Bees in Decline

A review of factors that put pollinators and agriculture in Europe at risk

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Executive Summary

The next time you see a bee buzzing around, remember that much of the food we eat depends significantly on natural insect-mediated pollination – the key ecosystem service that bees and other pollinators provide.

Without insect pollination, about one third of the crops we eat would have to be pollinated by other means, or they would produce significantly less food. Up to 75% of our crops would suffer some decrease in productivity. Undoubtedly, the most nutritious and interesting crops in our diet (including many key fruits and vegetables), together with some crops used as fodder in meat and dairy production, would be badly affected by a decline in insect pollinators; in particular, the production of apples, strawberries, tomatoes, and almonds would suffer.

The most recent estimate of the global economic benefit of pollination amounts to some €265bn, assessed as the value of crops dependent on natural pollination. This is not a "real" value, of course, as it hides the fact that, should natural pollination be severely compromised or end, it might prove impossible to replace – effectively making its true value infinitely high.

And how much value can we place on the abundance of colour that greets us on a bright spring day, for example? Beside crop plants, most wild plants (around 90% of them) need animal-mediated pollination to reproduce, and thus other ecosystem services and the wild habitats providing them also depend – directly or indirectly – on insect pollinators.

Bees – including the managed honeybees, together with many wild species – are the predominant and most economically important group of pollinators in most geographical regions. Managed honeybees, however, have been suffering increasingly in recent years, even as the world moves progressively towards growing more crops that are dependent on bee pollination. Similarly, the role of wild pollinators – bee species, as well as other insects – is gaining relevance worldwide, and attracting increased research attention. Moreover, wild bees are also threatened by many environmental factors, including lack of natural and semi-natural habitats, and increased exposure to man-made chemicals.

Put in simple terms, bees and other pollinators – both natural and managed – seem to be declining globally, but particularly in North America and Europe. Lack of robust regional or international programmes designed to monitor the current status and trends of pollinators means there is considerable uncertainty in the scale and extent of this decline. Nonetheless, the known losses alone are striking. In recent winters, honeybee colony mortality in Europe has averaged around 20% (with a wide range of 1.8% to 53% between countries).

Three important concerns regarding the global health of pollinators can be identified:

1. Currently, there are no accurate data available to reach firm conclusions on the status of global pollinators in terms of their abundance and diversity.

2. As demand for pollinators – both locally and regionally – increases faster than the supply, we could be facing limitation of pollination, currently and in the near future. This is because the growth in cultivation of high-value, pollination-dependent crops is outpacing growth in the global stock of managed honeybees, while wild pollinator abundance and diversity is also constrained.

3. Honeybee population abundance is very uneven among agricultural regions: there is growth in some honey-producing countries, but decline elsewhere, including regions with high agricultural production in the US, and in the UK and many other western European countries.

In some specific regions of North America, East Asia and Europe, the value of pollination can be as high as $1,500 US dollars per hectare; money that farmers – and society at large – will be losing if pollinators were to decline in those regions. Large parts of Italy and Greece have exceptionally high values attached to pollination benefits, together with extensive regions in Spain, France, the UK, Germany, the Netherlands, Switzerland and Austria, which also have high pollination value "hot spots".

Recent "warning signals" of the tensions between pollinator decline and crop yields may exist in the observed increases in prices from 1993 to 2009 for some pollination dependent crops. If we are to avoid additional limits to food production and further deforestation to increase the area of agriculture land, we must work to address the underlying factors putting stress on pollination services, focussing on the impacts on honeybees and wild pollinators.

No single factor can be blamed for the overall global decline in bee populations, or in their overall health. This decline is undoubtedly the product of multiple factors, both known and unknown, acting singly or in combination.

Nonetheless, the most important factors affecting pollinator health relate to diseases and parasites, and to wider industrial agricultural practices that affect many aspects of a bee's life cycle. Underlying all the other factors, climate change is also putting increased strains on pollinator health. Some pesticides pose direct risk to pollinators. The elimination of bee-harming chemicals from agriculture is a crucial and most-effective first step to protect the health of bee populations.

Diseases and parasites

Many beekeepers agree that the external invasive parasitic mite, *Varroa destructor*, is a serious threat to apiculture globally. Other parasites, such as *Nosema ceranae*, have been found to be highly damaging to honeybee colonies in some southern European countries. Other new viruses and pathogens are likely to put further pressure on bee colonies.

The ability of bees to resist diseases and parasites seems to be influenced by a number of factors, particularly their nutritional status and their exposure to toxic chemicals. Some pesticides, for example, seem to weaken honeybees that then become more susceptible to infection and parasitic infestation.

Industrial agriculture

Pollinators, managed or wild, cannot escape the various and massive impacts of industrial agriculture: they suffer simultaneously from the destruction of natural habitats caused by agriculture, and, because pollinators' natural ranges inevitably overlap with industrial farming landscapes, the harmful effects of intensive agricultural practices.

Fragmentation of natural and semi-natural habitats, expansion of monocultures and lack of diversity all play a role. Destructive practices that limit bee-nesting ability, and the spraying of herbicides and pesticides, make industrial agriculture one of the major threats to pollinator communities globally.

On the other hand, agriculture systems that work with biodiversity and without chemicals, such as ecological farming systems, can benefit pollinator communities, both managed and wild. By increasing habitat heterogeneity for bees, for example, ecological mixed-cropping systems can provide additional flower resources for pollinators. This emphasises the potential beneficial roles of ecological/organic agriculture methods.

Climate change

Many of the predicted consequences of climate change, such as increasing temperatures, changes in rainfall patterns and more erratic or extreme weather events, will have impacts on pollinator populations. Some of these changes could affect pollinators individually and ultimately their communities, becoming reflected in higher extinction rates of pollinator species.

Insecticides

Insecticides in particular pose the most direct risk to pollinators. As their name indicates, these are chemicals designed to kill insects, and they are widely applied in the environment, mostly around cropland areas. Although the relative role of insecticides in the global decline of pollinators remains poorly characterised, it is becoming increasingly evident that some insecticides, at concentrations applied routinely in the current chemical-intensive agriculture system, exert clear, negative effects on the health of pollinators – both individually and at the colony level.

The observed, sub-lethal, low-dose effects of insecticides on bees are various and diverse. These general effects can be categorised as follows:

1) Physiological effects, which occur at multiple levels, and have been measured in terms of developmental rate (i.e. the time required to reach adulthood), and malformation rates (i.e. in the cells inside the hive), for example.

2) Perturbation of the foraging pattern, for example through apparent effects on navigation and learning behaviour.

3) Interference with feeding behaviour, through repellent, antifeedant, or reduced olfactory capacity effects.

4) Impacts of neurotoxic pesticides on learning processes (i.e. flower and nest recognition, spatial orientation), which are very relevant and have been studied and largely identified in bee species.

These negative effects serve as a warning about unexpected impacts that bee-harming pesticides can potentially have on other pollinators, and are a reminder of the need to apply the precautionary principle to protect pollinators as a whole, both managed and in the wild. Restrictions applied only to crops attractive to honeybees might still put other pollinators at risk from the impacts of bee-harming pesticides.

Some insecticides, illustrated by the group known as neonicotinoids, are systemic, meaning that they do not stay outside when applied to a plant, but enter the plant's vascular system and travel through it. Some neonicotinoid insecticides are coated around seeds to protect them when planted. When the coated seed starts to germinate and grow, the neonicotinoid chemicals become distributed throughout the plant stems and leaves, and may eventually reach the guttation water (drops of water produced by the seedling at the tip of the young leaves), and later on the pollen and nectar. The increased use of neonicotinoids means there is a greater potential for pollinators to be exposed to these chemicals over longer periods, as systemic insecticides can be found in various places over the lifetime of a plant.

Bee-collected pollen can contain high levels of multiple pesticide residues. Pollen is the main protein source for honeybees, and it plays a crucial role in bee nutrition and colony health. The potential for multiple pesticide interactions affecting bee health seems likely, when so many different residues are present in the environment around bees. As one study has concluded: "Surviving on pollen with an average of seven different pesticides seems likely to have consequences." (Mullin et al, 2010).

Bee-harming pesticides can be shortlisted in order to focus action on the immediate potential risks to pollinator health. Based on current scientific evidence, Greenpeace has identified seven priority bee-harming insecticide chemicals that should be restricted in use and eliminated from the environment, in order to avoid exposure of bees and other wild pollinators to them. This list includes **imidacloprid, thiamethoxam, clothianidin, fipronil, chlorpyriphos, cypermethrin** and **deltamethrin.**

These seven chemicals are all widely used in Europe, and at high concentrations have been shown to acutely affect bees – mostly honeybees as the model target, but also other pollinators. Further concerns arise from the fact that impacts have also been identified as a result of chronic exposure and at sub-lethal low doses. Observed effects include impairment of foraging ability (bees getting lost when coming back to the hive after foraging, and an inability to navigate efficiently), impairment of learning ability (olfactory – smelling- memory, essential in a bee's behaviour), increased mortality, and dysfunctional development, including in larvae and queens (see Table 1 for a summary of the potential harms of the seven priority chemicals).

The science is clear and strong: the potential harm of these pesticides appears to far exceed any presumed benefits of increased agricultural productivity from their role in pest control. In fact, any perceived beneficial trade-offs are likely to prove completely illusory. The risks of some of these pesticides – the three neonicotinoids in particular – have been confirmed by the European Food Safety Authority (EFSA), while it is very widely accepted that the economic benefits of pollinators are, in parallel, very significant.

		LD_{50} ORAL (µg per bee)	LD_{50} CONTACT (µg per bee)	EU countries where it is used	In seed coatings?	Systemic chemical?	Main crops where used in Europe
	IMIDACLOPRID	0.0037	0.081	AT, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HU, IE, IT, LT, LU, MT, NL, PL, PT, RO, SE, SI, SK, UK	yes	yes	Rice, cereal, maize, potatoes, vegetables, sugar beets, fruit, cotton, sunflower and in garden areas. Systemic mode of action when used as a seed or soil treatment.
Class	Neonicotinoid						
Maker	Bayer						
Commercial names	Gaucho, Confidor, Imprimo and many others						
	THIAMETHOXAM	0.005	0.024	AT, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HU, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK, UK	yes	yes	Maize, rice, potatoes, sunflower, sugar beet, leafy and fruity vegetables, cotton, citrus, tobacco and soya beans.
Class	Neonicotinoid						
Maker	Syngenta						
Commercial names	Cruiser, Actara						
	CLOTHIANIDIN	0.00379	0.04426	AT, BE, BG, CZ, DE, DK, EE, EL, ES, FI, FR, HU, IE, IT, LT, NL, PL, PT, RO, SI, SK, UK	yes	yes	Maize, rape seed, sugar beet, sunflower, barley, cotton, soybean.
Class	Neonicotinoid						
Maker	Bayer, Sumitomo Chemical Takeda						
Commercial names	Poncho, Cheyenne, Dantop, Santana						
	FIPRONIL	0.00417		BE, BG, CY, CZ, ES, HU, NL, RO, SK	yes	moderately	Seed coating for maize, cotton, dry beans, soybeans, sorghum, sunflower, canola, rice and wheat. Non-crop use to control fleas, termites, cockroaches, and as fruit fly attractant.
Class	Phenylpyrazole						
Maker	BASF						
Commercial names	Regent						
	CHLORPYRIPHOS	0.25	0.059	AT, BE, BG, CY, CZ, DE, EE, EL, ES, FR, HU, IE, IT, LU, MT, NL, PL, PT, RO, SI, SK, UK	yes	no	Maize, cotton, almonds, and fruit trees including oranges and apples Non-crop use to control fleas, ants, termites, mosquitoes, etc.
Class	Organophosphate						
Maker	Bayer, Dow Agroscience, and others						
Commercial names	Cresus, Exaq, Reldan and many others						
	CYPERMETHRIN	0.035	0.02	AT, BE, BG, CY, CZ, DE, DK, EE, EL, ES, FI, FR, HU, IE, IT, LT, LU, LV, MT, NL, PT, RO, SE, SK, UK	yes	no	Fruit and vegetable crops, cotton. As biocide for domestic and industrial uses (i.e. schools, hospitals, restaurants, food processing plants, livestock)
Class	Pyrethroid						
Maker	Many, including French SBM DVLPT and CPMA						
Commercial names	Demon WP, Raid, Cyper, Cynoff, Armour C, Signal						
	DELTAMETHRIN	0.079	0.0015	AT, BE, BG, CY, CZ, DE, EE, EL, ES, FI, FR, HU, IE, IT, LT, LU, LV, MT, NL, PL, PT, RO, SE, SI, SK, UK	yes	no	Fruit trees (apple, pear, plum), brassicas (cabbage family), peas. Greenhouse crops such as cucumbers, tomatoes, peppers, and ornamentals.
Class	Pyrethroid						
Maker	Many						
Commercial names	Cresus, Decis, Deltagrain, Ecail, Keshet, Pearl Expert, and many others						

Table 1. Seven pesticides that should be completely eliminated from the environment, based on their bee-harming potential.

(Note: LD_{50}: (Lethal Dose 50%) is the dose required to kill half the members of a tested population after a specified test duration).

Rationale behind banning this chemical to protect bee population health
A common seed treatment neonicotinoid with low-dose bee toxicity/ sub-lethal effects: - Found in guttation water in plants grown from treated seeds at concentrations toxic to bees (Girolami et al, 2009). -Possibility of synergistic effects with the parasite Nosema (Pettis et al, 2012; Alaux et al, 2010). - Repels pollinating wild flies and beetles from potential food sources (Easton and Goulson, 2013). **At sub-lethal concentrations:** - Impairs medium-term memory and brain metabolic activity in honeybees (Decourtye et al, 2004). - Results in abnormal foraging behavior in honeybees (Schneider et al, 2012; Yang et al, 2008). - Damaging effects even at very low doses on bumblebee colony development. Particular impacts observed on queen bees (Whitehorn et al, 2012). - Affects neural development and impairs the walking behavior of newly emerged adult workers in a wild bee species (Tomé et al, 2012). - At low levels comparable to field concentrations, and combined with the pyrethroid l-cyhalothrin, it increases worker mortality and decreases success in foraging in bumblebees, thereby compromising colony health (Gill et al, 2012).
A common seed treatment neonicotinoid with low-dose bee toxicity and sub-lethal effects: - Found in guttation water in plants grown from treated seeds at concentrations toxic to bees (Girolami et al, 2009). **At sub-lethal concentrations:** - Worker honeybees become lost after foraging, making the colony weaker and at greater risk of collapse (Henry et al, 2012). - Affects medium-term olfactory memory in bees (Aliouane et al, 2009). - Impairment of brain and midgut function and reduction of lifespan in Africanised honeybee (Oliveira et al, 2013).
A common seed treatment neonicotinoid with low-dose bee toxicity and sub-lethal effects: - Found in guttation water from plants grown from treated seeds at concentrations toxic to bees (Girolami et al., 2009). **At sub-lethal concentrations:** - Reduction of foraging activity and more time needed in foraging flights in honeybees (Schneider et al, 2012).
A common seed treatment with low-dose bee toxicity and sub-lethal effects: - Synergistic negative effects observed with other pesticides (thiacloprid) and with the parasite Nosema, in honeybees (Vidau et al., 2011). **At sub-lethal concentrations:** - Affects mobility, increases water consumption and impairs odor recognition in honeybees (Aliouane et al, 2009). - Reduction of learning performance in honeybees. One of the most toxic pesticides on learning
One of the most commonly used pesticides worldwide. High bee toxicity. - Uruguayan species of honeybee found to be about 10x more sensitive than bees tested in Europe (Carrasco-Letelier et al, 2012), highlighting potential variability in response from different pollinator species. - Affects physiology and reduces motor activity of honeybees at low concentrations (Williamson et al, 2013).
A very commonly used pesticide worldwide. At sublethal concentrations: - Long-term low level exposure has negative effects on honeybee colony health, including health of larvae (Bendahou et al, 1999).
A widely used insecticide globally. - At crop field application/residue levels, it reduces foraging trips and affects learning capabilities in honeybees (Ramirez-Romero et al, 2005). - Impacts on fecundity, growth and the development of individual honeybees (Dai et al, 2010).

References for LD_{50} values:

LD Imidacloprid: http://www.efsa.europa.eu/en/efsajournal/doc/3068.pdf

LD Thiomethoxam http://ec.europa.eu/sanco_pesticides/public/index.cfm?event=activesubstance.ViewReview&id=399

LD Clothianidin http://ec.europa.eu/sanco_pesticides/public/index.cfm?event=activesubstance.ViewReview&id=368

LD Fipronil: http://sitem.herts.ac.uk/aeru/iupac/316.htm
Acute 48 hour LD_{50}

LD Chlorpyriphos: http://ec.europa.eu/sanco_pesticides/public/index.cfm?event=activesubstance.ViewReview&id=138

LD Cypermithrin: http://ec.europa.eu/sanco_pesticides/public/index.cfm?event=activesubstance.ViewReview&id=143

LD Deltamethrin: http://ec.europa.eu/sanco_pesticides/public/index.cfm?event=activesubstance.ViewReview&id=60
Acute 48 hour LD_{50}

What can we do?

Any progress in transforming the current destructive chemical-intensive agricultural system into an ecological farming system will have many associated benefits on other dimensions of the environment and on human food security, quite apart from clear benefits to global pollinator health.

In the short to medium term, there are specific issues that society can begin to address straight away, in order to benefit global pollinator health. The benefits could become evident almost immediately. Based on analysis of the current science on global pollinator health, Greenpeace believes that eliminating exposure to pesticides with the potential to harm bees is a crucial step in safeguarding not only managed and wild bees, but also the high ecological and fiscal value of natural pollination.

Examples of scientifically based short to medium term actions to help reverse the decline of global pollinators fall into two basic groups:

1) avoid harm to pollinators (e.g. through eliminating exposure to potentially harmful substances); and

2) promote pollinator health (e.g. through changing other practices within existing agro-ecosystems).

Many practices that increase plant diversity, at different scales, can improve the flower resources available to pollinators, both in space and time.

The recent expansion of organic agriculture, together with the growth of the application of techniques that reduce and/or eliminate chemical pesticides (i.e. integrated pest management), demonstrates that farming without pesticides is entirely feasible, economically profitable and environmentally safe.

Ecological farming

Ecological or organic farming that maintains high biodiversity without any application of chemical pesticides or fertilisers has repeatedly been shown to benefit pollinator abundance and richness. This in turn benefits crop pollination, and hence potential yields. Organic or ecological production methods bring out many other benefits in addition to those related to pollinators. For example, they can also enhance control of weeds, diseases and insect pests, and inherently increase the overall resilience of ecosystems.

However, these approaches have received significantly less public funding for research targeted at developing improved agricultural practices and management compared to conventional chemical intensive techniques. This lack of support is remarkable, given that ecological and organic farming systems can produce more or less the same amount of food – and profit – as conventional farming, while generating far fewer environmental and social harms. Accordingly, more public and private funding is needed for research and development on improved ecological farming practices. Ultimately such methods represent the best options for maximising ecological services, alongside food production and environmental protection, while at the same time helping to promote sustainable social and economic development.

European agriculture policies

European agricultural policies – first and foremost the Common Agricultural Policy (CAP) – should incorporate and act upon current scientific evidence about the benefits of, and threats to, populations of both managed honeybees and wild pollinators. Urgent action is required to protect the essential ecosystem service of pollination. The evidence outlined above of tools which already exist to protect pollinators should be incorporated into agricultural policies as a means of encouraging bee-enhancing farming practices.

In addition, rigorous EU regulations on the use of potentially bee-harming substances should be put into place, following the precautionary principle by incorporating current scientific evidence about harms and vulnerability of honeybees. Precaution should also extend to other wild pollinators, in view of their crucial role in securing pollination services now and in an uncertain future.

Greenpeace demands

Honeybees and wild pollinators play a crucial role in agriculture and food production. However, the current chemical-intensive agriculture model is threatening both, and is thereby putting European food supply at risk.

This report shows that there is strong scientific evidence that clearly suggests that neonicotinoids and other pesticides play an important role in the current bee decline. Consequently, policy makers should:

1) Ban the use of bee-harming pesticides, starting with the top-ranking most dangerous substances currently authorised for use in the EU, i.e. the seven priority chemicals imidacloprid, thiamethoxam, clothianidin, fipronil, chlorpyriphos, cypermethrin and deltamethrin (see Table 1).

2) Through the adoption of pollinators' national action plans, **support and promote agricultural practices that benefit pollination services within agriculture systems,** such as crop rotation, ecological focus areas at farm level, and organic farming methods.

3) Improve conservation of natural and semi-natural habitats in and around agricultural landscapes, as well as **enhance biodiversity within agricultural fields.**

4) Increase funding for research, development and application of ecological farming practices that move away from reliance on chemical pest control towards the use of biodiversity-based tools to control pests and enhance ecosystem health. EU policy makers should **direct more funding for ecological agriculture solutions research** under the auspices of the CAP (direct payments) and Horizon 2020 (EU research framework).

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Introduction: Importance of bees and other pollinators for agriculture and ecosystem conservation

> *"Bees are reaching their tipping point because they are expected to perform in an increasingly inhospitable world."*
>
> – Spivak et al, 2010

Human wellbeing is sustained and improved by a number of ecosystem services (functions provided by nature) that support our life on Earth. These ecosystem services – such as water purification, pest control, or pollination, to name just a very few – are often taken for granted as being there for our benefit, even though they may not always be obvious as we go on with our daily technologically-driven lives.

The next time you see a bee buzzing around, remember that much of the food we eat depends significantly on natural insect-mediated pollination – the key ecosystem service that bees and other pollinators provide. Without this essential function carried out by insects bringing pollen effectively from one flower to another, about one third of the crops we eat would have to be pollinated by other means, or they would produce significantly less food (Kremen et al, 2007). In addition, many wild plants (estimated at between 60% and 90% of them) need animal-mediated pollination to reproduce, and thus other ecosystem services and the wild habitats providing them also depend – directly or indirectly – on insect pollinators.

Grains like wheat, rice and corn, which make up a large part of the global human diet, are mostly pollinated by wind and are not so much affected by insect pollinators. However, the most nutritious and interesting crops in our diet such as fruit and vegetables, and some fodder crops for meat and dairy production, would undoubtedly be affected badly by a decline in insect pollinators (Spivak et al, 2011).

Wild organisms involved in pollination include bees, many butterflies, moths, flies, beetles, and wasps, together with some birds and mammals. Commercially managed bee species (primarily the honey bee, *Apis mellifera*) are also significant pollinators. Indeed, bees are the predominant and most economically important group of pollinators in most geographical regions. In recent years, however, managed honeybees have been increasingly suffering from various diseases, pesticides and other environmental stresses. Accordingly, the contributions of wild pollinators to crop pollination (comprised of many other bee species as well as other insects) appear to have been increasing in relevance (Kremen and Miles 2012; Garibaldi et al, 2013).

In this report we focus mainly on bees. Most of the scientific information on pollination relates to managed honeybees, but also bumblebees to a lesser extent. In referring often to bees as the iconic pollinators, we nonetheless acknowledge the essential role played by other insects and animals. In many cases, what affects bee populations can also apply to other insect pollinators (such as butterflies, flies, etc), although many specific and complex factors make generalised assumptions very risky. Much more scientific information is needed to fully assess the status and health of insect pollinator communities.

The great majority of plants on Earth need animal pollination to produce seeds and fruits; only a handful of plant species do not need pollen transfer from other plants to reproduce and are not likely to be affected by changes in the health of bee populations. Many of the plant species that do require pollen transfer from neighbouring plants for seed and fruit production could be dramatically impacted as and when bee populations change; even where it is not an essential requirement for reproduction, many tend to produce more seeds and bigger fruits when bees transfer pollen among them.

> *"Some commercial plants, such as almonds or blueberries, do not produce any fruit without pollinators. For many, a well-pollinated flower will contain more seeds, with an enhanced capacity to germinate, leading to bigger and better-shaped fruit. Improved pollination can also reduce the time between flowering and fruit set, reducing the risk of exposing fruit to pests, disease, bad weather, agro-chemicals and saving on water."*
>
> – UNEP, 2010

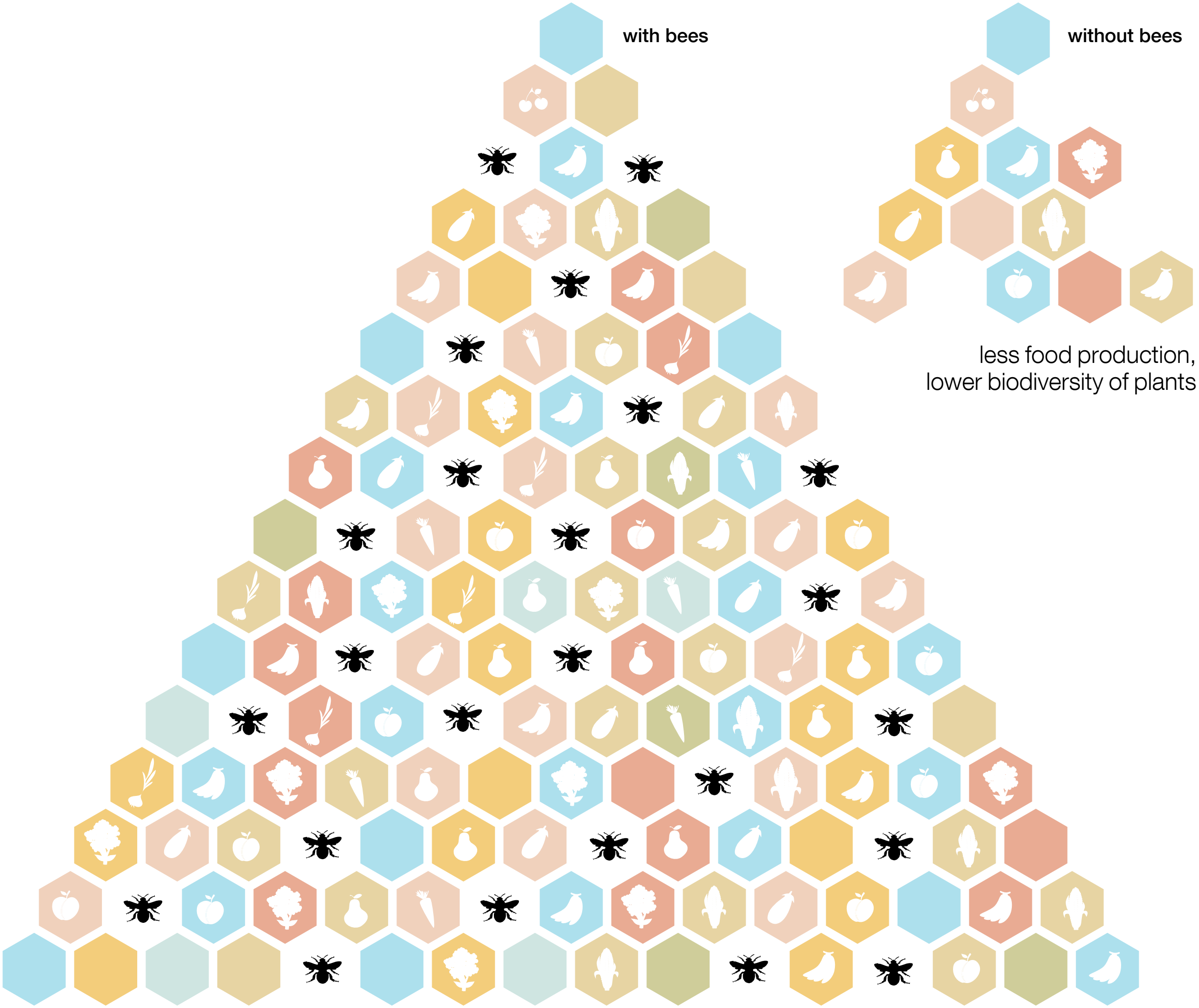
It has recently been estimated that 87.5% of flowering plants are pollinated by animals (Ollerton et al, 2011). This covers both crop and wild plants, and points to the crucial importance of bees – as one of the chief global pollinators – to the maintenance of food production and wild plant ecosystems. Animal pollination results in increased fruit or seed in 75% of the world's leading food crops (Klein et al, 2007), and the most recent estimate of the global economic benefit of pollination amounts to a value of €265bn in productivity due to pollination (Lautenbach et al, 2012). Of course, as with any ecosystem service valuation, if any vital ecosystem service is compromised, then its value tends towards infinite if it cannot be replaced.

> *"The Food and Agriculture Organisation of the United Nations (FAO) estimates that out of some 100 crop species which provide 90% of food worldwide, 71 of these are bee-pollinated. In Europe alone, 84% of the 264 crop species are animal pollinated and 4 000 vegetable varieties exist thanks to pollination by bees."*
>
> – UNEP, 2010

> *"The production value of one tonne of pollinator-dependent crop is approximately five times higher than one of those crop categories that do not depend on insects."*
>
> – UNEP, 2010

In some European regions, viable populations of wild honeybees do not exist, because they are not able to survive the pressure from industrial agricultural practices (monocultures, herbicides, pesticides), as well as the pressure from a number of natural diseases and parasites, without human management. In Spain, for example, only domestic honeybees survive in highly-managed colonies provided with external feeding and with drugs (Mariano Higes, personal communication).

Humans have already occupied large areas of the potentially cultivable land on Earth for agricultural production, but in recent decades there appears to have been a relative increase in the area dedicated to cultivation of crops that depend on pollinators, both in developed and developing countries. In developed countries there has been a 16.7% increase in cropped land devoted to pollinator dependent crops, while in developing countries a 9.4% increase took place between 1961 to 2006) (Aizen and Harder, 2009; Aizen et al, 2009). The abundance of pollination services, however, has not kept pace with this increase in crops that need pollination. This suggests there might be undesired (and undesirable) consequences in the form of declines in global agricultural production. In turn this could further promote compensatory land conversion to agriculture.



more food production, higher biodiversity of plants

less food production,
lower biodiversity of plants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2

The global and European situation with bees and other pollinators

“If wild pollinator declines continue, we run the risk of losing a substantial proportion of the world’s flora.”

– Ollerton et al, 2011

Bees and other pollinators, both natural and managed, seem to be declining globally, particularly in North America and Europe (Potts et al, 2010). There is considerable debate about this perceived decline, however, mostly due to lack of robust regional or international programmes designed to monitor the current status and trends of pollinators (Lebuhn et al, 2013). Nonetheless, where they have been documented, the scale and extent of the losses are striking.

In the US the loss of 30-40% of commercial honeybee colonies, which has occurred since 2006, was linked to “colony collapse disorder”, a syndrome characterised by disappearing worker bees (see references in Lebuhn et al, 2013). Since 2004, losses of honeybee colonies have left North America with fewer managed pollinators than at any time in the last 50 years (UNEP, 2010).

China has 6 million bee colonies; about 200,000 beekeepers in this region raise western honeybees (*Apis mellifera*) and eastern honeybees (*Apis cerana*). In recent years, Chinese beekeepers have faced inexplicable colony losses in both *Apis* species. These losses were largely inexplicable and the associated symptoms highly complex. Egyptian beekeepers based along the River Nile have also reported symptoms of colony collapse disorder (UNEP, 2010).

In central Europe, estimated losses since 1985 point to a 25% loss of honeybee colonies, with a 54% loss in the UK (Potts et al, 2010).

“Since 1998, individual beekeepers in Europe have been reporting unusual weakening and mortality in colonies, particularly in France, Belgium, Switzerland, Germany, the United Kingdom, the Netherlands, Italy and Spain. Mortality has been extremely high when activity is resumed at the end of winter and beginning of spring.”

– UNEP, 2010

In recent winters, colony mortality in Europe has averaged about 20% (with a wide range of 1.8% to 53% between European countries)[1]. Over the 2008/09 winter, honeybee losses in Europe ranged between 7% and 22%, and over the 2009/10 winter between 7% and 30%. For countries that participated in both years’ surveys, winter losses appeared to significantly increase from 2008/09 to 2009/10.[2]

In addition to managed bee colonies, a decline in native wild pollinators has also been widely reported in specific locations across the globe (Cameron et al, 2011; Potts et al, 2010). Well known examples include the UK and the Netherlands (Biesmeijer et al, 2006).

Set against these observations is the fact that global honey production appears to have been growing over the last few decades. This has led to suggestions that honeybee declines are very localised, mostly in North America and Europe, and that these declines are compensated for by increases in the major honey-producing countries (China, Spain and Argentina) (Aizen and Harder 2009).

[1] Proceedings of the 4th COLOSS Conference, Zagreb, Croatia, 3-4 March 2009, available at: http://www.coloss.org/publications as cited in Williams et al, 2010.

[2] http://www.ibra.org.uk/articles/Honey-bee-colony-losses-in-Canada-China-Europe-Israel-and-Turkey-in-2008-10

However, most scientists in the field agree that there are three important concerns regarding the global health of pollinators:

1) Currently, there are not accurate data available to reach firm conclusions on the status of global pollinators in terms of their abundance and diversity (Lebuhn et al 2013; Aizen and Harder 2009). Indeed, potential variability in census attempts for animal species is so high that "populations may be reduced by almost 50% before evidence for a decline could be detected" (Lebuhn et al, 2013).

2) As the demand for pollinators – both locally and regionally – increases faster than the supply, we could face limitation of pollination, currently and in the near future. This is because the growth in cultivation of high-value, pollination-dependent crops is outpacing growth in the global stock of managed honeybees (Garibaldi et al, 2011; Lautenbach et al, 2012). Wild bees are also providing significant pollination services, especially where there are limitations to pollination by honeybees (as, for example, in the UK). However, increasing agricultural intensification puts further pressure on wild pollinators through habitat destruction and reduced habitat diversity (Kremen et al, 2007, Lautenbach et al, 2012). In addition, any potential increase in managed honeybee hives is unlikely to satisfy increased demand for agricultural pollination or to mitigate any loss of native pollinators (Aizen and Harder, 2009).

3) In spite of global increases, honeybee population abundance is very uneven between agricultural regions: there is growth in honey-producing countries (Spain, China and Argentina) but decline elsewhere, including regions with high agricultural production in the US, and in the UK and many other western European countries (Aizen and Harder 2009; Garibaldi et al, 2011; Lautenbach et al, 2012).

No regional, national or international monitoring programmes exist, however, to document whether insect pollinator decline is actually occurring. It is therefore difficult to quantify the status of bee communities or estimate the extent of any declines (Lebuhn et al, 2013). Establishment of such programmes is urgently needed, and would allow tracking of the global status and trends of pollinator populations, as well as providing an early warning system for pollinator decline. The cost of such a system (estimated at $2m US dollars) represents a small investment compared to the likely potential economic cost of severe pollinator decline. Such programmes would "allow for mitigation of pollinator losses and avoid the financial and nutritional crisis that would result if there were an unforeseen and rapid collapse of pollinator communities." (Lebuhn et al, 2013).

In conclusion, it seems clear that agriculture – and therefore food production – is becoming more pollinator-dependent over time. At the same time, there are clear indications of some significant losses of wild and domesticated pollinators. Recent "warning signals" of the tensions between pollinator population decline and crop yields may exist in the observed increases in producer prices from 1993 to 2009 for pollination-dependent crops (Lautenbach et al, 2012). If we are to avoid additional limits to food production and further deforestation to increase the area of agricultural land, we must work to address the underlying factors putting stress on pollination services, including impacts on honeybees and wild pollinators.

Moreover, demand for agriculture products, and the corresponding need for pollination, obviously cannot grow to the infinite. An equitable sustainable agriculture system should put limits to its absolute production – and the corresponding strain it puts on the planet – by supporting global equitable diets with crops grown mostly for human food, not animal feed, and with less animal protein consumption. This will also allow for the preservation of more natural and semi-natural areas and possibly release some of the constraints on wild pollinators.

Economic value of pollination

The first global estimate carried out concluded that an economic value of $117bn (€88bn) was associated with pollination considered as a global ecosystem service (Costanza et al, 1997). More recently, Gallai et al (2009) revised this estimate, using an improved methodology, to reach a value of $153bn (€115bn) (Gallai et al, 2009). The most recent estimate, taking into account increases in the relative importance of pollinator-dependent crops in the global food supply, values pollination at €265bn (Lautenbach et al, 2012). This rising trend highlights the increase in our dependency upon pollinators in the global food system, as well as the considerable uncertainties associated with this kind of fiscal valuation of nature and natural systems.

As with many contingent valuation exercises, the economic value of pollination depends also on perspective. For an individual farmer it might just be the price that has to be paid to bring in managed bees to the farm in the absence of other pollinators. In others, it might be the value of foregone yields in farms lacking natural pollination services. For example, in northern Canada, canola in farms near uncultivated areas had the advantage of more diverse and abundant wild bees, and thus greater pollination and greater seed yields (Morandin and Winston, 2006). The cost/benefit analysis can become intricate. These authors suggest, by extrapolation, that farmers could maximise profits by not cultivating 30% of their farm area, so that they receive higher yields on the remaining 70% and save on cultivating costs in the fallow 30% (Morandin and Winston, 2006).

Two examples of crop yield losses due to lack of pollination, and associated institutional responses, are summarised by Kremer et al 2007:

- "Following massive applications of the pesticide fenitrothion (used for control of gypsy moth in nearby forests) in Canada, both pollinator communities and blueberry production declined (Kevan & Plowright 1989). Economic losses of blueberry growers influenced government policy, causing a virtual ban on the use of fenitrothion for gypsy moth control, and both blueberry pollinators and crop production rebounded" (Tang et al 2006).
- "Shortages of honey bee colonies in 2004 for almond pollination prompted the United States Department of Agriculture to alter honey bee importation policies to allow shipments of honey bee colonies from Australia into the USA." (National Research Council of the National Academies 2006).

The difficulty of arriving at an accurate valuation for animal pollination arises from the fact that it contributes much more than just simply the pollination of crops or wild plants. By promoting fruit production in wild plants, it also increases the food available for many insects, birds, mammals, and fish, thereby directly contributing to the maintenance of biodiversity. By also helping to maintain plant productivity and vegetation cover, it also contributes to many and various ecosystem services, such as flood protection, prevention of erosion, control of climate systems, water purification, nitrogen fixation, and carbon sequestration (Kremer et al, 2007). Hence, pollination is a key ecosystem service. By promoting plant production generally, bees are also key to the many other ecosystem services, in addition to food production alone, that contribute to human wellbeing on the planet.

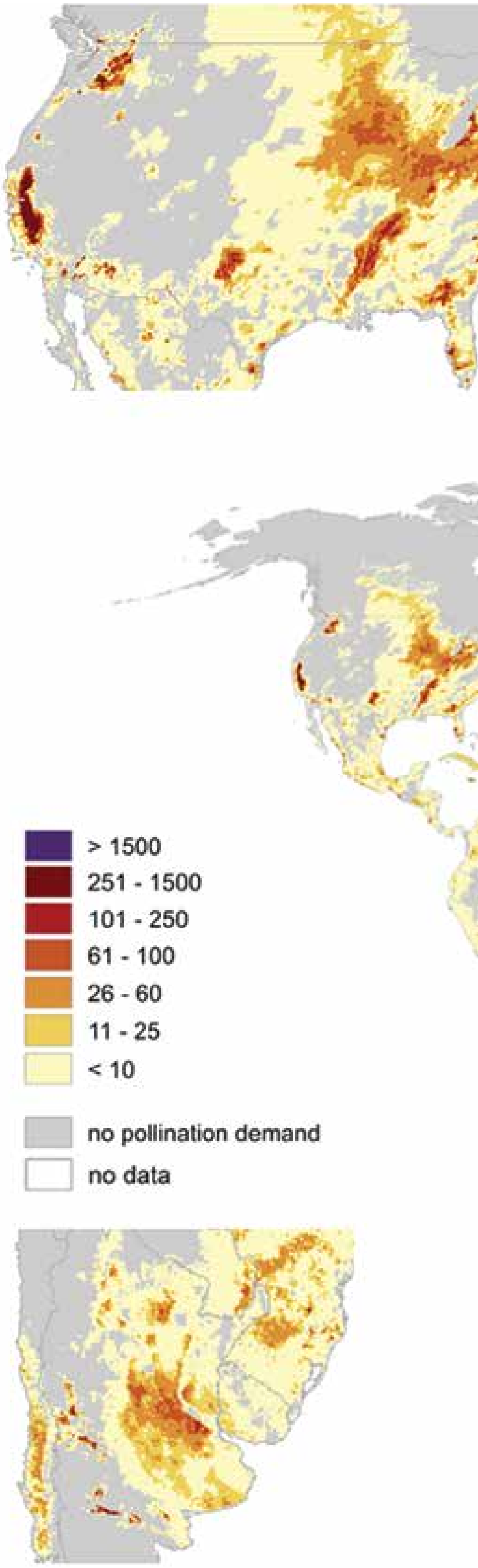
In a recent exhaustive study, Lautenbach et al (2012) showed the distribution of pollination benefits and vulnerabilities in a series of global maps. These were based on the agricultural importance of pollination for different regions. The analysis was based on estimates of the monetary value of the part of agricultural production that depends on pollination by animals, related, in turn, to the crops grown in any given "cell" of a 5' by 5' (approximately 10km by 10km at the equator) latitude-longitude grid. These global maps shed light on hot spots of pollination benefits, as well as regions with high vulnerabilities, to any decline in pollination ecosystem services (Lautenbach et al, 2012).

The global map of pollination services in Figure 1 highlights in darker colours the regions where pollination services, in units of US dollar per hectare, are highest: parts of North America, East Asia and Europe all contain regions where the value of pollination can be as high as $1,500 per hectare (Lautenbach et al 2009). That is money that farmers – and society at large – will be losing if pollinators were to decline in those regions.

Europe is very dense in terms of the amount of land with high fiscal value attached to pollination benefits per hectare (see Figure 1). Large parts of Italy and Greece have exceptionally high values of pollination benefits, together with extensive regions in Spain, France, the UK, Germany, the Netherlands, Switzerland and Austria, with high pollination value "hot spots". Poland, Hungary and Romania also show regions where pollination values are significant. Furthermore, Italy and Spain have relatively high overall dependency of their agricultural systems on natural pollination services (Lautenbach et al, 2009).

Globally, countries like Brazil, China, India, Japan and the US also derive great economic benefits from pollination services. In Africa, it is highest in Egypt, along the Nile. In China, notional benefits from pollination increased by 350% from 1993 to 2009, reflecting a push for fruit production to meet demands from the growing urban middle class and for export markets. China alone benefits by between 30% and 50% of the total global economic benefits that result from pollination (Lautenbach et al, 2009).

Figure 1. Global pollination benefits across sub-national scales. “Values are given as US dollar per hectare for the year 2000. The values have been corrected for inflation (to the year 2009) as well as for purchasing power parities. The area we relate yields to is the total area of the raster cell.” Reproduced from Lautenbach et al (2012). “Spatial and Temporal Trends of Global Pollination Benefit.” PLoS ONE 7(4): e35954, under Creative Commons Attribution License.



Overall, the scientific research emphasises the urgent need to protect our insects and the essential pollination services they carry out: “Given the monetary value of the pollination benefit, decision makers should be able to compare costs and benefits for agricultural policies aiming at structural diversity. Therefore, the information provided in the map should be used when considering modifications of agricultural policies such as the common agricultural policy in the EU.” (Lautenbach et al, 2009).

> *“The benefit from pollination is high enough in a large part of the world to seriously affect conservation strategies and land-use decisions if these values were taken into account.”*
>
> – Lautenbach et al, 2012

> *“Since 2001 the costs of production for pollination-dependent crops have also risen significantly, indeed far faster than the prices of non-pollination-dependent field crops such as rice, grains or maize. For the researchers this is an indication that the intensification of agriculture is reflected in a global price increase for pollination-dependent cultures.* ***When fields are sprayed with more pesticides, more fertilisers are applied and valuable agricultural structural elements, such as hedges and rows of trees, are transformed into fields, the insects vanish****.”*
>
> – Helmholtz Centre for Environmental Research (UFZ), 2012[3].

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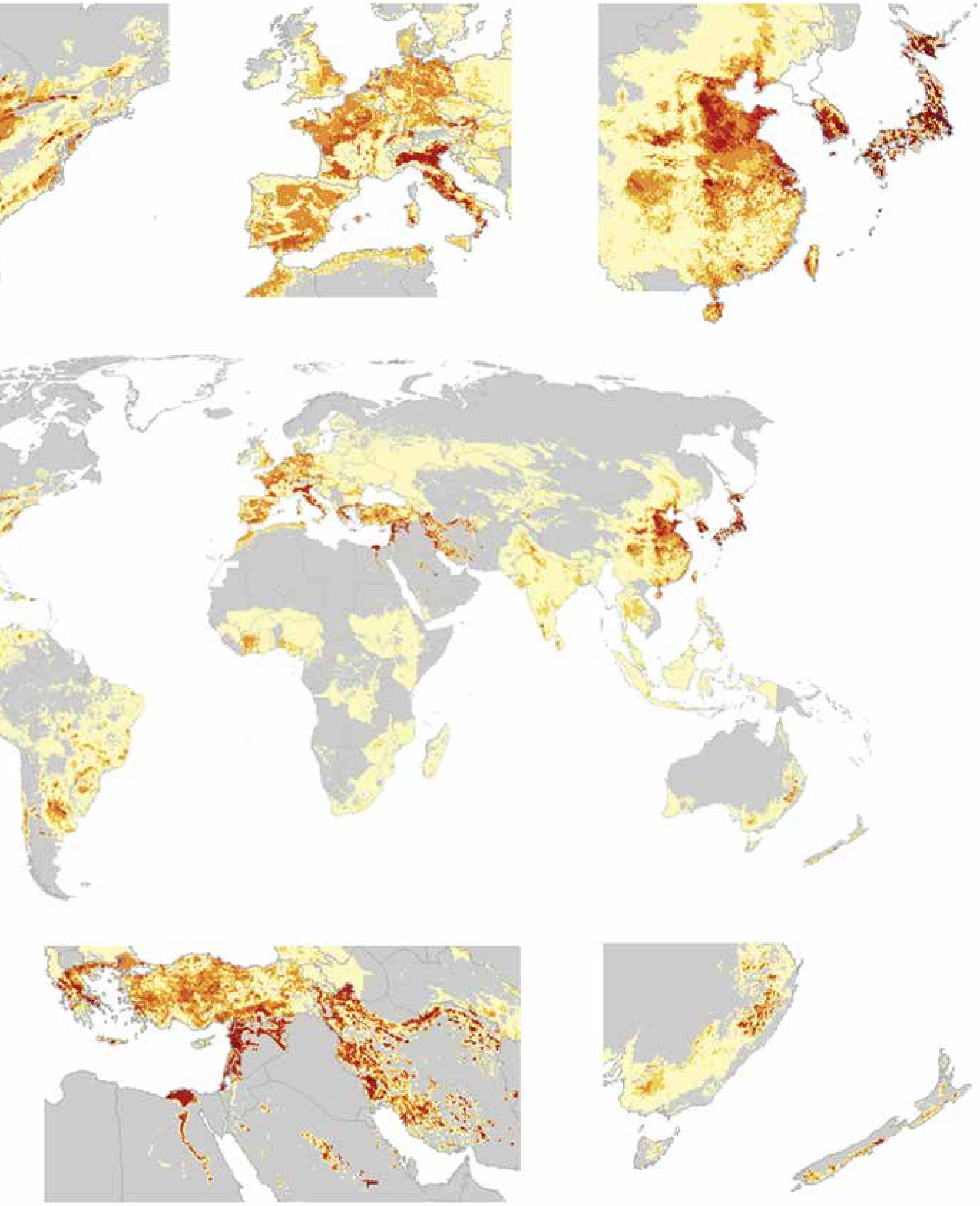
[3] Press release dated 27 April 2012 about the study from Lautenbach et al, 2012. http://www.ufz.de/index.php?en=30403



Source: Lautenbach, S., R. Seppelt, et al. (2012). "Spatial and Temporal Trends of Global Pollination Benefit." PLoS ONE 7(4): e35954.
(Creative Commons Attribution Licence)
http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0035954

Values are given as US $ per hectare for the year 2000. The values have been corrected for inflation (to the year 2009) as well as for purchasing power parities. The area yields are related to is the total area of the raster cell.

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3

The main factors affecting bee populations' health

There seems to be general agreement that declines in bee populations and their overall health (colony collapse disorder and other phenomena) are the product of multiple factors, both known and unknown, that can act singly or in combination (Williams et al, 2010).

In general, bee declines can arise from three general stressors:

Sick bees:
Bees suffer from their own **diseases and parasites** that weaken and often kill them. Most of these diseases and parasites are invasive species that cannot be fought through the natural adaptation of native bees or emergence of resistance. Sick bees, or bees with parasites, can in turn be more vulnerable to other factors, such as poor nutrition or exposure to toxic chemicals.

Hungry bees:
Bees feed on flowers, so they need a stable supply of flowers both in space and time. Managed bees are given supplementary feed by beekeepers to complete their feed, but they still need flowers to collect pollen, their main food and source of protein, from around hives. When there are not enough blooming flowers during the bee season, as for example in monocultures that produce only one kind of flower during a peak time, bees are not able to feed themselves and their progeny. Bees can go hungry as a result of a diversity of factors, mostly related to **industrial agriculture practices**: herbicides that reduce the diversity of wild plants in and around farms; and the expansion of agriculture that removes field margins, borders, hedges, and so on, that hold a diversity of plants around farms. In addition, **climate change** may modify flowering patterns, displace plants that were major sources of food for bees in a given area, or cause "season creep", where flowering no longer coincides with the emergence of bees in the spring. (Kremen et al, 2007, Cameron et al, 2011).

Poisoned bees:
Many flowers, nest sites, and the general environment around bees – including dust from farm operations – are often contaminated with chemicals, mostly pesticides. These **insecticides, herbicides and fungicides** are applied to crops, but reach the bees through pollen, nectar, and through the air, water or soil. These pesticides, by themselves or in combination, can be toxic to bees acutely in the short term or, in low-doses, with chronic effects that weaken and can ultimately kill bees (see also the following chapter).

Different specific factors that have been implicated in unhealthy bee populations

Diseases and parasites: invasive species

Many beekeepers agree that the external parasitic mite, *Varroa destructor*, is a serious threat to apiculture globally. It seems to have originated in Asia, but has now spread almost globally. Varroa is a small mite the size of a pinhead, which feeds on the blood of the bee and spreads from hive to hive. In addition to weakening the bees, Varroa can also spread viral diseases and bacteria. Its effects are severe and, if left uncontrolled, usually lead to the early death of colonies within three years (UNEP, 2010).

Varroa and other pathogens have been linked to winter loss of honeybee colonies, although in general there are always multiple factors involved. For example, in Germany it was found that high Varroa infestation, infection with certain viruses, and additionally the queen's age and the weakness of the colony in autumn, were all related to observed winter losses in honeybee colonies (Genersch et al, 2010).

Another honeybee pathogen is the microsporidium *Nosema ceranae*, which is found almost worldwide but is more prevalent and damaging in Mediterranean countries (for a current review see Higes et al, 2013). It has been found to be highly damaging to honeybee colonies in Spain and other southern European countries, but its impacts seem less severe in northern European regions. Nosema causes a high mortality rate in foragers, which in turn affects colony development and may possibly end in colony depopulation and collapse. In spite of the advances in knowledge about Nosema in recent years, its role in colony loss is still controversial, apparently due to its high variance between different geographical regions (Higes et al, 2013).

The ability of bees to resist diseases and parasites seems to be influenced by a number of factors, particularly their nutrition and their exposure to toxic chemicals.

For example, the combined exposure of honeybees to the neonicotinoid pesticide imidacloprid and the parasite Nosema was found to significantly weaken honeybees (Alaux et al, 2010). The combined effects of both agents caused high individual mortality and stress, blocking the ability of bees to sterilise the colony and their food, and thus weakening the colony as a whole.

In another recent study, a higher proportion of bees reared from brood comb with high levels of pesticide residues were found to become infected with *Nosema ceranae* at a younger age, compared to those reared in low-residue brood combs (Wu et al, 2012).

> *"These data suggest that developmental exposure to pesticides in brood comb increases the susceptibility of bees to* Nosema ceranae *infection."*
>
> – Wu et al, 2012

The authors concluded: "This study suggests there is an increased susceptibility to *N. ceranae* infection in treatment bees, which may be due to the added stress of developing in pesticide-laden comb and the possible utilisation of critical energetic resources and detoxifying enzymes. Although the quantity and identification of the mixed pesticide residues contained in comb Y and G are known, we cannot definitively pinpoint causative active ingredients. Nonetheless, interactive effects between pesticide exposure and *N. ceranae* infection need further investigation, especially considering the levels of pesticide residues found in brood comb."

Another recent study showed that exposure to sub-lethal doses of the pesticides fipronil and thiacloprid caused much higher mortality to honeybees previously infected by *N. ceranae* than in uninfected ones (Vidau et al, 2011).

In light of these and other interactions, there is a clear need for more studies to tease apart the multiple factors that place stresses on pollinator health. In addition, these studies focused solely on honeybees. Other pollinators like bumblebees share similar sensitivities to pesticides, similar parasites like Nosema, and their populations are also declining (Williams and Osborne, 2009; Alaux et al, 2010; Winfree et al, 2009; Cameron et al, 2011). More studies, together with stronger actions based on the precautionary principle, are needed to limit potentially interactive factors such as the possibility of an increased susceptibility to diseases with exposure to pesticides, and thereby protect the overall health of pollinators on a global basis.

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Industrial agriculture

Agriculture, in both croplands and pastures, occupies about 35% of the ice-free land surface on Earth, and is one of the largest ecosystems on the planet, rivalling forests in extent (Foley et al, 2007). In addition, agriculture has been quickly becoming increasingly industrialised over the past century or so. This has taken the form of greater use of fertilisers, more toxic chemicals, more monoculture crops, and the increased expansion of agriculture into other land. All make the impact of current agriculture on the environment a tremendously damaging one (Tilman et al, 2001; Foley et al, 2011; Rockstrom et al, 2009).

Pollinators, managed or wild, cannot escape the various and massive impacts of industrial agriculture. They suffer simultaneously from the destruction of their natural habitats by agriculture, and also from the harmful effects of intensive agricultural practices when their natural ranges overlap (inevitably), with industrial farming landscapes.

Industrial agriculture affects bees and other pollinators in a variety of ways, but in particular:

Intensification of agriculture prompts the loss and fragmentation of valuable natural to semi-natural perennial habitats for pollinators, such as agroforestry systems, grasslands, old fields, shrublands, forests, and hedgerows. This is thought to be the major cause of wild pollinator declines, although with smaller effects on managed honeybees (Brown and Paxton, 2009; Winfree et al, 2009).

Industrial monocultures and, in general, the lack of plant biodiversity within and around croplands, limit the amount of food that pollinators have access to, both in space and time. A parallel decline in plant diversity at the local scale with the decline in bees and other pollinators has been shown both in the UK and the Netherlands (Biesmeijer et al, 2006), and it is possibly a much more widespread phenomenon.

Practices such as tillage, irrigation, and the removal of woody vegetation, destroy nesting sites of pollinators (Kremen et al, 2007).

Large-scale herbicide application drastically reduces non-crop plant diversity and abundance, and thus limits food availability for bees at any given moment. The chemical destruction of habitats through the massive application of herbicides can have long term consequences, particularly on the distribution of pollinators in agro-environments (UNEP, 2010).

Finally, widespread and ubiquitous use of pesticides, common practice in the current chemical intensive agriculture systems, can lead to mortality and/or altered foraging abilities for both wild and managed bees (this element is addressed in detail in the following chapter). Determining the specific role of pesticides in pollinator health is further complicated because sites where pesticide use is intense often also correspond with places with low availability of both flower resources and nesting sites (important for many wild pollinators) (Kremen et al, 2007). Differentiating among the relative weight of the different impacts remains an important challenge.

Agricultural intensification from local to landscape-scale is generally correlated with a decline in the abundance and richness of wild pollinators, and hence in the ecosystem services they provide to crops (Kremer et al, 2007). Intensification is also likely to impact negatively on the health and stability of honeybee populations.

In contrast to these general negative impacts, some studies show certain positive effects of agriculture on pollinator communities, for example by increasing floral resources in fragments of natural habitats (Winfree et al, 2006, in Kremer et al, 2007). Significantly, however, these positive effects seem to occur in regions where the type of agriculture increases, rather than decreases, habitat heterogeneity for bees (such as small farms, mixed cropping, hedgerows, etc.) (Tscharntke et al, 2005, in Kremer et al, 2007), emphasising the potential beneficial roles of ecological/organic agriculture methods.

In addition, farming itself can suffer from pollination limitation, reflecting the often-difficult co-existence of industrial agriculture with the pollinators on which it, in part, depends.

Climate change

Many of the predicted consequences of climate change, such as increasing temperatures, changes in rainfall patterns, and more erratic or extreme weather events, will have impacts on pollinator populations. Such changes might affect pollinators individually and ultimately their communities, reflected in higher extinction rates of pollinator species (UNEP, 2010).

For example, it has been documented how honeybees in Poland are responding to changes in climate by advancing the date of their first winter flight (the wakening moment after winter), part of a phenomenon often known generally as “season creep”. The first winter flight date has advanced by over one moth during 25 years of observations, and this is attributed to increasing temperatures (Sparks et al, 2010).

In addition to species level effects, climate change will very likely affect the interaction between pollinators and their sources of food, i.e. flowering plants, by inter alia changing the dates and patterns of flowering. Recent analysis has suggested that between 17% and 50% of pollinator species will suffer from food shortages under realistic scenarios of projected climate change that cause modified plant flowering pattern plants (Memmott et al, 2007). The authors concluded that the anticipated result of these effects is the potential extinction both of some pollinators and some plants and hence the disruption of their crucial interactions (Memmott et al, 2007).

In conclusion, climate change – in addition to its predicted impacts in the form of species extinctions – may also lead to “the large-scale extinction of interactions which are responsible for a key ecosystem service, that of the pollination of plants.” (Memmott et al, 2007).

Image February 2013: Greenpeace activists and local beekeepers hand a 80,000 signature petition to the Swiss government, calling for the protection of the bees and an end to pesticide use.

4

Insecticides

Insecticides are a particular class of pesticide specifically designed to kill insect pests of crops and livestock, or in domestic environments. They kill or repel insect pests at high enough doses (lethal), but they also may have unintended (sub-lethal) effects at low doses on non-target insects, including upon the natural enemies of pests and upon pollinators (Desneux et al, 2007). Because of their intrinsic nature and function, insecticides are the group of pesticides that pose the most direct risk to pollinators.

Although the relative role of insecticides in the global decline of pollinators remains poorly characterised, it is now more evident than ever that some insecticides show clear negative effects on the health of pollinators, both individually and at the colony level (Henry et al, 2012; Whitehorn et al, 2012; Easton and Goulson, 2013; Mullin et al, 2010). This is clear even when most studies of the effects of insecticides are focussed primarily upon acute effects taking place at relatively high levels of exposure. More subtle, long-term effects of exposure to low doses have not been consistently analysed or targeted in toxicity studies. In addition, most studies have focused on the honeybee (and to a lesser extent upon the bumblebee), neglecting the potential impacts upon other of the many species of wild pollinators that are clearly important for crop pollination and biodiversity maintenance (Potts et al, 2010; Brittain et al, 2013a; Easton and Goulson, 2013).

Insecticides, both at high and low doses, can potentially impact pollinators even though they have not been deliberately targeted. Such chemical exposure, however, tends to be fairly ubiquitous for a number of reasons:

1. Agriculture, globally, now uses the highest volume of pesticides than at any other point in history (Tilman et al, 2001).

2. Residues of insecticides can reach, and potentially persist, in many places around treated crops that also provide habitat for many pollinator species. Residues of insecticides can, for example, persist in farm soils, be mobilised in dust and air following seeding operations or spraying, reach watercourses around farms, or be present in pollen and nectar of crop plants and neighbouring weeds. They may ultimately be found in the wax of hives (Mullin et al, 2010).

3. Some insecticides are systemic, meaning that they do not stay outside when applied to a plant, but enter the plant system and travel through it. For example, some neonicotinoid insecticides, which are systemic in mode of action, are coated around a seed to protect it when planted. When the coated seed starts to germinate and grow, the neonicotinoid chemicals become distributed through the plant stems and leaves, and may eventually reach the guttation water (drops of water produced by the seedling at the tip of the young leaves). Bees often drink from these guttation drops in fields of coated-seeds crops, and thus will be exposed to this chemical (Girolami et al, 2009). Further, when a plant grown from a neonicotinoid coated-seed produces flowers, residues of the chemical can also be found in pollen and nectar. Consequently, bees feeding on these flowers will potentially be exposed to the chemicals in this way as well. The increased use of neonicotinoids means there is a greater potential for pollinators to be exposed to these chemicals over longer periods, as systemic insecticides can be found in various places throughout the life cycle of a plant, growing from coated seed, to guttation water, and to the pollen and nectar of plants throughout their blooming period (Ellis, 2010).

Effects of insecticides on pollinators can be described as *acute* or *lethal,* when the effects are quick and severe and cause rapid mortality, and *sub-acute* or *sub-lethal*, when the effects do not induce mortality in the experimental population, but may provoke more subtle physiological or behavioural effects in the longer term, for example by impacting learning performance, behaviour or other aspects of neurophysiological performance (Desneux et al., 2007).

Historically, most attention has been given to the acute impacts of chemicals on honeybees, while the problems of sub-lethal effects, that might nevertheless impact pollinator health and reduce agricultural production, were less well understood and much more poorly documented. Even so, there are abundant examples of documented sub-lethal effects (Desneux et al, 2007), and these can be classified in four loose groups based on the nature of the observed effects:

1) Physiological effects, which occur at multiple levels, and have been measured as developmental rate (i.e. time required to reach adulthood) or malformation rates (i.e. in the cells inside the hive), for example.

2) Perturbations of the foraging pattern of honeybees, for example through effects on navigation and behaviour.

3) Interference with feeding behaviour by repellent, antifeedant, or reduced olfactory capacity effects.

4) Impacts of neurotoxic pesticides on the learning processes (i.e. flower and nest recognition, spatial orientation) of insects, which are very relevant and have been largely identified and studied in the honeybee.

Examples of sub-lethal effects

Physiological and developmental effects

The pyrethroid deltamethrin has been shown in laboratory analysis to affect a wide range of cellular functions in honeybees, for example by causing marked dysfunctions in the heart cells, with changes in the frequency and force of cardiac contractions. In addition, when associated with the chemical prochloraz, it has been shown to affect thermoregulation and cause hypothermia in honeybees, although this effect is not observed when deltamethrin is used alone (Desneux et al, 2007).

Exposure to low sub-lethal concentrations of the neonicotinoid thiamethoxam in the Africanised honeybee can cause impairment in the function of the brain and mid-gut, and contribute to lifespan reduction (Oliveira et al, 2013).

The neonicotinoid imidacloprid has shown damaging effects even at very low doses on bumblebee colony development, and especially on queen bees (Whitehorn et al, 2012). Bumblebees eating food contaminated with tiny amounts of imidacloprid do not grow so well, and as a result their colonies are smaller (8-12% smaller). More importantly, this translates into a disproportionately large decline in the number of queens: one or two queens as compared to the 14 found in pesticide-free colonies. Queens are fundamental to colony survival, as they are the only individuals that survive the winter and go on to found colonies the following spring (Whitehorn et al, 2012).

A recently published laboratory study (Hatjina et al, 2013) has shown that exposure to sub-lethal doses of the neonicotinoid imidacloprid resulted in marked changes in the respiratory pattern of bees, and also in hypopharyngeal glands growing to a smaller size as compared to untreated bees. The researchers concluded that physiological impacts caused by exposure to imidacloprid needed to be considered in addition to other measures of impact because they too have implications at both the individual level and at the level of the whole colony.

Mobility

Under laboratory observation, the neonicotinoid imidacloprid was found to affect the mobility of honeybees at low doses. This effect was dose-dependent and changed with time (Suchail et al, 2001; Lambin et al, 2001), revealing that the time of observation could be crucial in detecting some of the more subtle effects of insecticides.

In another laboratory experiment, sub-lethal doses of imidacloprid caused significant reductions in mobility. Bees were less active than untreated bees, although this effect was transitory. Bees also showed a loss of ability to communicate, and this could have profound effects upon social behaviour (Medrzycki et al, 2003).

Navigation and orientation

For some pollinators, visual learning of landmarks is important for spatial orientation. For example, honeybees use visual landmarks to navigate to a food source, as well as to communicate accurately to the rest of the colony about distance and direction to it. Pesticides might affect both the learning of visual patterns during foraging trips and the communication of this information back in the hive.

The pyrethroid deltamethrin has been shown to alter the homing trips of foragers treated topically with sub-lethal doses, decreasing the number of flights back to the hive in treated foragers (Vandame et al, 1995).

A recent highly sophisticated study performed under semi-natural conditions with honeybees showed that bees eating pollen or nectar contaminated with the neonicotinoid thiamethoxam, even at very low doses, can get lost on their way back home. As a result, they are twice as likely to die within a day, making the colony weaker and putting it at greater risk of collapse (Henry et al, 2012).

The neonicotinoid imidacloprid has also been shown to impact honeybee foraging trips at low concentrations, causing delays in feeding trips and increased losses when bees are fed sub-lethal doses of the pesticide (Yang et al, 2008).

Foraging trips of honeybees were reduced by between 20% and 60% when exposed to either the neonicotinoid imidacloprid or the pyrethroid deltamethrin. Deltamethrin also induced changes in learning capabilities (Ramirez-Romero et al, 2005).

Feeding behaviour

> *"In the case of honey bees, impaired feeding behaviour can induce a drastic decline in hive population. Most of the large-scale farming areas, when food resources are reduced to cultivated plants, the repellent effect of pesticides may reduce pollen and nectar uptake, potentially leading to a demographic decrease of the colony."*
>
> – Desneux et al, 2007

Pyrethroids are probably the best-known case of pollinator-repellent insecticides, and this avoidance behaviour was assumed in many cases to be an adaptation for reducing the risk of exposure (Desneux et al, 2007). However, it was subsequently shown that pyrethroid applications during peak foraging activity (in broad daylight) result in high exposure levels (see discussion in Desneux et al, 2007).

> *"Therefore, a repellent effect must not be misconstrued as providing any protection against exposure to pesticides."*
>
> – Desneux et al, 2007

Pesticide exposure can also reduce the capacity of bees to detect food sources. For example, fipronil applied topically at low concentrations to honeybees decreased their capacity to sense low-sucrose concentrations by about 40% relative to the capacity of untreated bees (El Hassani et al, 2005).

Imidacloprid repels some pollinators (pollinating flies and beetles), so their exposure might be reduced, but as a result pollinators could starve if the only feed available is from imidacloprid-treated crops in agricultural regions. In addition, if insects do avoid visiting the flowers of treated crops, this could impact adversely on crop yields, depending upon the strength of the response and how abundant the pollinators are (Easton and Goulson, 2013).

Learning performance

Effects of pesticides on learning processes have been the target of several studies in honeybees, because of the importance of learning to their foraging efficiency, and because they offer a reasonably well understood system (Desneux et al, 2007). Olfactory learning and memory in honeybees play a crucial role in their feeding strategy and the efficiency of foraging trips, both at the individual and at the colony level. Thus, negative effects of long-term exposure to low concentrations of pesticides could play a critical role in honeybee colony health.

In laboratory conditions, the neonicotinoid thiamethoxam and fipronil at sub-lethal doses decreased the olfactory memory of bees. Honeybees were unable to discriminate between a known and an unknown odorant. Fipronil-treated bees also spent more time immobile (Aliouane et al, 2009).

In bioassay experiments with different pesticides, honeybees surviving oral exposure to imidacloprid, fipronil, deltamethrin and endosulfan showed reduced learning performance in the longer term (Decourtye et al, 2004; Decourtye et al, 2003; Decourtye et al, 2005). Low-dose exposure of honeybees to imidacloprid seems to impair their medium-term olfactory memory (Decourtye et al, 2004). The consequences of these chronic effects on foraging behaviour are still uncertain (Desneux et al, 2007).

The impacts of sub-lethal effects of pesticides on other pollinator communities

Sub-lethal effects of pesticides seem to affect multiple functions involved in the health of honeybee and bumblebee communities (i.e. foraging, fecundity, mobility). It is possible that they impact on other pollinator communities as well. The analysis of sub-lethal effects on the community ecology of many pollinators remains very poorly understood (Desneux et al, 2007). In addition, most examples of how insecticides affect pollinators are at the species level, and there is little information on the impacts on wild pollinators at the community level.

Honeybees have often been used as a model organism to study sub-lethal effects of pesticides on pollinator communities, but they are considered to poorly represent effects on other pollinators, including other bees. Indeed, bees are a very diverse group, with major differences in their vulnerability to pesticide exposure.

> *"In honey bees, pesticides may affect social organisation (reduction of food uptake or reduction of worker/brood population), but these effects may be compensated for because the queen does not take part in foraging and is probably less likely to be exposed than workers. In contrast, in other social pollinators such as bumblebees, the queen must find food during spring in order to found the colony. In this case, the potential negative effects of pesticides may substantially affect colony establishment. In summary, social pollinators having no perennial colony and no social pollinators are more likely to suffer from insecticide exposure."*
>
> – Desneux et al, 2007

In addition, pollinators with certain traits may be more vulnerable to insecticides. For example, aphidophagous hoverflies lay their eggs within crop fields, potentially exposing their offspring to insecticides (Brittany and Potts, 2011). Differential risks related to specific pollinator traits or life habits could result in disturbance by insecticides. This exposure could alter the pollinator community composition and therefore possibly alter the floral community in turn, in a non-random way (Brittany and Potts, 2011). Such potential effects serve as a warning about unexpected impacts of bee-harming pesticides on other pollinators, and as a reminder of the need to apply the precautionary principle to protect pollinators as a whole, both managed and wild. Other pollinators might still be at risk from the impacts if proposed restrictions on bee-harming pesticides are only applied to those crops attractive to honeybees.

Exposure to multiple pesticide residues and synergic effects

In industrial agricultural areas there is high potential for exposure of pollinators to a mixture of agrochemicals, including insecticides, herbicides, fungicides, and others.

Herbicides may affect bees by limiting the food resources available to them and to other pollinators, especially if the large-scale crop monocultures typical of industrial agriculture are also present (Brittany and Potts, 2011). The body size of the pollinator might determine the overall impact, with smaller species being more impacted. Larger bees might be able to fly further foraging for food, but smaller ones might starve (Brittany and Potts, 2011).

> *"Herbicides have also been found to increase the toxicity of a number of insecticides in flies and mice, but this has not been documented for bees. A sub-lethal impact of an insecticide that reduces bees' foraging efficiency may have more damaging consequences for its health if the bees are exposed at a time when its food resources have been reduced by the application of herbicides."*
>
> – Brittany and Potts 2011

Farmers routinely apply fungicides to many bee-pollinated crops during the blooming period when bees are foraging, as they are classified as less toxic to bees, and currently there are few restrictions to this practice. However, some fungicides have exhibited direct toxicity to honey or solitary bees at field use rate (Mullin et al, 2010). Equally as worrying, some fungicides have been found to increase the toxicity to honeybees of pyrethroid insecticides (Brittany and Potts, 2011).

Several studies indicate the possibility of synergistic interactions of pesticides with fungicides. Ergosterol-biosynthesis-inhibitors (EBI) interacts synergistically with pyrethroids (Nørgaard and Cedergreen, 2010). Exposure to deltamethrin in combination with the fungicides prochloraz or difenoconazole induced hypothermia in honeybees at doses that did not induce a significant effect on thermoregulation when used alone (Vandame et al, 1998). Another study found that a common neonicotinoid, thiacloprid, becomes some two orders of magnitude times more toxic to honeybees when combined with the fungicide propiconazole, and some three orders of magnitude times more toxic when combined with triflumizole (Iwasa et al, 2004).

EFSA in a late 2012 report stated: "Significant synergy has been reported between EBI fungicides and both neonicotinoids and pyrethroid insecticides but in some cases where high levels of synergy are reported the doses of fungicides have been well in excess of those identified in the exposure section of this report. … Greater synergy is observed in the laboratory between EBI fungicides at field rates application rates [sic] and pyrethroids used as varroacides (flumethrin and fluvalinate) and between coumaphos and fluvalinate varroacides." (Thompson, 2012).

However, the implications of these results and of the potential interactions of fungicides with other insecticides remains very poorly characterised, despite the potential importance of such findings (Mullin et al, 2010).

In addition to interactions between different pesticides, insecticides have also been shown to interact with other stress-causing factors, such as parasite infestations (Alaux et al, 2010, Wu et al, 2012). For example, "the mortality of honeybees from the insecticide imidacloprid (neonicotinoid) was found to be greater in bees infected with the parasite Nosema and a synergistic interaction between the two factors was found to reduce enzyme activity related to colony-food sterilisation" (Alaux et al, 2010; Brittany and Potts, 2011).

> *"Pollinators are being increasingly exposed to a cocktail of pesticides, for instance up to 17 different pesticides detected in just one sample of pollen from a honeybee colony (Frazier et al, 2008); and this has unknown consequences for bee health and pollination services. Given the prediction of increasing global pesticide production (Tilman et al, 2001) and cultivation of pollinator dependant crops (Aizen et al, 2008), this issue is likely to increase in importance in the future. There are difficulties in disentangling the impacts of insecticides from other aspects of agricultural intensification, and the cumulative and synergistic effect of multiple insecticide applications further complicates the issue."*
>
> – Brittany and Potts 2011

Residues of pesticides in honeybee hives

The largest sampling exercise carried out to date – of pesticide residues in honeybee hives, which targeted pollen, wax and the bees themselves – was recently performed in North America. This showed that honeybees are routinely exposed to multiple pesticides (Mullin et al, 2010). The authors found "unprecedented levels of miticides and agricultural pesticides in honeybee colonies from across the US and one Canadian province".

This study clearly showed that bee-collected pollen might contain high levels of multiple pesticide residues, including significant amounts of the insecticides aldicarb, carbaryl, chlorpyrifos and imidacloprid, the fungicides boscalid, captan and myclobutanil, and the herbicide pendimethalin. They also found high levels of fluvalinate and coumaphos. These latter two are miticides that are often applied by beekeepers within their hives to control Varroa infestations.

Pollen is the main protein source for honeybees, and it plays a crucial role in bee nutrition and colony health. Interactions between multiple pesticides seem entirely possible when so many different residues are present in the environment around bees. Ten pesticides were found in pollen at greater than one tenth the bee LD50 level, indicating that sub-lethal effects of these toxicants alone are possible (Mullin et al, 2010). Overall, "surviving on pollen with an average of seven different pesticides seems likely to have consequences".

In addition to insecticides, fungicides were the most significant pesticide residues found in pollen. The authors noted a correlation between some fungicides and poor health in the hives (Mullin et al, 2010). As explained above, fungicides might exacerbate the damaging effects of some insecticides on honeybees.

Highly toxic pyrethroids, including deltamethrin and bifenthrin, were the most frequent and dominant class of insecticide found in the North American survey, at levels that could prove lethal to honeybees under some conditions. In addition, pyrethroids are often applied by farmers together with certain fungicides, some of which, again, have been shown to increase the toxicity of some pyrethroids to bees

> *"Potential for interactions among multiple pyrethroids and fungicides seems highly likely to impact bee health in ways yet to be determined."*
>
> – Mullin et al, 2010

Neonicotinoid residues were often found on pollen and in wax, generally at lower levels than pyrethroids. However, one pollen sample contained an exceptionally high level of imidacloprid. The potential for neonicotinoids to interact with other pesticides remains poorly understood (Mullin et al, 2010).

The authors conclude: "The widespread occurrence of multiple residues, some at toxic levels for single compounds, and the lack of any scientific literature on the biological consequences of combinations of pesticides, argues strongly for urgent changes in regulatory policies regarding pesticide registration and monitoring procedures as they relate to pollinator safety. This further calls for emergency funding to address the myriad holes in our scientific understanding of pesticide consequences for pollinators. The relegation of bee toxicity for registered compounds to impact only label warnings, and the underestimation of systemic pesticide hazards to bees in the registration process may well have contributed to widespread pesticide contamination of pollen, the primary food source of our major pollinator. Is risking the $14 billion contribution of pollinators to our food system really worth lack of action?" (Mullin et al, 2010).

Sampling in Europe of honeybee hive material has also shown residues of pesticides. For example, in apiaries across Spain, both acaricides (to fight mites) and agriculture pesticides were found in beebread, including some insecticides with high sub-lethal bee-toxicity, namely cypermethrin, deltamethrin and chlorpyrifos. Acaricides were found in much higher amounts than agricultural pesticides (Orantes-Bermejo et al, 2010). In Slovenia, honeybee colonies based in apple orchards treated with insecticides showed residues in beebread up to 16 days after treatment for diazon, and in pollen loads up to 6 days after application of thiacloprid and up to 10 days after application for diazinon (Škerl et al, 2009).

Shortlist of bee-harming pesticides: the seven priority bee-harming chemicals

Based on available evidence on pesticide usage in Europe, and impacts on bees and other pollinators, we have drawn up a list of bee-harming pesticides that should be eliminated from the environment in order to avoid any acute poisoning with lethal effect, and potential sub-lethal harm, to pollinators. Based on current scientific evidence, Greenpeace has identified seven priority insecticide chemicals that should be restricted in use, and eliminated from the environment in order to avoid exposure of bees and other wild pollinators to them. These seven priority chemicals are **imidacloprid, thiamethoxam, clothianidin, fipronil, chlorpyriphos, cypermethrin** and **deltamethrin**. See Table 1 for a brief summary on the characteristics of each pesticide, and some references that evidence potential harms and the need to apply the precautionary principle to exclude their presence in the environment.

Neonicotinoid pesticides

Neonicotinoids have become one of the most commonly used insecticides over the past few decades. There are two neonicotinoid subclasses: nitroguanidines and cyanoamidines. Nitroguanidines, which include imidacloprid, clothianidin, thiamethoxam and dinotefuran, are acutely toxic to honeybees, and their oral toxicity is extremely high at 4-5 ng/ individual bee. According to the manufacturers of these insecticides, neonicotinoids have been "the fastest growing class of insecticides with widespread use against a broad spectrum of sucking and certain chewing pests." (Jeschke et al, 2010). Parallel to this growth in use has been increasing concern about their potential effects on pollinators, especially on honeybees and bumblebees (many research papers have been produced together with reviews by UNEP, and most recently by the European Food Safety Authority (EFSA)). However, policy makers have been slow in responding to the concerns, except in some countries such as France or Italy that have made tentative steps in the right direction towards increased regulation. Even so, the increased regulation does not provide a complete safeguard for pollinators (EEA, 2013).

EFSA has very recently articulated its concerns about the risks associated with certain uses of three neonicotinoids (clothianidin, imidacloprid and thiamethoxam)[4], and it has asked the European Commission to consider changes in the regulation of these substances. Opposition from some Member States, however, and strong lobby efforts from industry, seem to be slowing down any attempt to change current approvals in light of the risks that have been identified. These three neonicotinoids are among the biggest selling insecticides in the world, and account for 85% of the neonicotinoid insecticide market worth $2,236m US dollars in 2009) (Jeschke et al, 2010). Imidacloprid is the biggest selling insecticide in the world, with sales of $1,091m in 2009 (Jeschke et al, 2010).

Greenpeace believes that the identified concerns are compelling enough to reasonably suspend the use of a number of bee-harming pesticides completely, including the neonicotinoids. Suspending only certain specific uses cannot, in itself, guarantee the safety of all species of pollinators. As the authors of a recent study looking at the effects of imidacloprid on other pollinators like flies and beetles observed: "indeed, almost nothing is known of the impacts of neonicotinoid pesticides on the behaviour of non-target insects other than bees… In general, it is remarkable how little we understand about the environmental toxicology of this widely used class of insecticides." (Easton and Goulson, 2013).

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[4] http://www.efsa.europa.eu/en/press/news/130116.htm

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What we can do to protect bees and other pollinators

The threats to both wild and managed pollinators are real, significant and complex. Addressing all the threats in an integrated way will be an immense, yet fundamentally necessary, task. What seems clear is that taking steps to address one of the major sets of the current factors affecting pollinators, i.e. the impacts of chemical-intensive agriculture, will be crucial steps in the right direction. Any progress in transforming the current destructive chemical-intensive agricultural system into an ecological farming system will have many associated benefits on other dimensions of the environment and of human food security, besides the clear benefits to global pollinator health.

Transforming the current system into one that fulfils both environmental protection ambitions and global food needs is a daunting task, and one that needs strong progressive steps towards a robust long-term vision. An important one of these steps is to work towards avoiding harm to pollinators by eliminating exposure to potentially bee-harming pesticides. In doing so, key components of natural and managed ecosystems will be protected both directly and indirectly.

In the short to medium term there are specific issues that modern society can move to address with immediate effect that will benefit global pollinator health. The benefits could become evident almost immediately. Based on analysis of the current science on global pollinator health, Greenpeace believes that eliminating exposure to established bee-harming pesticides is a crucial step in safeguarding bees, both managed and wild, and the high ecological and fiscal value of natural pollination.

Some examples of scientifically based short to medium term actions to help reverse the decline of global pollinators fall into two basic groups:

1) avoid harm to pollinators (e.g. through eliminating exposure to potentially harmful substances); and

2) promote pollinator health (e.g. through changing other practices within agro-ecosystems).

Avoiding harm to pollinators by eliminating use and exposure to potentially bee-harming pesticides

In the preceding chapters of this report we have summarised the current science pointing at significant risks associated with the use of some bee-harming pesticides. This science is clear and strong: the potential harm of these pesticides far exceeds any presumed benefits of increased agricultural productivity. In fact, any perceived beneficial trade-offs are likely to prove completely illusory. The European Food Safety Authority (EFSA) has confirmed the potential risks of some of these pesticides (three neonicotinoids)[5], while it is accepted that the economic benefits of pollinators are, in parallel, very significant.

In addition, the expansion of integrated pest management (IPM) and organic agriculture, particularly in Europe[6], demonstrates that farming without pesticides is entirely feasible, economically profitable, and environmentally safe (Davis et al, 2012). Even in Italy, where the use of some bee-harming pesticides was suspended for coated seeds a few years ago, farmers have not reported increases in pest problems after discontinuing use of these biocides. On the contrary, farmers reported no statistically significant decreases in yields as a result of quickly adopting and observing more judicious regulation of bee-harming pesticides (APENET, 2011).

[5] "EFSA identifies risks to bees from neonicotinoids". Press release dated 16 January 2013 http://www.efsa.europa.eu/en/press/news/130116.htm

[6] "Organic farming is a sector of European agriculture which has seen a constant growth in recent years." http://ec.europa.eu/agriculture/organic/home_en

Nevertheless, farmers need more support in finding new ways of protecting their crops against pests in a non-toxic, environmentally safe way. There is a clear need for more research and development on those alternatives. In addition, it will be crucial to increase the promotion of those alternative solutions that already exist. This should include support to make them available commercially, once their efficiency has been trialled and established.

Enhancing the health of pollinators, both within agroecosystems and in semi-natural habitats

Increasing diversity and abundance of flower resources within agriculture landscapes

Industrial agricultural landscapes are often effective deserts for bees. When large-scale monocultures dominate – with few flowering plants, overall low plant diversity, and large-scale use of herbicides – bees may find it difficult to find adequate food.

Many practices that increase plant diversity, at different scales, can improve the flower resources available to pollinators, both in space and time. For example, at the scale of individual sites, including crops that provide large flushes of pollen and nectar – such as red clover, sunflowers, melon, oilseed rape, or almonds – can enhance conditions for pollinators in the short term (Kremer et al, 2007).

At the farm level, pollinators benefit from growing or preserving alternative forage before and after blooming of the main crop. Maintaining flower-rich field margins, set asides, grassy borders or permanent hedgerows (Kremer et al, 2007; Carvell et al, 2004) are effective ways of doing this. Intercropping with different varieties of crop plants that attract beneficial insects, including pollinators, also serve as a "reservoir" of flowers (Kremer et al, 2007). Annual communities of plants otherwise regarded as weeds can also support healthy pollinator communities (Morandin and Winston, 2006). Orchards and olive groves, for example, can be managed efficiently, but with high biodiversity to build habitats for wild pollinators (Potts et al, 2006).

On a wider, local scale, integrating semi-natural areas into managed agricultural areas can increase the abundance of, and pollination services from, wild pollinators. Wild pollinator abundance in farms is often associated with the existence of nearby natural or semi-natural areas, and can significantly increase the production of vegetables, as shown in the case of field-grown tomatoes in California (Greenleaf and Kremen, 2006). Increasing the overall diversity of pollinators to encourage, for example, the presence of both managed honeybees and wild bees, has recently been shown to improve pollination success and fruit production in almond orchards (Brittain et al, 2013b). In mango orchards, fruit production was significantly higher per tree in orchards that had a plot of wild flowers maintained in their margins. Production was also improved by proximity of the orchard to natural areas, and low pesticide use (Carvalheiro et al, 2012). Combining native flower plots with areas of natural habitat within agricultural regions encourages wild bees in productive areas, and can boost pollination and yields while at the same time preventing loss of natural habitats to damaging agricultural practices.

Wild insect pollinators, mostly many species of bees but also some flies, butterflies and beetles, are gaining importance as drivers of pollination services in agriculture landscapes. A very recent global analysis showed that, in sites with lower diversity and abundance of wild insects, crops are less productive regardless of how abundant honeybees are around a farm site (Garibaldi et al, 2013). This highlights the importance of conserving wild pollinators not only for biodiversity preservation, but also for their crucial role in food production. Honeybees are important, but they cannot replace the efficient pollination role played by a diversity of wild insects around crops (Garibaldi et al, 2013).

It has been shown that cherries are pollinated more efficiently, and thus are more productive, when visited by wild bees as compared to managed honeybees (Holzschuh et al, 2012). In turn, the abundance and diversity of wild bees was linked to natural habitats maintained in the proximity of the cherry orchard. The effect of natural habitats and wild bee presence on fruit productivity is actually rather a strong one: "An increase of high-diversity bee habitats in the landscape from 20% to 50% enhanced fruit set by 150%." The authors concluded: "Farmers need to protect semi-natural habitats in their landscapes to guarantee pollination and high yields". (Holzschuh et al, 2012).

Natural pollinators like bumblebees have been shown to travel longer distances to forage in more diverse flower patches (Jha and Kremen, 2013). This finding further suggests that actions to promote species-rich flowering patches, in both natural and managed landscapes, could magnify the benefits of wild pollination services. This offers a great opportunity to involve farmers, land managers, and even urban dwellers, in actions that simultaneously promote both biodiversity conservation and pollination services (Jha and Kremen, 2013).

> *"The integration of unmanaged land into agricultural areas can achieve conservation issues and a protection of ecosystem services at rather low economic costs."*
>
> – Lautenbach et al, 2012

Farming with high biodiversity and without agrochemicals: ecological, organic, sustainable systems

It has been shown that when a site has higher diversity and abundance of pollinators, crop flower pollination is more successful, and hence fruit and seed production is increased. This has been demonstrated in experiments with oilseed rape crops. Increased yield and greater market value resulted from increased pollination success (Bommarco et al, 2012).

Farming at the same time as maintaining high biodiversity, and without any application of chemical pesticides or fertilisers as is the case with organic or ecological farming methods, has repeatedly been shown to benefit pollinator abundance and richness. These techniques also benefit crop pollination, and hence potential yields (Morandin and Winston, 2005; Andersson et al, 2012). However, the benefits of organic or other non-chemical farming upon pollinator health remain poorly studied. More importantly, these alternative methods are often neglected as a potentially very effective tool for protecting and enhancing bee populations.

A recent study in Sweden clearly showed how strawberry crops benefited from organic farming. Organic strawberries received more pollinators and achieved higher pollination success than conventionally grown strawberries, and this difference was evident quickly after the conversion from conventional to organic farming. The authors concluded that organic agriculture benefited crop pollination in terms of both the quantity and quality of the yield. (Andersson et al, 2012).

Ecological farming practices can benefit both pollinator diversity and abundance, particularly in more intensively farmed agricultural landscapes (Batáry et al, 2011; Holzschuh et al, 2008). This can confer benefits in the form of achieving full yield potentials in crops (Kremen and Miles, 2012). A comparison of wild bee abundance in organic, conventional and genetically engineered (GE) herbicide-resistant canola farms in Canada showed that organic canola fields had the highest bee abundance and the lowest pollination deficits (defined as the increase in seed production per fruit with supplemental pollination) compared to either conventional or GE crops (see Figure 2) (Morandin and Winston, 2005). Conventional fields were intermediate in terms of bee abundance and pollination limitations, while GE herbicide-tolerant canola showed the lowest bee abundance and the highest pollination deficit. Although the reasons for the highest pollination limitation in GE herbicide-tolerant canola remain uncertain, it seems plausible that high application of the herbicide glyphosate could impact bee population health either directly, or indirectly through a decrease in flower resources. It is possible that "a genetically modified crop variety designed to improve yields through weed management might have the undesired consequence of reducing bee abundance in the field", thus limiting crop yield (Morandin and Winston, 2005).

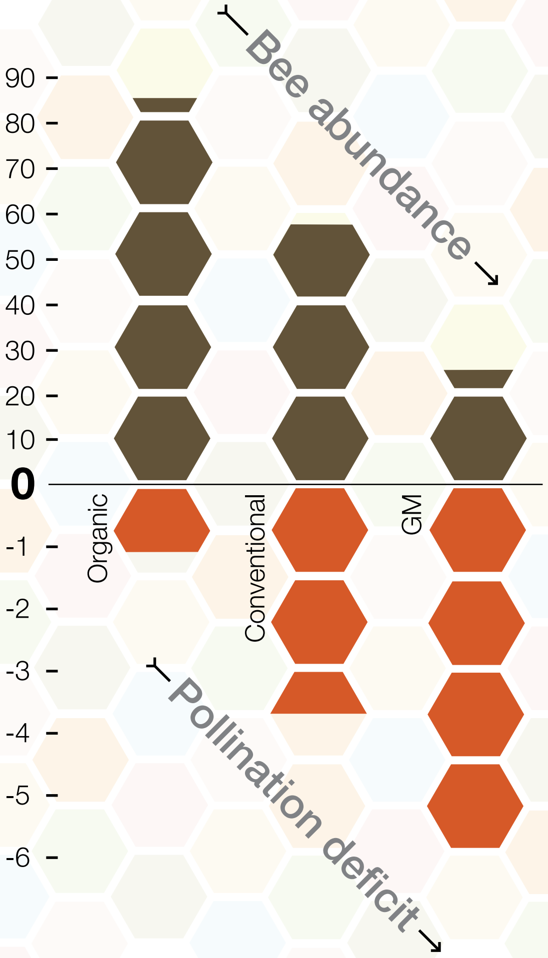

Figure 2. Bee abundance and pollination deficits (mean ± standard errors) for each field type (number of fields per treatment = 4). Bee counts (above bars) and levels of pollination deficit (below bars) were significantly different among the three field types. Figure reproduced with permission from Morandin LA & Winston ML (2005). "Wild Bee Abundance and Seed Production in Conventional, Organic, and Genetically Modified Canola." Ecological Applications 15(3): 871-881.

The benefits of organic farming in terms of the diversity and abundance of pollinators that it supports can also extend to neighbouring conventional farming sites. In German wheat fields, organic practices increased richness of pollinators by 60%, and abundance by 130-160%, relative to conventional practices (Holzschuh et al., 2008). Furthermore, the increase of organic farm area at the landscape level from 5% to 20% enhanced pollinator diversity and abundance by more than 60% on both organic and on conventional fields (Holzschuh et al, 2008; Kremen and Miles, 2012).

Diversified farming systems, like those under organic or ecological production methods, bring out many benefits in addition to increased pollination services; they enhance the control of weeds, diseases, and insect pests (Kremen and Miles, 2012). However, these systems have received significantly less public funding for research as a means of improved management, compared to conventional farming systems. This lack of support is remarkable, given that ecological and organic farming systems can produce approximately the same amount of food and profits as conventional farming, while generating far fewer environmental and social harms (Kremen and Miles, 2012; Davis et al, 2012). Estimates by Urs Niggli, director of the Research Institute of Organic Agriculture (FiBL) in Switzerland are illuminating. He estimates that, of a budget of some $52bn annually spent on agricultural research, less than 0.4% goes towards researching and evaluating organic-specific initiatives[7].

Accordingly, more public and private funding is needed for research and development on ecological farming practices that maximise ecological services, alongside food production and environmental protection, while at the same time helping social and economic development (IAASTD, 2009).

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[7] "Network to push scientific case for organic farming", SciDev Net, 22 February 2013. http://www.scidev.net/en/agriculture-and-environment/farming-practices/news/network-to-push-scientific-case-for-organic-farming.html

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Conclusions and recommendations

Actions needed to protect the health of bees and other pollinators.

> *"The benefit from pollination is high enough in a large part of the world to seriously affect conservation strategies and land-use decisions if these values were taken into account. Implications reach from projects working with traditional local farmers to provide a sustainable livelihood to promoting pollinator restoration and conservation across the world."*
>
> – Lautenbach et al, 2012

European agricultural policies, first and foremost the Common Agricultural Policy (CAP), should incorporate current scientific evidence about the benefits of and threats to populations of both managed honeybees and wild pollinators. Urgent action is required to protect the essential ecosystem service of pollination. The evidence outlined in this report of tools that already exist to protect pollinators should be incorporated into agricultural policies as a means of encouraging bee-enhancing farming practices.

In addition, EU regulations on the use of potentially bee-harming substances should be emplaced following rigorously the precautionary principle, incorporating current scientific evidence about harms and vulnerability of honeybees, but also extending precaution to other wild pollinators in light of their crucial role in securing pollination services now and in an uncertain future.

Recommendations

Honeybees and wild pollinators play a crucial role in agriculture and food production. However the current industrial chemical-intensive farming model is threatening both, and putting European food at risk. As this report shows, there is strong scientific evidence proving that neonicotinoids and other pesticides play an important role in the current bee decline. As a consequence, policy makers should:

1) **Ban the use of bee-harming pesticides,** starting with the top-ranked most dangerous pesticides currently authorised for use in the EU, i.e. the seven priority bee-harming chemicals imidacloprid, thiamethoxam, clothianidin, fipronil, chlorpyriphos, cypermethrin and deltamethrin.

2) Through the adoption of pollinators' national action plans, **support and promote agricultural practices that benefit pollination services within agricultural systems**, such as crop rotation, ecological focus areas at farm level, and organic farming.

3) Improve conservation of natural and semi-natural habitats around agricultural landscapes, as well as **enhance biodiversity within agricultural fields.**

4) Increase funding for research and development on ecological farming practices that move away from reliance on chemical pest control towards biodiversity-based tools to control pests and enhance ecosystem health. EU policy makers should **direct more funding for ecological agriculture solutions research** under the auspices of the CAP (direct payments) and Horizon 2020 (EU research framework).

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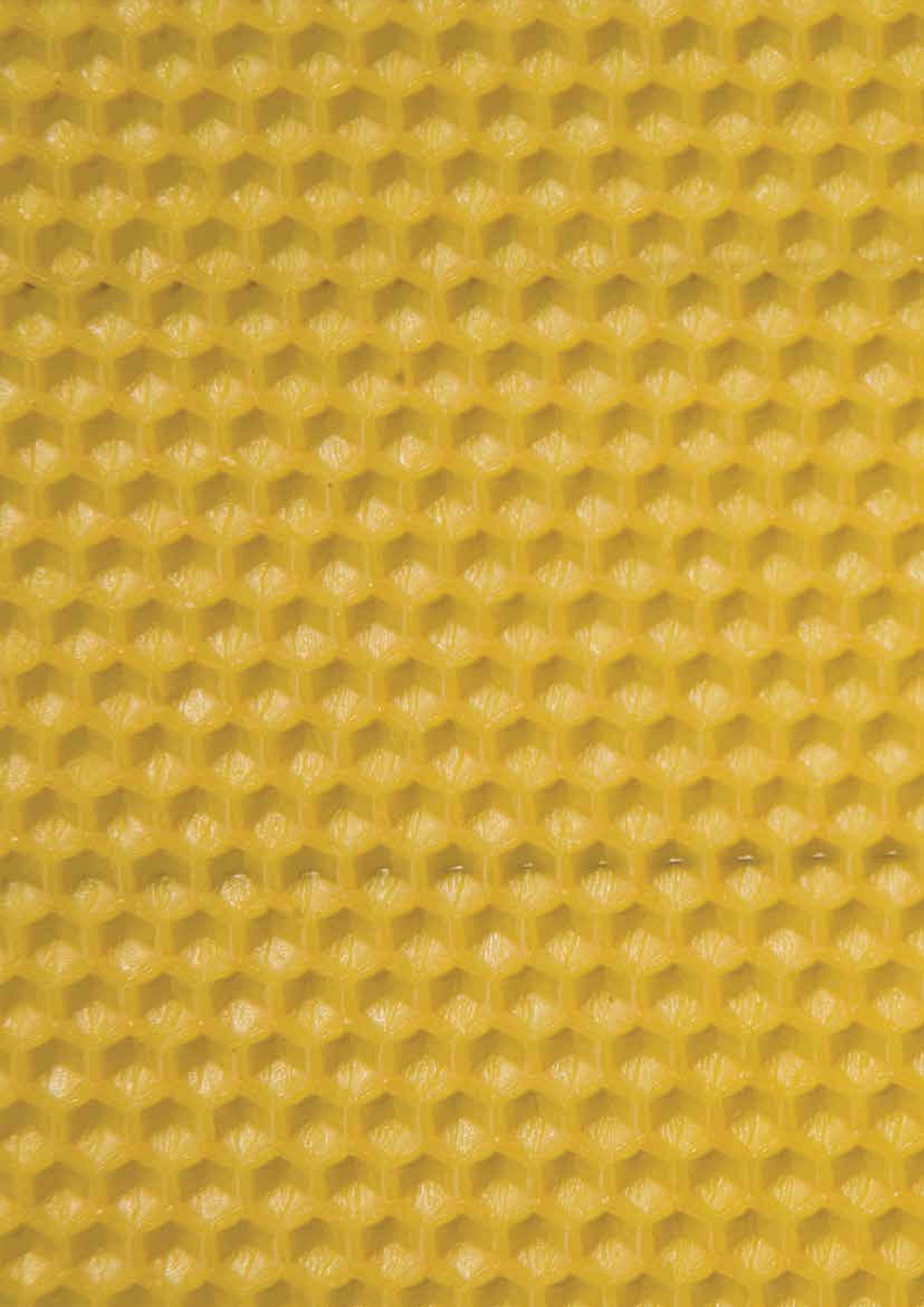

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