony to ensure the same individuals were not observed twice. This process was repeated until all cages had the same number of active foragers recorded (3–5 bees per colony each day). Individual level observations took place between 10:00 and 16:30.

Colony-level measurements. After individual-level observations, the two focal Scrumptious trees in each cage were removed and replaced with two new virgin trees. Again we standardized the number of flowers of each variety across cages with 40 open and receptive flowers on each tree marked with cable ties. Colony boxes were opened to allow free entry and exit to all active bees for a period of 60 min. This time period was chosen to avoid over-pollination of test flowers based on pilot observations. Colony activity was monitored at the nest entrance using video cameras. After an initial 10-min period to allow the bees to become accustomed to the setup, four 10-min focal observations were carried out on separate patches of Scrumptious flowers in each cage to estimate visitation rates. At the end of the 60-min period, the Scrumptious trees were immediately removed to prevent further visitation. Colony level observations were carried out between 14:30 and 18:30.

Estimation of pollination services. At the end of both the individual and colony observation periods, all test trees were returned to holding cages in which they were not visited by any other insects until apples were harvested at the end of the season. An initial assessment of fruit set from marked flowers (indicating flowers open during cage tests) was made at the end of May for all test Scrumptious trees to assess how many flowers were proceeding to fruit set stage (and how many aborted, Fig. 2a). Marked apples were collected on 27 August, and a final assessment made of the proportion of marked flowers that had produced mature fruit (Extended Data Fig. 2). In the lab, seed number was counted per apple for all collected fruit (274 apples from 96 trees across both experiments). Details of all data analyses carried out are given in the supplementary information.

Data analysis. *Individual level.* Measures of the number of flowers visited, numbers of switches between apple varieties, duration of total time in cage (from when the bee left the colony box until it returned/end of 60 min period) and time taken to visit the first flower (latency) were recorded for all individual bees. For 68 of 93 bees observed (evenly distributed across cages and treatments) a number of additional response variables were also recorded including mean duration of the first 5 flower visits, number of inter flower intervals longer than 60 s, mean duration of flower visits, mean period of time between flower visits, length of time spent foraging (time between first and last flower visit) and total time spent on flowers (sum of durations for all individual flower visits). We tested for differences in these measures among treatments by constructing mixed-effects models with pesticide treatment as a fixed effect. As several variables differed among days, including weather, floral abundance and the identity of colonies used, day of testing was included as a random blocking factor in all models. Data were analysed in R version 3.1.0 (ref. 38), using either linear mixed effects (LME) models with the lmer function in the nlme package for continuous data[39], generalized mixed effects (GLMM) models with Poisson distribution used for response variables that were counts using the glmer function in the lme4 package[40], or the glmmPQL function in the MASS package[41] when data were overdispersed. Models were validated by plotting standardized residuals versus fitted values, normal qq-plots and histograms of residuals, and continuous response variables were logarithmically transformed ($\log(X+1)$) if necessary to improve residual fit. If treatment was significant, Tukey's post hoc tests were performed using the glht function in the multcomp package[42].

To assess differences in apple production on trees visited by pesticide exposed and control bees, we examined a number of variables including the number of fruits produced at the start of the season (May) and at the end (September; Fig. 2a), the change in proportion of apples forming from marked flowers per tree between the start and end measures (fruit abortion levels) and number of seeds per apple (measured in early September; Fig. 2b). Models were run as described previously with treatment as a fixed effect, although the tree on which fruits were produced, the number of bees released and date of testing were included as random effects. As a number of trees produced no fruit, seed set data were analysed in two steps. First, we tested whether there was a treatment difference in the number of trees that produced any fruit. Second, we tested for treatment differences in seeds per apple (a measure that only included trees that had produced some fruit).

Colony level. We tested for differences in colony activity levels (the combined number of entries and exits by workers to the colony box) and the number of bees carrying pollen among treatments using GLMM models in the MASS package[41], with Poisson distribution for count data. Treatment differences in flower visitation rate to Scrumptious trees were tested using LME models[39]. Date of testing was used as a random effect in all models (and patch included as a random effect in the flower visitation rate model), and models were validated as described above. Fruit abortion and seed set variables were analysed as described for the individual level experiment, using tree and date of testing as random effects.

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Extended Data Figure 1 | An example of the experimental setup at the Sonning Farm field site. Experimental pollinator exclusion cages containing a bumblebee colony (located in the corner of the cage) and potted experimental apple trees are shown. Photos: D.A.S.

Extended Data Figure 2 | An experimental bumblebee (*Bombus terrestris*) worker visiting an apple flower (left), and an example of an apple produced from a marked (yellow cable tie) apple flower (right; Scrumptious variety). Photos: D.A.S. and C. L. Truslove.

Extended Data Table 1 | Results from the colony-level experiment

Colony level	Mean ± SE			Model summary			
Activity	**control**	**2.4ppb**	**10ppb**		**df**	**p**	
Total no. of entrances and exits to colony	53.9 ± 22.3	44.3 ± 12.5	25.3 ± 12	χ2=4.19	2	0.12	glmmPQL
No. of bee visits returning with pollen	7.13 ± 4.28	3.57 ± 3.41	1.5 ± 1.13	χ2=9.65	2	**0.008**	glmmPQL
Visitation rate to Scrumptious flowers (no flowers/bee/minute)	0.08 ± 0.02	0.05 ± 0.01	0.04 ± 0.01	F=3.1	2,86	**0.05**	lme
Fruit set							
Start no. of fruit	8.63 ± 1.78	11.25 ± 1.35	9.68 ± 1.65	χ2=2.67	2	0.26	glmmPQL
End no. of fruit	3.44 ± 0.99	3 ± 0.85	2.25 ± 0.60	χ2=4.1	2	0.13	glmer
Change in proportion of fruit between May & Sept (Abortion rate)	0.13 ± 0.29	0.21 ± 0.03	0.19 ± 0.03	χ2=5.94	2	**0.05**	glmmPQL
Proportion of trees producing apples	0.69	0.69	0.81	χ2=1.2	2	0.55	glmer
Seed no. per apple	4.68 ± 0.3	5.2 ± 0.4	3 ± 0.4	χ2=8.27	2	**0.02**	glmer

Significant differences ($P \leq 0.05$) are highlighted in bold.

Extended Data Table 2 | Results from the individual-level experiment

Individual level	Mean ± SE			Model summary			
Behaviour	**control**	**2.4ppb**	**10ppb**		**df**	**p**	
Latency to first flower visit (secs)	339 ± 55	289 ± 41	245 ± 49	F=2.8	2,79	0.07	lme
Mean duration of first 5 flower visits (secs)	12 ± 1.3	18 ± 2.7	16 ± 2.3	F=1.97	2,58	0.15	lme
No. interflower intervals longer than 60 secs	1.7 ± 0.5	1.4 ± 0.3	2.1 ± 0.6	F=0.59	2,57	0.55	lme
Total no. flowers visited	83 ± 15	97 ± 14	125 ± 22	χ2=4.65	2	0.1	glmmPQL
Total no. Everest flowers visited	55.4 ± 15	49.6 ± 12	71.3 ± 21	χ2=1.9	2	0.39	glmmPQL
Total no. Scrumptious flowers visited	27.6 ± 5.1	47.3 ± 5.7	53.5 ± 5.7	χ2=12.79	2	**0.002**	glmmPQL
Proportion of bees that collected pollen	0.38	0.22	0.19	χ2=2.63	2	0.27	glmer
Mean duration of flower visits (secs)	7 ± 1	8 ± 1.2	11 ± 3.5	F=0.98	2,58	0.38	lme
Mean period of time between flower visits (secs)	28 ± 10	11 ± 3.1	17 ± 5.1	F=0.76	2,58	0.47	lme
Length of time spent foraging (time of last flower visit - time of first flower visit) (secs)	1157 ± 231	1191 ± 184	1856 ± 217	F=3.72	2,57	**0.03**	lme
Total length of time spent on flowers (secs)	375 ± 55	539 ± 66	762 ± 113	F=7.35	2,57	**0.001**	lme
Duration of total time in cage (secs)	2041 ± 239	2162 ± 202	2383 ± 204	F=1.338	2,84	0.27	lme
Total no. of switches between apple varieties	1.57 ± 0.3	3.17 ± 0.7	4.57 ± 0.9	χ2=11.32	2	**0.003**	glmmPQL
Fruit set							
Start no. of fruit	8.13 ± 1.28	9.50 ± 1.94	9.69 ± 2.03	χ2=0.53	2	0.77	glmer
End no. of fruit	1.38 ± 0.52	2.06 ± 0.80	3.13 ± 1.17	χ2=3.82	2	0.15	glmer
Change in proportion of fruit between May & Sept (Abortion rate)	0.17 ± 0.03	0.19 ± 0.04	0.16 ± 0.03	χ2=0.42	2	0.81	glmer
Proportion of trees producing apples	0.44	0.5	0.56	χ2=0.88	2	0.64	glmer
Seed no. per apple	3.52 ± 0.6	3.66 ± 0.4	3.02 ± 0.4	χ2=0.11	2	0.95	glmmPQL

Significance differences ($P \leq 0.05$) are highlighted in bold.