The problem with pesticides

Effects on wild species, food production and our environment

"Although, pesticides were used initially to benefit human life through increase in agricultural productivity and by controlling infectious disease, their adverse effects have overweighed the benefits associated with their use."
Gill and Garg, 2014

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1. Executive summary

The use of pesticides (a collective term used in this report for insecticides, herbicides, fungicides and other synthetic chemicals) is widespread in farming, in horticulture, in domestic gardens and household products and for amenity uses such as maintaining parks, housing estates, sports grounds, golf courses, paving and roadsides.

The orthodox view for many years has been that pesticide use is essential and a pre-requisite for food production and security of food supply. It's now increasingly recognised by leading authorities that the widespread, habitual and often indiscriminate use of pesticides isn't fundamental to crop production and is having serious implications for our environment, health and future food security.

A lot of attention has been given to how wild solitary and bumble bees and managed honeybees are affected by exposure to pesticides. Drawing on various scientific studies and reviews of evidence, this paper provides ample evidence of harm to wider nature from the routine use of pesticides.

Species not intended as targets for pesticides are being affected, and there's also evidence of harm to soils and water. For example, in humble earthworms pesticides disrupt behaviour, such as feeding affecting growth, reproduction and survival rates.

Pesticide and herbicide use are implicated in the continued decline of bird species which were once common on farmland, perhaps because of the effects of pesticides on earthworms, insects and other invertebrates sought by birds for food.

Most common chemicals are broad spectrum, meaning they tend to affect more than the intended target species of pest, disease or weed. But the problem with pesticides starts much earlier with how they are tested before being approved for use.

The way pesticides are tested isn't as robust as the public has been told. Testing regimes don't properly assess both the lethal and the sub-lethal (e.g. behavioural and reproductive) effects of a product on the range of species which will be indiscriminately exposed, and whose biology and sensitivity will be very different from a product's intended target.

Pesticides are also usually tested alone rather than for their realistic combined "chemical cocktail" effect when used alongside other treatments, as occurs in real conditions. These combined or synergistic effects aren't well monitored despite the real-world use of different treatments in fields, parks and roadsides across seasons and years. And years is how long some pesticide residues can remain in soils, plant matter and in rivers, water courses and systems. Testing that's transparent and separate from manufacturers' own often secretive testing must be improved.

Proper understanding of the effects of pesticides, including on species and habitats other than the intended targets, is handicapped by the inadequate tracking of pesticides in the environment and the lack of routine monitoring of soil and water. Similarly, the lack of proper monitoring of many wild species compounds the lack of reliable data for how they are affected.

There's also little study into how pesticide use over many years is affecting the food chain and, potentially, human health. Better data on species, habitats and pesticide effects would inform better decisions on products, their licensing, review and, if necessary, withdrawal.

Pesticides are applied prophylactically (see Appendix 1) even if the actual risk of harm from pests or diseases is low or unlikely. To some extent this is understandable as there is a fear of failure, guilt avoidance and risk aversion along with industry and media pressure in which farmers and growers are told what to do, when and how.

Due to inadequate monitoring, the effects of such overuse are unknown although it's readily associated with reduced efficacy of treatments as pests develop resistance, similar to what is being seen with the overuse of antibiotics in treating animals and humans.

The convention of reaching for pesticides, regarding them as an instant solution to solve a problem before one arises, also means that inadequate attention is given to other ways to produce and protect crops which can help restore soil health and water quality, while supporting more diverse wild species, including those that help control pests, on farms and across entire landscapes.

Another feature of the pesticide culture is that farmers, growers, landowners and managers rarely receive impartial advice on ways to improve soil health, crop protection and land management, given that many advisers are linked to pesticide companies. Farmer and growers need a way out from partial advisers making money out of their purchasing choices.

Pesticide use should be a last resort, with priority given to Integrated Pest Management (IPM; see Appendix 2) and other methods to produce and protect crops, and manage land and amenity.

Although not the main focus of this report, evidence is emerging that pesticide exposure can affect brain development and produce subtle effects on foetal development in humans (see Appendix 3).

Summary of recommendations

1. **Set ambitious targets to reduce the use and impacts of pesticides** – based on the frequency of use and toxic load, not on the weight of pesticides used – to signal the scale of change needed, to prompt proper monitoring and to create a new category of farming adviser for food production and nature so that farmers and growers trying to do the right thing are helped by the right system. The core need is to reduce and manage risk rather than just manage pesticides.

2. **Incentivise pesticide reduction and low pesticide use** to end the rising use of pesticides. This should include financial support payments to farmers and landowners to adopt other methods of land and crop management. Just as incentives can be deployed to support greater use of agronomic methods, they can also be geared to reduce pesticide use. For example, payments can support farmers and landowners to adopt other methods of land and crop management, and can be used to support polluter pays policies.

3. **End the prophylactic use of pesticides** so that they're used as a last resort, not a first line of defence. Prioritise other ways to produce and protect crops, and to

manage land in ways which support soil health, water quality and conditions for beneficial creatures which can help to control pests. Many agronomic practices can be deployed more extensively to boost soil quality and fertility, and these techniques and methods require significantly more support.

4. **Properly monitor and assess pesticide use** to discover how chemicals behave in the environment such as indirect effects on aquatic species or to attribute declines or losses of wild plants to pesticide use.

5. **Improve pesticide testing** to cover all species likely to be affected, the synergistic effects of chemicals acting in combination, and the environmental effects after they have been applied. Testing must be transparent with data from testing made public allowing scrutiny that's independent of the pesticides sector.

6. **Improve monitoring and use the evidence to inform ongoing product testing**. This could reduce or avoid the need for further tests when the safety of a product or active ingredient is questioned. Technological advances mean that it's easier to track and monitor pesticides in the environment continuously, allowing more timely assessment of their effects and alteration of their use, and even reviews of their licensing.

7. **Change farming and land use to deliver multiple benefits.** Moving away from agricultural monocultures will optimise more desirable, multi-functional activities. And it will protect and restore the resilience and full functioning of the natural ecosystems, which food and farm production depend on.

8. **Close the gap between producer and user,** reversing the trend that's seen the distance widen between food production and its consumption, which has led to excessive food production, consumption and waste. This excess requires more use of harmful chemicals and increased pressure on agricultural land to be productive, and on other land to be drawn into production. The focus should be on ending inefficiencies in food supply chains.

9. **Improve agronomic advice** to ensure information is independent of the pesticides industry and its advisers and to support better knowledge transfer to and between farmers and growers about managing land, crops and pests. This would help ensure that advice to farmers, landowners and users is no barrier to reduced pesticide use and the adoption of IPM as a primary method of control. The BASIS syllabus for agronomists should be reviewed to ensure training is provided on promoting IPM and deployment of alternative non-pesticide solutions as the primary response to threats of pests and diseases.

10. **Focus on soil quality and fertility,** because there are many agronomic practices exist which can be boost soil quality and fertility. These techniques and methods warrant proper support and adoption, along with incentives and finance streams to support more use.

11. **Boost research into and development of alternatives** that aid pesticide reduction and the adoption of IPM; aid conventional plant breeding and

development of crop varieties to boost tolerance to pests and diseases; support cultural and mechanical measures to control pests and disease; and develop novel chemical solutions with significantly reduced toxicity load.

12. **Change the structure of research** to restore the broken link between research, advisory services, and what farmers and landowners need. The failure to investigate many low-tech, low-input techniques has arisen as research capability to examine them has been lost, with the closure of research stations with attached farms.

13. **Support farmers and land managers with knowledge transfer** geared to adoption of practices such as IPM and backed by continuing professional development. Training delivery should prioritise peer-to-peer learning, involvement of regional teams, and incorporate consideration of local and regional conditions.

14. **Clear government leadership and guidance.** The European Commission has highlighted important shortcomings in EU member states' National Action Plans on pesticides, with too many failing to specify how farmers' adoption of IPM can be measured, to set targets and to indicate how implementation will be ensured.

    The UK should champion IPM and the practical application of the various techniques it implies and create a system that can be readily understood and practised by farmers, growers and land managers, and promoted by the government and its agencies.

2. Introduction to pesticides

Pesticides, herbicides, fungicides and other chemicals are toxic substances designed to kill or reduce insect pests, plants regarded as weeds, rodents, slugs and other molluscs, and fungal disease.

This paper, which uses pesticides as a generic term for all chemicals, summarises some of the evidence on how a variety of wild species are affected by the widespread, cumulative and often prophylactic use of pesticides mainly in farming. The paper also looks at ecological effects such as on soil and water environments and the efficacy of pesticides in food production.

Rising pesticide use

The post-WWII years saw a rise in pesticide use and the 1970's Green Revolution saw global crop yields rising substantially with increased use of pesticides and fertilisers. Higher yields addressed food shortages and avoided some, but not all, famines, but they came with lasting environmental health effects and unsustainable trends in agricultural and land-use practices. The UN states:

> "While records on global pesticide use are incomplete, it is generally agreed that application rates have increased dramatically over the past few decades."[1]

The most reliable source of global data on pesticide use appears to be the United Nations' Food and Agriculture Organisation (FAO)[2].

UK data for pesticide use on arable land in 2016 shows continued rising use across more land as the choice of crops grown changes, influenced by subsidies, product marketing and consumer trends[3]:

- Fungicides – used on 38% of the total pesticide-treated area
- Herbicides – used on 33% of the treated area
- Growth regulators – 11%
- Seed treatments – 8%
- Insecticides and nematicides – 6%
- Molluscicides – 3%
- Sulphur and physical control agents – less than 1% each.

By weight, herbicides & desiccants accounted for 49% of the pesticide active substances applied, fungicides 33%, growth regulators 15%, seed treatments, molluscicides and insecticides 1% each, and sulphur less than 1%. For more on pesticides use, trends and toxicity see Appendix 1.

In the UK, it is often claimed that pesticide use has declined but this usually refers to pesticide use by weight which masks growth in the frequency of pesticide applications and the number of active ingredients used, as explored below

When measured only by weight, and looking at an overall trend for all crops, pesticide use over the past twenty years (Fig. 1) appears to have declined but examination of the data since 2000 demonstrates that 75% of the decline is due to the elimination of sulphuric acid as a desiccant on potatoes, a crop which represents only 1% of UK agricultural land use. Looking at trends by sector, use by weight on arable crops has been rising between 2010 and 2018.

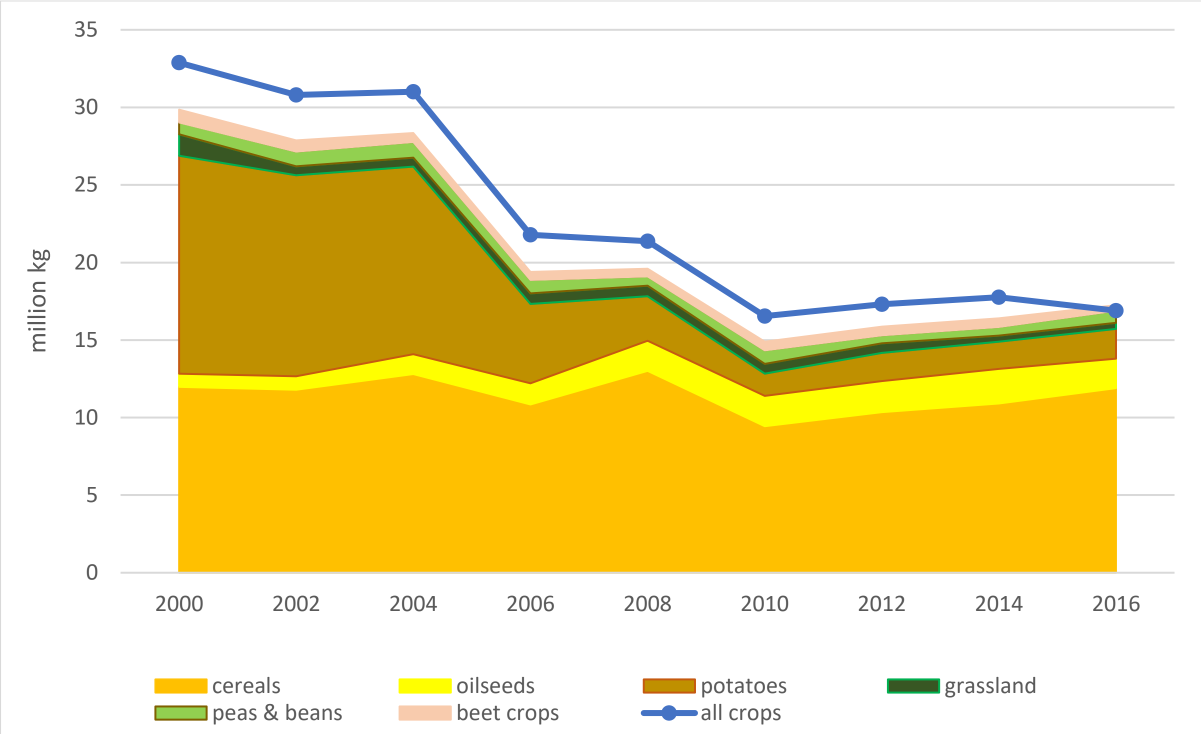

Figure 1: Weight of pesticides applied to UK crops (million kg), 2000-2016[4]

Since 2000, the planted area of UK cropland has remained constant at approximately 4.6 million hectares (mpa). However, the total area treated with individual pesticide active ingredients has increased from 59 m ha in 2000, to 73 m ha in 2016 (Fig. 2). That represents a 24% rise in active ingredients applied, from an average of 12.8 actives per ha in 2000, to 15.9 per ha in 2016.

Clearly, several active ingredients may be applied at the same time, but spray passes are also increasing: 41% of cereal hectarage was sprayed more than four times in 2000, but by 2016 this had increased to 55%.

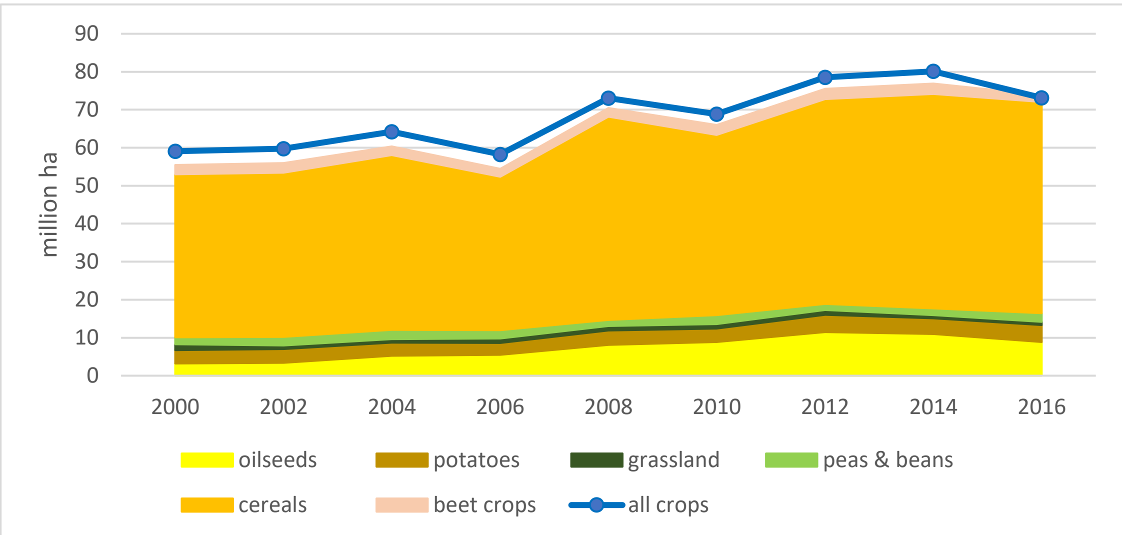

Figure 2: UK "pesticide treated area" (million hectares). NB: actual area of cropland remains constant at approx. 4.6 m ha

A closer look at individual crops, such as wheat (Fig. 3) confirms growing numbers of active ingredients, products, and spray passes.

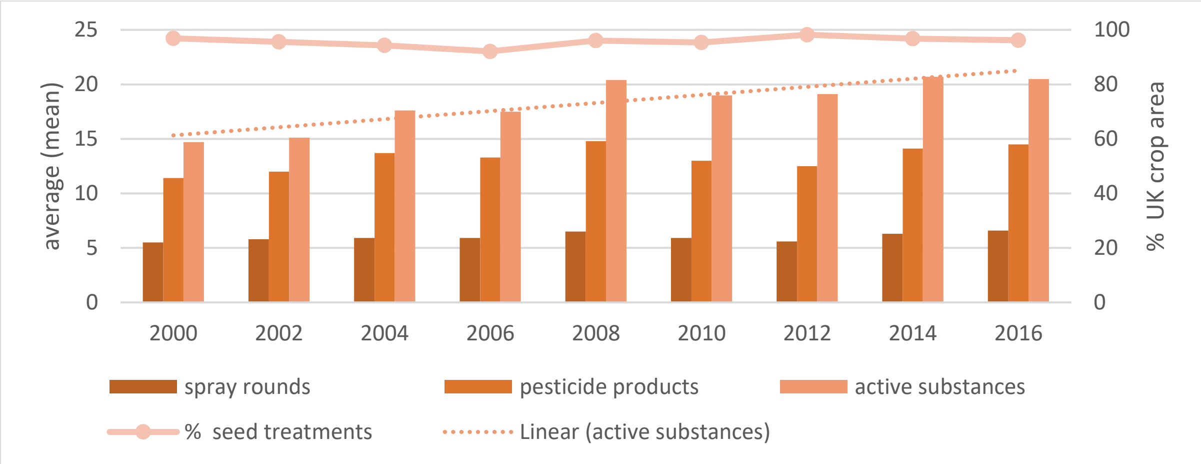

Figure 3: Average number of pesticide treatments in UK wheat crop, 2000-2016

More recent data was published for arable crops in November 2019 and shows – by area treated – continued increase in use of herbicides, some reduction in insecticide use, and fungicide slightly down, but still higher than in 2010.

Understanding unintended effects

Even after decades of use and despite testing regimes that are claimed to be rigorous, the effects of widespread use of pesticides and other chemicals on wildlife and ecosystems aren't well understood.

As a 2013 study put it:

> "During the past 50 years, the human population has more than doubled and global agricultural production has similarly risen. However, the productive arable area has increased by just 10%; thus the increased use of pesticides has been a consequence of the demands of human population growth, and its impact has reached global significance. Although we often know a pesticide's mode of action in the target species, we still largely do not understand the full impact of unintended side effects on wildlife, particularly at higher levels of biological organization: populations, communities, and ecosystems. In these times of regional and global species declines, we are challenged with the task of causally linking knowledge about the molecular actions of pesticides to their possible interference with biological processes, in order to develop reliable predictions about the consequences of pesticide use, and misuse, in a rapidly changing world."[5]

This contrasts with pesticide industry claims, such as the following extract from a 2013 pesticide industry promotional publication:

> "The biologically active characteristics of pesticides pose a risk to non-target species; this is acknowledged and accommodated in European pesticide regulation; pesticides are today one of the most regulated classes of products on the European market. None of the key drivers of biodiversity loss (such as land use change) is subject to regulation as rigorous as those applied to crop protection products. Pesticide regulations are there to ensure the safety and safe use of pesticides, so that farmers are equipped with the right tools for sustainable productivity, and so consumers can be confident of the safety, availability and affordability of food. To be certain that this remains so, farmers, industry and other stakeholders work together within the framework of EU Regulations and Directives to minimise any negative impacts."[6]

This familiar pesticide industry line ignores that the pesticides regulation have been found wanting and independent scientists have found problems with pesticides not picked up official product tests the safety. It should also be noted that land use change should mean that environmental impact assessments are carried out.

That said, one pesticide company, Sumitomo, has at least acknowledged that testing and assumptions may not reflect reality and the complexity of nature, different species, habitats and conditions:

> "…even with the assessment systems introduced in Europe and the USA early on, there are a variety of problems with current evaluation systems and assessment methods because of the complexity of organisms and ecosystems, the large number of points that are unknown ecologically and the difficulty of assessing risks related to the results, and more research, investigations, improvements and proposals are being done on terrestrial ecological risk assessment methods. For example, the conventional bird and mammal risk assessment."[7]

Lack of knowledge about effects because of a dearth of adequate studies is underlined by a 2016 review of the current understanding of the indirect effects of herbicides in edge-of-field habitats:

> "The bulk of work has focused on invertebrate and bird species, with few studies investigating small mammals, amphibians, or reptiles (riparian field margins were not included, where amphibians and reptiles are more likely to occur). Key knowledge gaps identified in the review include: (1) a lack of studies incorporating exposures to edge-of-field habitats that would be relevant based on current agronomic practices; (2) few studies attempt to quantify the herbicide exposure within edge-of-field habitats and consider the influence of methods of herbicide application on exposure; (3) few studies incorporate quantitative linkages between direct effects on the plant community, indirect effects on animal species, and population-level effects; and (4) the majority of studies have been conducted in Europe, with a distinct lack of research investigating the indirect effects of herbicides on field margin fauna under agricultural practices in other regions of the world.
>
> "Of the studies reviewed, many lack one or more key components of a robust experimental design that would be necessary to quantify exposure to and/or effects of herbicides. Adequate quantification of exposure of the plant community is often lacking, including poor representation of exposure scenarios that adequately mimic spray drift.

> "Further, there is a dearth of studies that even attempt to investigate ecologically-relevant linkages between direct effects on plants and associated indirect effects on plant-dependent communities and population-level effects."[8]

The study concludes:

> "The state of knowledge pertaining to the indirect effects of herbicides in agricultural field margins is currently insufficient to adequately assess the nature and extent of risks posed by herbicides in these important habitats. There is a strong need for carefully planned and executed field experiments to quantitatively characterize the risks posed by application of herbicides to terrestrial environments…"

Creature contact with chemicals

The abundant use of pesticides means that it's relatively easy for wildlife to come into contact with them indirectly in fields and field margins, across the public realm and in watercourses due to run-off. Creatures not intended to be affected will be exposed and / or affected by:

- Crop sprays drifting on the air to unintended areas.
- Pesticide residues affecting soil structure and quality, and being toxic.
- Soil residues being blown between fields such as when ploughing releases dust.
- Chemical coatings of seeds shed as dust and dissipating.
- Leaching into soils and then water courses, affecting aquatic life.
- Plants releasing chemicals stored in their structures, fibres and fluids, which then contact or are consumed by insects.
- Chemicals in manures and composts used on farms, parks and gardens.
- Chemical residues moving up the food chain, such as when birds eat insects.
- Loss of herbicide-treated plants, which removes food sources and shelter for wildlife, adding to pressure to relocate, alter their diet, or starve.

Many organisms are unintended targets of pesticides; they experience lethal or so-called sub-lethal exposures that affect their individual or collective development, growth, behaviour, physiology, communication and ability to reproduce. The UN also states:

> "Pesticides can persist in the environment for decades and pose a global threat to the entire ecological system upon which food production depends. Excessive use and misuse of pesticides result in contamination of surrounding soil and water sources, causing loss of biodiversity, destroying beneficial insect populations that act as natural enemies of pests and reducing the nutritional value of food."[9]

The UK government's former chief environment scientist, Professor Ian Boyd, has questioned the assumption that widespread use of pesticides is safe, even after a product has been tested.

In a paper with fellow scientist, Alice Milner, Ian Boyd said:

> "The current assumption underlying pesticide regulation – that chemicals that pass a battery of tests in the laboratory or in field trials are environmentally

> benign when they are used at industrial scales – is false. The effects of dosing whole landscapes with chemicals have been largely ignored by regulatory systems. This can and should be changed. Vigilance on the scale that is required for medicines does not exist to assess the effects of pesticides in the environment."

The authors identify weaknesses in the UK's highly developed regulatory system:

> "Yet it has no systematic monitoring of pesticide residues in the environment. There is no consideration of safe pesticide limits at landscape scales."[10]

A UK case study illustrates the potential for the widespread, combined use of different treatments to cause harm, including to non-target species, habitats and the wider environment:

> "…British farmers growing wheat typically treat each crop over its growing cycle with four fungicides, three herbicides, one insecticide, and one chemical to control molluscs. They buy seed that has been precoated with chemicals against insects. They spray the land with weedkiller before planting, and again after. They apply chemical growth regulators that change the balance of plant hormones to control the height and strength of the grain's stem. They spray against aphids and mildew. And then they often spray again just before harvesting with the herbicide glyphosate to desiccate the crop, which saves them the energy costs of mechanical drying." [11]

A 2015 review of evidence illustrates how direct and indirect effects on wild species are inadequately assessed in safety tests. The review looked at two neonicotinoids, imidacloprid and clothianidin, and a third insecticide, fipronil, which acts in the same systemic manner and found imidacloprid and fipronil to be toxic to many birds and most fish, respectively:

> "All three insecticides exert sub-lethal effects, ranging from genotoxic and cytotoxic effects, and impaired immune function, to reduced growth and reproductive success, often at concentrations well below those associated with mortality. Use of imidacloprid and clothianidin as seed treatments on some crops poses risks to small birds, and ingestion of even a few treated seeds could cause mortality or reproductive impairment to sensitive bird species. In contrast, environmental concentrations of imidacloprid and clothianidin appear to be at levels below those which will cause mortality to freshwater vertebrates, although sub-lethal effects may occur. Some recorded environmental concentrations of fipronil, however, may be sufficiently high to harm fish. Indirect effects are rarely considered in risk assessment processes and there is a paucity of data, despite the potential to exert population-level effects. Our research revealed two field case studies of indirect effects. In one, reductions in invertebrate prey from both imidacloprid and fipronil uses led to impaired growth in a fish species, and in another, reductions in populations in two lizard species were linked to effects of fipronil on termite prey. Evidence presented here suggests that the systemic insecticides, neonicotinoids and fipronil, are capable of exerting direct and indirect effects on terrestrial and aquatic vertebrate wildlife, thus warranting further review of their environmental safety."[12]

A 2019 of lowland in Switzerland detected five neonicotinoids in 93% of arable fields and more than 80% of soils and plants in ecological focus areas, which one might think would be free from contamination.[13]

The study measured concentrations of imidacloprid, clothianidin, thiamethoxam, thiacloprid and acetamiprid in 702 soil and plant samples in 169 arable fields and ecological focus areas from 62 conventional, integrated production and organic farms. The study also tested 16 samples of organic seeds, of which 14 were found to be contaminated with neonicotinoid pesticides.

In terms of hazard, the study found between 5.3 - 8.6% of ground dwelling invertebrates may be exposed to lethal concentrations of clothianidin, and 31.6 to 41.2% to sublethal concentrations, in “integrated production” and conventionally farmed fields. The study also found that between 1.3 - 6.8% (up to 12.5% based on Hazard Quotients) of beneficial invertebrates may be exposed to sublethal concentrations of neonicotinoids in organic fields and ecological focus areas.

The study authors concluded:

> “Our study suggests that diffuse contamination by neonicotinoids may harm a significant fraction of non-target beneficial species. The use of neonicotinoids on crops may threaten biodiversity in refuge areas, while also potentially jeopardizing the practice of organic farming by impeding the biological control of pests. Based on our results, we call for a reduction in the dispersion and overuse of neonicotinoid insecticides in order to prevent any detrimental effects on biodiversity and ecosystem services associated with agroecosystems.”

Loosening the grip of pesticides

Gill and Garg in 2014[14] summarise the dominance of pesticide use, highlighting that global spend on pesticides amounts to some $38 billion a year with the industry producing new formulations and products to meet demand despite concerns about safety and overuse:

> “Ideally, the applied pesticides should only be toxic to the target organisms, should be biodegradable and eco-friendly to some extent. Unfortunately, this is rarely the case as most of the pesticides are non-specific and may kill the organisms that are harmless or useful to the ecosystem. In general, it has been estimated that only about 0.1% of the pesticides reach the target organisms and the remaining bulk contaminates the surrounding environment. The repeated use of persistent and non-biodegradable pesticides has polluted various components of water, air and soil ecosystem. Pesticides have also entered into the food chain and have bioaccumulated in the higher tropic level. More recently, several human acute and chronic illnesses have been associated with pesticides exposure.
>
> “Over the past era there has been an increase in the development of pesticides to target a broad spectrum of pests. The increased quantity and frequency of pesticide applications have posed a major challenge to the targeted pests causing them to either disperse to new environment and/or adapt to the novel conditions. The adaptation of the pest to the new environment could be attributed to the several mechanisms such as gene mutation, change in

> population growth rates, and increase in number of generations etc. This has ultimately resulted in increased incidence of pest resurgence and appearance of pest species that are resistant to pesticides."

> "Although, pesticides were used initially to benefit human life through increase in agricultural productivity and by controlling infectious disease, their adverse effects have overweighed the benefits associated with their use. The above discussion clearly highlights the severe consequences of indiscriminate pesticide use on different environmental components. Some of the adverse effects associated with pesticide application have emerged in the form of increase in resistant pest population, decline in on beneficial organisms such as predators, pollinators and earthworms, change in soil microbial diversity, and contamination of water and air ecosystem. The persistent nature of pesticides has impacted our ecosystem to such an extent that pesticides have entered into various food chains and into the higher trophic levels such as that of humans and other large mammals. Some of the acute and chronic human illnesses have now emerged as a consequence of intake of polluted water, air or food."

Gill and Garg advocate alternative ways to produce and protect crops:

> "This is the time that necessitates the proper use of pesticides to protect our environment and eventually health hazards associated with it. Alternative pest control strategies such as IPM that deploys a combination of different control measures such as cultural control, use of resistant genotype, physical and mechanical control, and rational use of pesticide could reduce the number and amount of pesticide applications. Further, advanced approaches such as biotechnology and nanotechnology could facilitate in developing resistant genotype or pesticides with fewer adverse effects. Community development and various extension programs that could educate and encourage farmers to adopt the innovative IPM strategies hold the key to reduce the deleterious impact of pesticides on our environment."

A 2018 review of the global use of organophosphates (OP) also sees a way forward:

> "What are the alternatives, if synthetic pesticides other than OPs are also neurotoxic? Agriculture represents the vast majority of OP pesticide use, which includes both crop and livestock production. Widespread implementation of IPM is needed to reduce this use. IPM is a reduced-risk pest management strategy that emphasizes inspection, monitoring, prevention, and pest control using the least toxic methods including (agri)cultural practices such as intercropping (growing two or more crops in close proximity, which can reduce susceptibility to disease and pests), crop rotation, and cover crops (to reduce soil erosion and improve soil health); physical controls such as traps or bug vacuums; habitat management that encourages beneficial insects; and biological control, such as the release of parasitic wasps to control aphids, with pesticides used only as a last resort…"[15]

As described in the section on wild plants (see page 39) and contrary to conventional wisdom, reduced use of herbicides and use of wildflowers can boost crop production.

3. Evidence of effects – a) Soils, microorganisms and earthworms

Healthy soils are packed with microorganisms including bacteria, algae, fungi and protozoa, as well as larger, visible earthworms and invertebrates.

A 2011 review of extensive pesticide use on a variety of microorganisms reports that:

> "…Indiscriminate, long-term and over-application of pesticides have severe effects on soil ecology that may lead to alterations in or the erosion of beneficial or plant probiotic soil microflora. Weathered soils lose their ability to sustain enhanced production of crops/grains on the same land…"[16]

According to *World's soils are under threat*, a 2016 review of evidence, well managed soils circulate chemical elements, water, and energy and provide immense benefits for humans in doing so. By contrast, with poorly managed soils "it is impossible to be optimistic about the future":

> "The current trajectories in soil condition have potentially catastrophic consequences that will affect millions of people in some of the most vulnerable regions over coming decades. More importantly, the global community is presently ill-prepared and ill-equipped to mount a proportionate response. Countries can change current trajectories."[17]

The UN's 2017 Global Land Outlook study states that increased mechanisation and pesticide use has boosted yields in the short term but with significant effects on soil, water, species and ecosystems with consequences for food security.[18] The study states:

> "Indications of decreasing productivity can be observed globally, with up to 22 million km2 affected, i.e., approximately 20 per cent of the Earth's vegetated land surface shows persistent declining trends or stress on land productivity. These global trends are evident in 20 per cent of cropland, 16 per cent of forest land, 19 per cent of grassland, and 27 per cent of rangeland (i.e., shrubland, herbaceous and sparsely vegetated areas).[19]

A 2015 Canadian study was perhaps the first to assess how residues of neonicotinoid pesticides accumulated in wind-blown surface soil and dust in southwestern Ontario.[20]

Concentrations of residues were measured in the top 5 cm of soil and overlying soil surface dust before planting of maize in 25 fields with a history of being treated with neonicotinoid treated seeds in 2013 and 2014. Mean total concentrations were 3.05 and 47.84 in 2013, and 5.59 and 71.17 ng/g in 2014, for parent soil and soil surface dust, respectively. When surface and parent soil residues were compared the mean concentration in surface dust was 15.6 and 12.7 fold higher than in parent soil in 2013 and 2014, respectively. Pooled over years, the surface dust/parent soil ratio was 13.7, with mean concentrations of 4.36 and 59.86 ng/g for parent soil and surface dust, respectively. The study authors conclude that:

"To our knowledge these data are the first reported to assess the concentrations of neonicotinoid residues in wind-erodible sediments in areas of agricultural production where neonicotinoid seed treatments are common. These results show that concentrations of neonicotinoids can be detected in parent soil as well as in surface soil dust at least one year after the previous planting season, with all samples containing detectable concentrations."

A 2016 Danish study examined the interaction of pesticides, types of soil and crop management, including tillage and fertilisation, and the resulting effects on soil life. It found them to be complex, with the effects of pesticides being significantly influenced by management practices.[21]

The study recommended that such interactions should be considered in risk assessments and that test systems should also consider factors other than direct exposure. This is because simple test systems that measure exposure of single organisms convey an incomplete picture of the true effects of pesticides.

In 2016, the European Food Safety Authority (EFSA) was asked for its opinion on the state of science for pesticide risk assessments and soil organisms.[22] EFSA reviewed current risk assessment systems and recommended the need for:

> "A new testing strategy which takes into account the relevant exposure routes for in-soil organisms and the potential direct and indirect effects is proposed. In order to address species recovery and long-term impacts of PPPs, the use of population models is also proposed."

Earthworms

Humble earthworms are among the most important soil invertebrates, relied on by farmers for healthy soils and by birds and other wildlife in the food chain. Along with other soil invertebrates such as mites, nematodes, springtails, micro-arthropods, spiders and other small organisms, earthworms are essential to the decomposition of leaves, manures, plant residues and other organic compounds to aid soil structure and fertility.

Earthworms feed primarily on fungus growing on decomposing matter and their food supply is cut off if the fungus they seek is removed by use of pesticides (fungicides). This section sets out findings from recent studies (since 2009), which have started to examine both the singular and combined effects of pesticides on earthworms.

A common finding is that pesticides tended not to be tested in realistic conditions that replicated how soils, organisms and water are exposed to multiple pesticides and treatments, not just one. In the UK recently there have been moves to assess risks from more than one active ingredient.

Overall, though, the effect of pesticides on earthworms has not been extensively studied. In particular, not the combined effect of multiple pesticides is not well understood, despite several hundred pesticides having been authorised for use in Europe. A 2014 review of studies of pesticides effects on earthworms found a lack of comprehensive testing of pesticides currently licensed for use.[23] The review identified limitations to most of these studies, including:

- A lack of experiments to assess the effects of the same pesticides on the same earthworm species at different organisation levels to derive the links between the responses at these different levels.
- A lack of studies of the effects of pesticides authorised in Europe on earthworms, especially species found in cropping systems, and replicating realistic conditions in terms of soil, pesticide dose and experimental duration.

- The effects of multiple pesticides and chronic exposure to them that earthworm populations face in cropping systems are insufficiently studied. It's been shown that responses to mixtures of pesticides is hard to predict from responses to the isolated pesticides.

Notwithstanding these limitations the review authors found that earthworms are affected by various agricultural practices particularly the wide use of pesticides:

> "Earthworms provide key soil functions that favour many positive ecosystem services. These services are important for agroecosystem sustainability but can be degraded by intensive cultural practices such as use of pesticides. Many literature reports have investigated the effect of pesticides on earthworms. Here, we review those reports to assess the relevance of the indicators of earthworm response to pesticides, to assess their sensitivity to pesticides, and to highlight the remaining knowledge gaps. We focus on European earthworm species and products authorised in Europe, excluding natural compounds and metals. We consider different organisation levels: the infra-individual level (gene expression and physiology), the individual and population levels (life-history traits, population density and behaviour) and the community level: community biomass and density. Our analysis shows that earthworms are impacted by pesticides at all organisation levels. For example, pesticides disrupt enzymatic activities, increase individual mortality, decrease fecundity and growth, change individual behaviour such as feeding rate and decrease the overall community biomass and density. Insecticides and fungicides are the most toxic pesticides impacting survival and reproduction, respectively."

A 2009 review of laboratory tests noted that most tests on earthworms involve just one species that tends to be least sensitive to pesticides, rather than a range of species likely to be found in cropped soils, which will have a range of pesticide tolerances:[24]

> "The standard test earthworm species, *Eisenia fetida* sensu lato, is the species that is least sensitive to insecticides based on acute mortality, whereas the standard Collembola test species, *Folsomia candida*, is among the most sensitive species for a broad range of toxic modes of action (biocide, fungicide, herbicide, and insecticide). These findings suggest that soil arthropods should be tested routinely in regulatory risk assessments. In addition, the data indicate that the uncertainty factor for earthworm acute mortality tests (i.e., 10) does not fully cover the range of earthworm species sensitivities and that acute mortality tests would not provide the most sensitive risk estimate for earthworms in the majority (95%) of cases."

It's not surprising that the regulatory tests for pesticides are inadequate. Friends of the Earth has found the same from our work on the risks to bees and other pollinating insects from neonicotinoid pesticides. Neonicotinoids passed regulatory tests but were found to have serious sub-lethal effects on individual bees and on colonies, including impairing the ability to forage for food, to navigate back to nests, and to reproduce. Profound failures of the apparently robust testing regime were exposed.

Most testing also ignores that many pesticides reside in soils and water rather than on the treated plant. For example, many neonicotinoids are applied as a seed coating or dressing to be absorbed into the crop plant as it grows, yet only 1.6–20% of the active ingredient is absorbed and most remains in the soil. Neonicotinoid pesticides can then persist in soils for several years, leading to chronic contamination and, in some instances, accumulation over time.

A 2014 study examined twenty years' exposure of earthworms to *Opus®*, epoxiconazole, a fungicide widely used on wheat, barley, oats and rye.[25] The study found that earthworms in treated fields grew to only half of their normal weight and didn't reproduce as well as worms in unsprayed fields. The researchers said:

> "We see that the worms have developed methods to detoxify themselves, so that they can live in soil sprayed with fungicide. They spend a lot of energy on detoxifying, and that comes with a cost: The worms do not reach the same size as other worms, and we see that there are fewer of them in sprayed soil. An explanation could be that they are less successful at reproducing, because they spend their energy on ridding themselves of the pesticide."[26]

In 2017, one of the first studies to examine both the use of a single pesticide and the combined use of different types of pesticide and herbicide on soil organisms and soil processes was conducted.[27] The study found that seed dressings reduced earthworm activity regardless of the class of pesticide used for the seed treatment. Herbicide application itself reduced earthworm activity, and further decreased it in interaction with pesticide seed dressings. Activity of soil micro-organisms or litter decomposition appeared to be little affected by these pesticides.

The researchers reproduced a typical farmland situation in greenhouses, with wheat sown with pesticide-treated seeds receiving an additional herbicide application later in the season. They reported that:

> "Seed dressings significantly reduced the surface activity of earthworms with no difference whether insecticides or fungicides were used. Moreover, seed dressing effects on earthworm activity were intensified by herbicides (significant herbicide × seed dressing interaction). Neither seed dressings nor herbicide application affected litter decomposition, soil basal respiration, microbial biomass, or specific respiration. Seed dressing did also not affect wheat growth. We conclude that interactive effects on soil biota and processes of different pesticide classes should receive more attention in ecotoxicological research."

In other words, the study indicates that the way pesticide tests are conducted – where risk assessments consider a single species subjected to a single application of a pesticide – might underestimate what happens in real fields where different types of pesticides are used.

A 2018 study of the toxic effects of the herbicide tribenuron-methyl and the fungicide tebuconazole on *Eisenia fetida* earthworms, stated that:

> "The mixture of two pesticides had an antagonistic effect on the earthworm… Our results suggest that pesticides can negatively affect soil earthworms…"[28]

A 2017 study also recommended that regulatory tests should be improved.[29]

Evidence of effects – b) Insects

Many species of insects are important as a form of biological pest control and can be regarded as a free ecosystem service supporting agriculture. For example, hoverfly larvae and ladybirds feed on aphids and ground beetles feed on pests harmful to cereal crops.

As with pollination by bees and other pollinating insects, natural pest control by insects benefits crop production worldwide. Measures to protect and boost beneficial insects should be central to benign farm practices, as well as deployment of IPM and effective crop management and measures to increase food security. A 2016 review of studies into effects on beneficial insect species concludes:[30]

> "Botanical and synthetic pesticides generate acute toxicity and sub-lethal effects on beneficial insects responsible for natural pest control and pollination. The detrimental effects caused by synthetic pesticides have long been reported and several strategies are in place including biological pest control. The negative effects posed by botanicals however, are of more concern as this might limit the effectiveness of biological pest control strategies. Botanicals are often categorized as safe and environmentally friendly but their use for insect pests control should always be done with caution. Evaluation of the potential risks of the pesticides to non-target organisms is crucial in optimizing ecosystem services (e.g. natural pest control or pollination) and consequently better agricultural yields. More research is therefore needed to determine the side effects of both botanical and synthetic pesticides on predators, parasitoids and pollinators..."

A 2013 study of bee and ground beetle species in UK arable settings observed that:

> "Deficits in functional diversity for both pest control and pollination were found in areas of high arable crop production."[31]

The study advised that both pollination and natural pest control are vital for crop production now and for the future:

> "Invertebrates supporting natural pest control and pollination ecosystem services are crucial to world-wide crop production. Understanding national patterns in the spatial structure of natural pest control and pollination can be used to promote effective crop management and contribute to long-term food security."

Neonicotinoid insecticides are a widely used systemic neurotoxin designed to destroy the nerves and impair the brain function of insects and have received much attention in recent years because of active campaigns and scientific study which have undermined claims about their safety.

Perhaps as a result of the public debate over neonicotinoids, many people tend to think that they're the main type of pesticide and that curbing or ending their use will solve all problems with pesticides. Neonicotinoids are certainly widely used globally, but their use doesn't replace other pesticides, despite industry suggestions that they can supplant other products, especially so-called "older, dirtier" pesticides, such as pyrethroids.

In fact, the data shows that rather than neonicotinoids replacing pyrethroids, the use of pyrethroids continued to grow and peaked in 2013, well before EU restrictions were introduced on the outdoor use of three neonicotinoids in 2016 (Fig. 4).

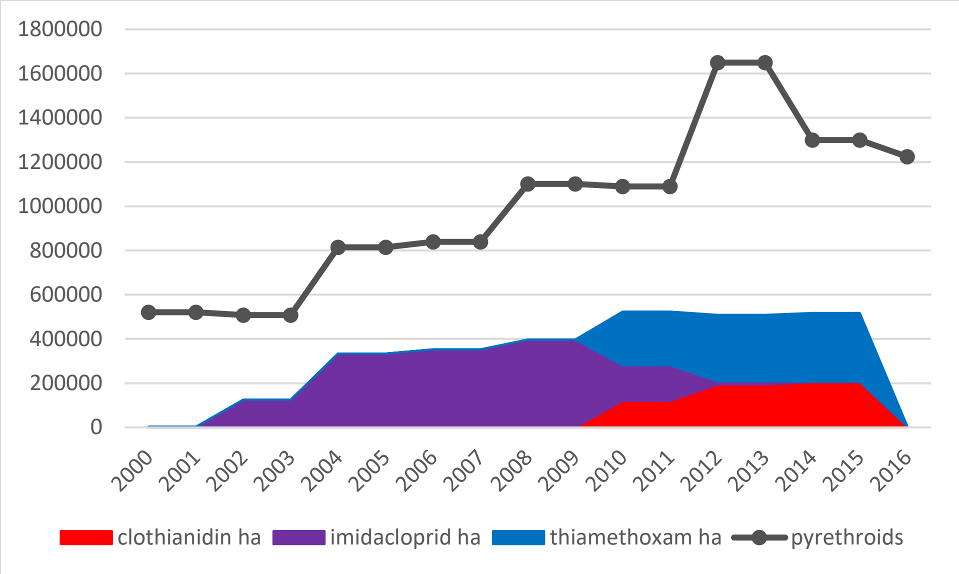

Figure 4: The use of neonicotinoids and pyrethroids on oilseed crops

In the EU only three neonicotinoids have been restricted and new pesticides with a similar mechanism, but which have been classified separately by the pesticide industry, are being approved for use.

Neonicotinoids are applied both by spraying and by coating the seeds of crops with the active ingredient, which becomes absorbed inside plants as they grow. In theory, this technical advance delivers the active ingredient more precisely than by spraying, but studies show that for seed coatings, pesticide take-up into the plant is at best 20%, and could be as low as 5%. The remaining active ingredient contaminates surrounding areas, and the persistence of residues affects non-target species and soil quality.

In recent years, the inadequacy of industry and official testing has been exposed by independent scientific studies, which have filled many of the gaps in knowledge about the true effects of neonicotinoid pesticides on wild and managed bees.

For most other taxa data is less well developed and it cannot be assumed that all other species are similarly affected. But the fact that so little data exists for species which may be vulnerable to exposure is worrying, given the safety assurances that've been given to the public about this family of pesticides for several decades.

As a result, the sensitivity of non-pest herbivorous taxa and natural predators of genuine crop pests to neonicotinoids and other chemicals aren't so well understood.

Hoverflies (Syrphidae)

Hoverflies are less well known than bees but are, along with moths, significant pollinating insects. Many hoverfly species are also important in the decomposition of materials such as compost and the aeration of soil substrates. Hoverflies are probably more important than they're given credit for in supporting healthy functioning soils and other ecosystems for farming and other purposes.

Some hoverfly species are beneficial predators of pests such as aphids and when these have themselves fed on treated plants and seeds this can be another way for hoverflies to be exposed to pesticides. Female hoverflies feeding on pollen and/or to mature their eggs is another way for hoverflies to be exposed to pesticides in the plant pollen and nectar.

There are few studies into the effects of pyrethroids, neonicotinoids and other pesticides on hoverflies and more detailed study is certainly needed. One study tested the effect of field-realistic doses of the neonicotinoid thiamethoxam on the development of the aquatic larvae, and adult behaviour, of the hoverfly *Eristalis tenax.*

The authors:

> '...found that thiamethoxam exposure results in elevated mortality of *E. tenax* larvae only at concentrations above those normally found in field-realistic situations. The larvae of this species appears to be less sensitive to thiamethoxam than some other aquatic insects that've previously been examined. Further research is required to investigate possible adverse effects via adult exposure, or from larval exposure to other neonicotinoids and currently used complex mixtures of pesticides. Farmland management may benefit from including hoverfly larval habitat to maintain an important pollinating species which, at least in the larval stage, appears to not be highly susceptible to at least one commonly used pesticide."[32]

Butterflies (Lepidoptera)

According to Sir David Attenborough, President of Butterfly Conservation:

> "The fortunes of the UK's butterflies have ebbed and flowed over this period (50 years). Sadly many species have struggled as their habitats have shrunk and climate change and pesticide use have taken their toll."[33]

In 2013, a European Environment Agency (EEA) study of 17 key species of grassland butterflies across 19 European nations found large declines in the past two decades, with some key species declining by half since 1990.[34]

The studied included 7 seven common and 10 specialist grassland butterfly species. Grassland butterflies comprise over 250 of the 400 or more of butterfly species in Europe and are particularly important because so much land in Europe is farmland and if butterflies cannot thrive on farmland, they'll suffer dramatic declines. Other species prefer woodlands, wetlands, heaths and other habitats. Of the 17 species studied:

- The large blue had declined steeply.
- Seven had declined moderately: small heath, wall brown, small copper, dusky large blue, meadow brown, common blue, dingy skipper.
- Two species remained stable: orange tip and Adonis blue.
- One species increased: red-underwing skipper.
- The trend for the other six species is still uncertain: marsh fritillary, large skipper, mazarine blue, small blue, chalkhill blue, Lulworth skipper.

As an indicator of the health of other insects, the findings for butterflies may show that species which are sought for food by birds and small mammals and which play a role in the health of the countryside may also be at risk. One of the authors, Chris van Swaay of De Vlinderstichting, the Dutch Butterfly Conservation group, said:

> “The pesticide problem is especially a problem in the intensive agricultural areas of western Europe. In eastern Europe, it is less of a problem."

The EEA has warned that:

- Many large areas of farmed land are becoming "sterile" for wildlife because of intensive farming methods, including the growing of single crops in large monoculture fields, the widespread use of chemicals and the loss of hedgerows, field margins and other semi-wild areas.
- In some areas of affluent north-western Europe, farming has become so intensive that butterflies are now confined to marginal areas, such as road and rail verges and urban gardens, with only a relatively small proportion of farmland being actively managed for wildlife.

Hans Bruyninckx, executive director of the EEA, said:

> "This dramatic decline in grassland butterflies should ring alarm bells – in general Europe's grassland habitats are shrinking. If we fail to maintain these habitats we could lose many of these species forever. We must recognise the importance of butterflies and other insects – the pollination they carry out is essential for both natural ecosystems and agriculture."

A 2015 study of 17 UK butterfly species and neonicotinoid use from 1985 to 2012 found that:

> “In England, the total abundance of widespread butterfly species declined by 58% on farmed land between 2000 and 2009 despite both a doubling in conservation spending in the UK, and predictions that climate change should benefit most species. Here we build models of the UK population indices from 1985 to 2012 for 17 widespread butterfly species that commonly occur at farmland sites. Of the factors we tested, three correlated significantly with butterfly populations. Summer temperature and the index for a species the previous year are both positively associated with butterfly indices. By contrast, the number of hectares of farmland where neonicotinoid pesticides are used is negatively associated with butterfly indices. Indices for 15 of the 17 species show negative associations with neonicotinoid usage. The declines in butterflies have largely occurred in England, where neonicotinoid usage is at its highest. In Scotland, where neonicotinoid usage is comparatively low, butterfly numbers are stable. Further research is needed urgently to show whether there is a causal link between neonicotinoid usage and the decline of widespread butterflies or whether it simply represents a proxy for other environmental factors associated with intensive agriculture.”[35]

Nevertheless, a 2018 review says that the complexities of the potential effects of pesticides on butterflies aren’t well known or properly studied, meaning that simple reference to butterfly population levels is unreliable.[36]

> “Butterflies play an important role in ecosystems, are well monitored and are recognised as good indicators of environmental health. The amount of information already known about butterfly ecology and the increased availability

> of genomes make them a very valuable model for the study of non-target effects of pesticide usage."
>
> "The effects of pesticides are not simply linear, but complex through their interactions with a large variety of biotic and abiotic factors. Furthermore, these effects manifest themselves at a variety of levels, from the molecular to metapopulation level. Research should therefore aim to dissect these complex effects at a number of levels, but as we discuss in this review, this is seldom if ever done in butterflies. We suggest that in order to dissect the complex effects of pesticides on butterflies we need to integrate detailed molecular studies, including characterising sequence variability of relevant target genes, with more classical evolutionary ecology; from direct toxicity tests on individual larvae in the laboratory to field studies that consider the potentiation of pesticides by ecologically relevant environmental biotic and abiotic stressors. Such integration would better inform population-level responses across broad geographical scales and provide more in-depth information about the non-target impacts of pesticides."

Ground beetles (Carabidae)

Ground beetles are beneficial carabid arthropods because they predate on cereal pests. They can be encouraged as a form of natural biological pest control. A 2016 study found that the abundance of ground beetle species was influenced by the choice of crop (oil seed rape, winter cereals), intensity of use of insecticides and proximity of nearby grassy fields.[37]

With oil seed rape, the study found that "high levels of insecticide use had a detrimental effect on the nutritional state of individuals" for two of the carabid species. The study concluded that:

> "This study highlights the importance of complementation and spillover processes in the functioning of populations living in agricultural shifting mosaics. Particular attention should thus be paid to the spatial distribution of cropping systems at various spatial scales if we are to enhance populations of organisms of benefit to agriculture."

Ladybirds (Coccinellidae)

Ladybirds are particularly beneficial for controlling aphids. There aren't many published studies into how they're affected by pesticide use. A 2018 study of ladybird vulnerability to non-selective pesticides concludes that: "The pest suppression provided by ladybirds, which could be severely hampered by the applications of nonselective pesticides, might be enhanced by the adoption of reduced-risk insecticides, selective for these beneficial insects."[38]

German studies in 2017 and 2019

In 2017 a study of insects in nature reserves across Germany found that the abundance of flying insects has fallen by three-quarters since 1989.[39]

Researchers used "malaise traps" (special types of tent) to capture over 1,500 samples of all flying insects at 63 different nature reserves (96 unique location-year combinations). The total weight of the insects in each sample revealed declines in abundance, with the annual average falling by 76% over 27 years. The fall was higher (82%) in summer, when insect numbers reach their peak.

The study showed the declines were apparent regardless of habitat type, and that changes in weather, land use, and habitat characteristics might affect but can't explain the overall decline. The cause is unclear, although the researchers indicated that destruction of wild areas and pesticides use were the most likely factors and climate change may play a role.

Research leader Hans de Kroon of Radboud University said:

> "The fact that the number of flying insects is decreasing at such a high rate in such a large area is an alarming discovery."

Caspar Hallmann of Radboud University said that the fact that the declines were found in protected nature areas made the findings more worrying:

> "All these areas are protected and most of them are well-managed nature reserves. Yet, this dramatic decline has occurred."

Martin Sorg from the Krefeld Entomological Society said:

> "The weather might explain many of the fluctuations within the season and between the years, but it doesn't explain the rapid downward trend."

Dave Goulson of Sussex University said:

> "Insects make up about two-thirds of all life on Earth [but] there has been some kind of horrific decline. We appear to be making vast tracts of land inhospitable to most forms of life, and are currently on course for ecological Armageddon. If we lose the insects then everything is going to collapse."

He added that one explanation could be that the flying insects perish when they leave the nature reserves:

> "Farmland has very little to offer for any wild creature. But exactly what is causing their death is open to debate. It could be simply that there is no food for them or it could be, more specifically, exposure to chemical pesticides, or a combination of the two."

The researchers said further work elsewhere is required to corroborate the findings. While most insects do fly, it may be that those that don't leave nature reserves less often and may be faring better. It's also possible that smaller and larger insects are affected differently, so the samples will be further analysed. Dr Lynn Dicks, University of East Anglia, was not part of the study and said the research:

> "…provides important new evidence for an alarming decline that many entomologists have suspected is occurring for some time. If total flying insect biomass is genuinely declining at this rate – about 6% per year – it is extremely concerning. Flying insects have really important ecological functions, for which their numbers matter a lot. They pollinate flowers: flies, moths and butterflies are as important as bees for many flowering plants, including some crops. They provide food for many animals – birds, bats, some mammals, fish, reptiles and amphibians. Flies, beetles and wasps are also predators and decomposers, controlling pests and cleaning up the place generally."[40]

The 2017 results are backed up by a 2019 study of 1 million individual insects across 2,700 different species found between 2008 and 2017 across 150 grassland and 140 forest sites in three protected regions of Germany.[41]

This study found that:

> "The decline affected rare and abundant species, and trends differed across trophic levels. Our results show that there are widespread declines in arthropod biomass, abundance and the number of species across trophic levels. Arthropod declines in forests demonstrate that loss is not restricted to open habitats. Our results suggest that major drivers of arthropod decline act at larger spatial scales, and are (at least for grasslands) associated with agriculture at the landscape level. This implies that policies need to address the landscape scale to mitigate the negative effects of land-use practices."

Dr Sebastian Seibold, Technical University of Munich said:

> "Our study confirms that insect decline is real – it might be even more widespread than previously thought considering, for example, that also forests are experiencing declines in insect populations. I think it's alarming to see that such a decline happens not only in intensively-managed areas but also in protected areas – so the sites that we think are safeguarding our biodiversity really working anymore."[42]

Damselflies (Odonates) (also see The Netherlands, page 31)

Studies conducted at the Living Lab outdoor research laboratory in Leiden show that the neonicotinoid thiacloprid, which is increasingly found in surface waters there, strongly influences damselflies, even common and robust species like the blue-tailed damselfly (*Ischnura elegans*).[43]

Thiacloprid is not the only and also not the most common neonicotinoid to be found in surface waters. Neonicotinoids are often found in mixtures that share a common mode of action and are mobile in soils, easily ending up in freshwater habitats.

The studies were conducted because of apparently conflicting data from laboratory and field tests for neonicotinoids in freshwaters, the lack of data for indicator species such as dragonflies and damselflies, and in response to the common assumption in pesticide testing that only insects that actually eat a treated crop would be harmed by exposure.

Using special test ditches, the study exposed both caged and free-living damselflies in the ditches to thiacloprid at levels found in nature when used in agricultural and horticultural production, ranging from low and commonly seen concentrations (0.1 μg/L) to less common higher concentrations (10 μg/L) observed in surface waters worldwide.

Blue-tailed damselflies exposed to low concentration in cages in the ditch ate less, grew more slowly and were less active. Effects were greater in damselflies finding their own food rather than being fed. Study leader Henrik Barmentlo said:

> "We found clear effects of environmentally relevant neonicotinoid concentrations on both caged *I. elegans* and natural populations. All sublethal parameters selected were affected by thiacloprid to some degree, but the severity of effects was stronger in caged individuals feeding on natural food supplies compared to fed individuals…This shows the importance of field realism.

> In the lab the insects receive high-quality food, but in a natural situation this is not always available. As a result, the susceptibility to insecticides in nature can be much higher."

The study found that the number of free-living damselflies that developed from larvae to adults (emerging), strongly decreased with increasing concentrations of insecticide. Such decreases in emerging damselflies are likely to lead to reduced reproduction. Over time this could lead to the local disappearance of common species like the blue-tailed damselfly. The Netherlands Butterfly Foundation data show declines in the number and distribution of blue tailed and other damselfly species since 2008.[44]

The results indicate that current laboratory assessments underestimate neonicotinoid toxicity in the actual environment, that even realistic exposure of caged damselflies in the experimental ditches underestimated the toxicity as the emergence of natural populations was more strongly affected, and that these effects may indicate a role for neonicotinoid exposure in adding to the ongoing decline of blue-tailed damselflies. The study concluded:

> "Literature reports that one out of seven Odonates is threatened and 24% of the species have declining populations. Our observations show that current risks of neonicotinoids to Odonates are underestimated in laboratory experiments as the toxicity is governed by multiple biotic factors such as food quantity/quality and predation. Given the widespread abundance of blue-tailed damselfly *Ischnura elegans*, the observed sensitivity to neonicotinoids and current population trends of this species, these results indicate neonicotinoids play a central role in the Odonate decline in general."

Dragonflies (Odonata)

Sympetrum dragonflies (Odonata) commonly inhabit rice fields in Japan, where they prey on insect pests and other aquatic organisms. One study sought to evaluate causality between use of fipronil and imidacloprid neonicotinoid pesticides in rice production and declines in *Sympetrum* dragonflies.

The study authors conclude that:

"…the use of these insecticides, particularly fipronil, was a major cause of the declines…"[45]

Evidence of effects – c) Birds

Birds are exposed to pesticides by ingestion of pesticide granules, treated seeds and crops, exposure to sprays or contaminated water, or feeding on contaminated prey and baits such as insects, earthworms, fish and other foods which have sufficiently high levels of toxins to have effects.

Even what are regarded as low levels of toxins can have effects which impair birds' behaviour and their ability to feed and to reproduce.

Birds hunt insects to feed themselves and their young and by doing so help control insect pests and manage the natural balance of insect populations. A lack of birds leads to pests thriving and potentially over-running crops and habitats.

UK birds

A 2001 study on the effect of herbicides on weed abundance and biodiversity for the Health and Safety Executive reported that:

> "Changes in farming practice in general are the cause of most population declines of farmland birds. Whilst the exact causal links are not known for most species, herbicides are implicated.
>
> "Data on farmland birds and invertebrates indicate that there have been significant reductions in populations and ranges over the past thirty years. In the case of the grey partridge, there is good evidence that herbicides have played a significant role in their decline."[46]

Seventeen years later the UK government's 2018 biodiversity indicators showed that farmland birds had declined by 56% between 1970 and 2015, linked to changes in agricultural practices, including pesticide use.[47]

Also, a government report on wild bird populations in England between 1970 and 2017 found that:

> "In 2017 the England farmland bird index was less than half (45%) of its 1970 value. The majority of this decline occurred between the late 1970s and early 1980s and was largely due to the negative impact of rapid changes in many farmland management practices during this period."[48]

European trends

The UK isn't alone, as data for EU member states shows:

> "Between 1990 and 2014, the population of common farmland birds declined by about one third (31.5 %) as a whole in the 26 European countries with monitoring schemes. In spite of year-to-year fluctuations, no trend towards recovery was observed. Furthermore, the reductions in farmland bird numbers since 1990 have followed on from earlier losses, structured data series for the period before 1990 being available for some EU countries only.
>
> "The long-term downward trend in common farmland bird populations points to a major decline in Europe's biodiversity associated with agro-ecosystems and grasslands. This has been primarily due to agricultural intensification and specialization as well as habitat loss. For example, the increased use of pesticides

and herbicides has resulted in reduced insect populations and seed production by plants, thereby reducing food for birds. Through habitat loss and fragmentation, birds have lost their nesting sites, further adding to population declines.

"It continues to be a challenge to achieve the wide and effective deployment of conservation measures contained in European policies such as the Birds and Habitats Directives, and the Water Framework Directive, as well as the environmental measures within the Common Agricultural Policy (CAP) in order to help populations recover at national and European scales."[49]

The Netherlands

In a 2014 study in the Netherlands, local populations of insect-eating birds were "significantly more negative" in areas with higher levels of a neonicotinoid pesticide in surface-waters. Where concentrations of the neonicotinoid imidacloprid were more than 20 nanograms per litre, bird numbers declined by 3.5% on average annually. Additional analyses revealed that this spatial pattern of decline appeared in the mid-1990's after imidacloprid started to be used.[50]

France

A 2014 study of birds and pesticides one of Europe's most intensively-farmed countries examined 70 farmland and non-farmland bird species across 66 fields in France's three main cereal producing departments (regions). The study found that:

- Intensive farming involving a high use of pesticides modified bird communities, with the proportion of specialist habitat birds, particularly herbivorous species, decreasing.
- The proportion of generalist bird species increased as pesticide doses increased (generalist species are more able to adapt to changing conditions and can take the place of more vulnerable specialist species).
- The abundance and richness of species was greatest where doses of insecticide or fungicide couldn't be detected.[51]

In 2018 a pair of studies – one national and one regional – tracked bird numbers and farming practice across France and reported that bird numbers had declined on average by a third in the past 17 years.[52]

The national study by France's National Museum of Natural History used bird census data collected since 2011. The regional study by the French National Center for Scientific Research (CNRS) used bird census collected data since 1995 for the large central farming region of Deux-Sèvres. The studies showed that declines were particularly severe for specific species:

- Grey partridge have declined by 90%.
- Meadows pipits have declined by 68%.
- Skylarks have declined by half.
- Common white throat, ortolan bunting and the Eurasian skylark have declined by at least a third.

The National Museum described the pace and extent of decline as "a level approaching an ecological catastrophe" and a co-author of one of the studies, Benoit Fontaine said:

> “The situation is catastrophic. Our countryside is in the process of becoming a veritable desert. We are losing everything and we need that nature, that biodiversity – the agriculture needs pollinators and the soil fauna.”

Ecologist Vincent Bretagnolle said:

> “There are practically no insects left, and this is the crux of the matter. What is really alarming, is that all the birds in an agricultural setting are declining at the same speed, even ’generalist’ birds. That shows that the overall quality of the agricultural eco-system is deteriorating.”

Commenting on the studies, the head of species monitoring and research at the Royal Society for the Protection of Birds, Richard Gregory, said:

> “Lots of these farmland birds that are declining, they eat invertebrates and they feed their young on invertebrates, and those are the things that are hit by general pesticides in the countryside. The volumes of usage are going up, and they’re becoming much more potent – so there is strong evidence to link pesticides to the decline of wildlife of different kinds.”

The French government plans to halve pesticide use by 2020, yet EU figures show sales have climbed steadily, reaching more than 75,000 tonnes of active ingredients in 2014.

Evidence of effects – d) Aquatic organisms

Aquatic insects are as vulnerable to neonicotinoids as bees and flying insects but have received less attention partly because of a lack of proper monitoring of pesticides in water and assessments of their real-world effects.

Reviews of aquatic organisms' sensitivity to neonicotinoids show that many aquatic insect species are several orders of magnitude more sensitive to these compounds than the traditional model organisms used in regulatory assessments for pesticide use. Studies are also starting to show the effects on fish.

As well as being persistent in soils and sediments for many months and even years (see page 11), the solubility in water of neonicotinoid pesticides makes them highly mobile and able to disperse from their intended treatment areas. Surface waters, including puddled water, ditches, irrigation channels and streams in and near farmland have all been found to be contaminated by neonicotinoids.[53]

According to a review of the effects of neonicotinoid pesticides on aquatic environments:

> "Negative impacts of neonicotinoids in aquatic environments are a reality. Initial assessments that considered these insecticides harmless to aquatic organisms may have led to a relaxation of monitoring efforts, resulting in the worldwide contamination of many aquatic ecosystems with neonicotinoids.
>
> "The decline of many populations of invertebrates, due mostly to the widespread presence of waterborne residues and the extreme chronic toxicity of neonicotinoids, is affecting the structure and function of aquatic ecosystems. Consequently, vertebrates that depend on insects and other aquatic invertebrates as their sole or main food resource are being affected. Declines of insectivore bird species are quite evident so far, but many other terrestrial and amphibian species may be at risk."[54]

Where systematic monitoring of pesticides *has* been undertaken, widespread contamination of waters with neonicotinoids has been reported, as described below.

Sweden

In 2008 the most comprehensive monitoring to date of the number of pesticides in Swedish watercourses tested for 126 different substances, 39 of which had not been investigated previously by official monitoring.

78 of the 126 substances were detected, with some individual locations having between 24 and 44 substances present in water. The highest numbers and concentrations were detected in areas of intensive vegetable growing and greenhouse production.[55]

California

In 2010-11, water samples from agricultural areas indicated that the neonicotinoid imidacloprid had travelled away from treated areas to contaminate surface waters at levels that could harm aquatic species.[56]

A 2016 study of water monitoring records showed neonicotinoid contamination. Of 132 sites monitored from January 2010 to October 2015, 72 (55%) had detectable levels of imidacloprid (typically 0.05 µg/L or more). In the 790 surface water samples taken, imidacloprid was detected in 468 (59%), up to a maximum of 12.7 µg/L. The study said:

> "The EPA acute benchmark of 35 µg/L was not exceeded in any sample, but toxicological studies suggest that acute exposures could impact sensitive species well below this level, at concentrations detected in California surface water."[57]

Midwest USA

In 2013-14, a study of neonicotinoids used in the intensive growing of corn and soybeans found similar patterns in 79 water samples from 9 streams for both frequency of detection and concentration of clothianidin (75%, median 8.2 ng/L, maximum 257 ng/L), thiamethoxam (47%, <2 ng/L, 185 ng/L) and imidacloprid (23%, <2 ng/L, 42.7 ng/L).[58]

Canada

A 2014 study of neonicotinoid use and water quality sampled water from wetlands in barley, canola and oat fields of the prairies. The wetlands consistently contained higher mean concentrations of neonicotinoids than in grasslands. The study said:

> "frequently detected neonicotinoid concentrations in Prairie wetlands suggest high persistence and transport into wetlands."[59]

Hungary

A 2015 study examined over 2,000 surface, ground and raw drinking water samples between 1990 and 2015 to assess the effects of pesticide contamination on water supplies. Most water contamination of agricultural origin related to the growing of maize. The study said:

> "High levels of water soluble pollutants in surface water result in temporarily enhanced levels in raw drinking water as well. Extreme levels observed for herbicide residues were of agrochemical industrial origin".[60]

The Netherlands (also see Damselflies, page 25)

A 2013 national study of the presence of the neonicotinoid imidacloprid in surface waters found a drop in the abundance of macrofauna (animals of a centimetre or more long, but smaller than an earthworm, living on or in sediment) where levels of imidacloprid were between 0.013 and 0.067 µg/L and significant impacts on the abundance of shrimps (Amphipoda), pond snails (Basommatophora), flies (Diptera), mayflies (Ephemeroptera) and hoglice (Isopoda).[61]

A 2014 study used data from Surface Water Quality Measurements and the standardised, long-term, national Common Breeding Bird Monitoring Scheme to examine 15 common farmland bird species and the extent to which average concentrations of imidacloprid residues between 2003 and 2009 spatially correlated with trends in bird population between 2003 and 2010.

The study, which found that water pollution levels of just 0.02 μg/L of imidacloprid led to a 30% fall in bird numbers, said that:

> "Invertebrates constitute a substantial part of the diet of many bird species during the breeding season and are indispensable for raising offspring. We investigated the hypothesis that the most widely used neonicotinoid insecticide, imidacloprid, has a negative impact on insectivorous bird populations…in the Netherlands, local population trends were significantly more negative in areas with higher surface-water concentrations of imidacloprid. At imidacloprid concentrations of more than 20 nanograms per litre, bird populations tended to decline by 3.5 per cent on average annually. Additional analyses revealed that this spatial pattern of decline appeared only after the introduction of imidacloprid to the Netherlands, in the mid-1990s. We further show that the recent negative relationship remains after correcting for spatial differences in land-use changes that are known to affect bird populations in farmland. Our results suggest that the impact of neonicotinoids on the natural environment is even more substantial than has recently been reported and is reminiscent of the effects of persistent insecticides in the past."[62]

Regarding levels of neonicotinoid contamination in waterbodies, in a 2017 review of evidence, Wood and Goulson wrote: [63]

> "…research since 2013 has demonstrated neonicotinoid migration into and persistence in agricultural soils, waterways and constituent parts of non-crop vegetation. Where assessments have been made of concentrations likely to significantly negatively affect non-target organisms, levels have been demonstrated to be above these thresholds in numerous non-crop agricultural habitats.
>
> "The strongest evidence for this is found in waterbodies surrounding agricultural areas, both temporary and permanent. The impact of neonicotinoids on aquatic organisms appears to be the easiest to quantify, as field-realistic concentrations can be easily obtained through sample collection and once neonicotinoids are present in waterbodies, aquatic organisms cannot limit their exposure to them.
>
> "Neonicotinoids continue to be found in a wide range of different waterways including ditches, puddles, ponds, mountain streams, rivers, temporary wetlands, snowmelt and groundwater and in outflow from water processing plants.
>
> "Reviews of the sensitivity of aquatic organisms to neonicotinoids show that many aquatic insect species are several orders of magnitude more sensitive to these compounds than the traditional model organisms used in regulatory assessments for pesticide use."

> "The most comprehensive review of levels of neonicotinoid contamination in global surface waters was conducted by Morrissey et al. (2015), though see also Anderson et al. (2015). Morrissey reviewed reported average and peak levels of neonicotinoid contamination from 29 studies from nine countries between 1998 and 2013. The waterbodies studied included streams, rivers, drainage, ditches, groundwater, wetlands, ponds, lakes, puddled surface waters and run-off waters. Study systems were adjacent to or receiving run-off water from agricultural land. From this dataset the geometric mean for average surface water neonicotinoid concentration was 0.13 μg/l (=0.13 ppb, *n* = 19 studies) and the geometric mean for peak surface water concentration was 0.63 μg/l (=0.63 ppb, *n* = 27 studies). Because most monitoring schemes use spot sampling, they are likely to underreport the true maximum concentrations that occur immediately after maximum periods of neonicotinoid influx (Xing et al. 2013). As peak concentrations are often found after acute events such as heavy rainfall, this limits our understanding of the true average and maximum concentrations that are found in waterbodies."

On sensitivity of aquatic invertebrates, Wood and Goulson also state:

> "The most comprehensive review of the acute and chronic effects of neonicotinoids on aquatic invertebrates was conducted by Morrissey et al. (2015). This followed on from and updated the reviews of Goulson (2013), Mineau and Palmer (2013) and Vijver and van den Brink (2014). Morrissey's analysis covered 214 toxicity tests for acute and chronic exposure to imidacloprid, acetamiprid, clothianidin, dinotefuran, thiacloprid and thiamethoxam for 48 species of aquatic invertebrate species from 12 orders (Crustacea: Amphipoda (11.7% of tests), Cladocera (21.0%), Decapoda (1.9%), Isopoda (4.2%), Mysida (7.9%), Podocopida (12.6%), Insecta: Diptera (22.9%), Ephemeroptera (6.5%), Hemiptera (3.7%), Megaloptera (1.9%), Odonata (1.9%), Trichoptera (3.3%)) from peer-reviewed and government studies. Both LC_{50} and ED_{50} values were included. Acute and chronic toxicity of neonicotinoids vary greatly across aquatic invertebrates with differences of six orders of magnitude observed. In general, insects were more sensitive than crustaceans; in particular, the Ephemeroptera (mayflies), Trichoptera (caddisflies) and Diptera (flies, most specifically the midges, Chironomidae) were highly sensitive."

UK study

In 2017, the conservation charity Buglife, carried out the first ever analysis of new monitoring data of neonicotinoid pesticide contamination in rivers and freshwaters in England, Scotland and Wales.[64]

Twenty-three sites were sampled in 2016 for five commonly used neonicotinoids – imidacloprid, clothianidin, thiamethoxam, acetamiprid and thiacloprid: 16 in England, 4 in Scotland, 3 in Wales and 3 in Northern Ireland. The findings showed:

- Half of the sites monitored in England exceeded chronic pollution limits.
- 88% of samples were contaminated with neonicotinoids.
- Two rivers in England were acutely polluted – the Waveney (Norfolk/Suffolk borders) and the Tame (West Midlands).
- Eight rivers in England were chronically polluted including: the Wensum (Norfolk), Ouse (East Anglia), Ancholme (Lincolnshire, a tributary of the Humber), Sincil Dyke (Lincolnshire), Wyke Beck (Yorkshire) and Somerhill Stream (Kent).
- Populations of mayflies and other insects in these rivers were likely to be heavily impacted, with consequences for fish and bird populations.

Buglife's analysis was assisted by use of the Riverfly Census analytical toolkit developed by Salmon & Trout Conservation (S&TC) to significantly improve monitoring of water quality for neonicotinoids and other insecticides by showing the impact of pesticides on aquatic invertebrates and the ecological damage it causes.[65]

By combining species-level data, SPEAR modelling and biometric finger printing, it's possible to assess the impact of harmful pesticide pollution long after the pollutant has dispersed and before official sampling is conducted by the Environment Agency, and to know the effects on water quality as well as threats to aquatic environments from nutrients, sediments, organic pollution and river flow. The S&TC said that in Wales:

> "chronic and acute pollution arising from intensive agricultural practices is having a devastating effect, not only on fish but also on aquatic invertebrates such as mayflies, sedges and dragonflies as well as freshwater plantlife. This, in turn, is affecting the fortunes of other species such as kingfishers, dippers and otters which cannot survive without a flourishing freshwater environment."

Commenting on the ongoing pollution of Welsh rivers from farming, National Officer for S&TC Cymru, Richard Garner Williams, said:

> "It is appalling that many of our rivers in Wales are under as much threat from human activity now as they were at the height of the Industrial Revolution. Agricultural pollution affects some 180 individual waterbodies in Wales and the number of reported pollution incidents shows no sign of a decline."

Commenting on the monitoring findings, Mark Lloyd, Chief Executive of the Angling Trust and Fish Legal said:

> "These results are highly alarming in the context of widespread declines in aquatic insect life and fish populations. We urge the government to act urgently to ban continued use of these chemicals to protect wildlife, fisheries and drinking water supply."

Arlin Rickard, Chief Executive of The Rivers Trust said:

> "Recent history has shown how agricultural chemicals which we initially thought were safe have proven extremely damaging to the environment and our wildlife."

Buglife's report provides a useful, condensed summary of various studies of aquatic invertebrates affected by levels of neonicotinoid pesticides in water:

> "It is now clear that neonicotinoids are very highly toxic to aquatic insects at low concentrations. The chronic LC50 (the concentration of dose at which half of creatures being tested die in 48 or 96 hours) for the midge Chironomus tentans is just 0.91 μg/L Imidacloprid (Stoughton et al.2008). Roessink et al. (2013) examined acute and chronic toxicity of Imidacloprid to a wide range of aquatic insects and other crustaceans and found that mayflies (Ephemeroptera) and caddisflies (Trichoptera) were the most sensitive species in both acute and chronic tests, with LC50 and EC50 values in the range of 0.1 to 0.3 μg/L. At an environmental concentration of just 0.03 μg/L 10% of mayflies died. Even hardy water fleas can be vulnerable to Imidacloprid when exposed also to the adjuvant that is used alongside the insecticide when sprayed; Chen et al. (2010) recorded a 19% reduction in Ceriodaphnia dubia population at 0.3 μg/L Imidacloprid in such conditions.
>
> "Mayflies of the genera Baetis and Epeorus showed a reduction in reproductive success when exposed to concentrations of Imidacloprid, applied as a formulated pesticide (Admire), at concentrations as low as 0.1 μg/L and in addition there were reductions in head length in Baetis and thorax length in Epeorus, indeed no male Epeorus emerged at 0.25 μg/L after 20-day exposure (Alexander, Heard & Culp 2008).
>
> "Short (24-h) pulses of Imidacloprid at 0.1 μg/L caused subsequent feeding inhibition for several days in the mayfly Epeorus longimanus (Alexander et al 2007)
>
> "Concentrations of Thiacloprid between 0.75 μg/L and 1 μg/L affected the behaviour of Gammarus shrimps and mayflies, resulting in the mayflies being more vulnerable to predation (Englert et al. 2012).
>
> "There was a reduction in growth and emergence rates in the midge Chironomus riparius when exposed to sublethal concentrations of 1.2 μg/L Imidacloprid and a significant delay in time-to-emergence when larvae were exposed to 0.4 μg/L and to high levels of predation cue (Pestana et al. 2009).
>
> "Cavallaro et al. (2016) is the only study that has compared the aquatic toxicity effects of Imidacloprid, Clothianidin, and Thiamethoxam. Using the midge Chironomus dilutus the effects of Imidacloprid and Clothianidin were similar, while Thiamethoxam was less toxic, but note again that Thiamethoxam decays into Clothianidin."

Fish

According to Gill and Garg in 2014:

> "Pesticides have been directly linked to causing fish mortality worldwide. For example, freshwater fish species are found to be affected by plant protection products (PPP) in Europe (Ibrahim et al., 2013). Another pesticide pentachlorophenol NaPCP* (An organochlorine compound used as an insecticide, as a herbicide, and as disinfectant and wood preservative) is reported to cause large numbers of fish mortality in the rice fields of Surinam (Vermeer et al., 1970). Pesticides not only impact the fish but also food webs related to them. The persistent pesticides organochlorine pesticides and polychlorinated biphenyls have already been found in the major Arctic Ocean food webs (Hargrave et al., 1992). A survey was conducted to examine the influence of pesticides on aquatic community in West Bengal, India. Many body tissues of the fish such as gills, alimentary canal, liver and brain of carp and catfish were found drastically damaged by pesticides. It was reported that such level of pesticides in fish could harm the fish consumers as well (Konar, 2011)."[66]

A 2019 study of fish species in Japan reports "that aquatic systems are threatened by the high toxicity and persistence of neonicotinoid insecticides" and that effects cascade through ecosystems by "altering food web structure and dynamics".[67]

Using data for fish yields, water quality and zooplankton over 25 years, this study found that:

> "neonicotinoid application to watersheds since 1993 coincided with an 83% decrease in average zooplankton biomass in spring, causing the smelt harvest to collapse from 240 to 22 tons in Lake Shinji. Shimane Prefecture, Japan. This disruption likely occurs elsewhere, as neonicotinoids are currently the most widely used class of insecticides globally."

Buglife's Matt Shardlow noted:

> "Japan has had a tragic experience with nerve-agent insecticides. In the paddy fields, where the air once thrummed with the clatter of billions of dragonfly wings, these insecticides have imposed near silence. The annihilation of humble flies and the knock-on effects on fish serve as further testament to the dreadful folly of neonicotinoids. Let's hope this is a wake-up call for Asian countries and they move to quickly ban the chemicals from paddyfields."[68]
>
> "It is also extremely worrying that the levels of neonicotinoids in rivers in eastern England, as recently reported by Buglife, (see page 34) are very similar to the levels reported in this research. Unfortunately, while it is clear that harm must have been done to UK river health, the exact impact of neonicotinoids has yet to be quantified."

Evidence of effects – e) Amphibians and reptiles

In 2018, EFSA reported its risk assessment of amphibians and reptiles, which are exposed to pesticides through their skin, from direct spraying, from eating pesticide treated food and by creatures and their eggs being in contact with pesticide residues in soil and on plant surfaces.[69]

EFSA reported:

> "Some amphibians and reptiles do occur in agricultural landscapes, some species resident and some migrating through. Amphibians often breed in water bodies in or adjacent to agricultural fields. Laboratory, field and survey studies have linked pesticides with harm to amphibians. Especially, studies on terrestrial stages of amphibian have shown that currently approved substances and authorised pesticides can cause mortality in frogs and toads at rates corresponding to authorised field rates. Even when including possible interception by crop plants, deposited residues are expected to lead to high risks for amphibians. There are few studies on reptiles, but those that exist suggest that pesticides can cause harm and that further investigation is needed. Field studies also exist where no unacceptable effects from the authorised use of pesticides were observed. However, the absence of evidence is not necessarily considered as evidence of absence of effects.
>
> "In addition to ecotoxicological concerns, amphibians are the most endangered group of vertebrates with faster decline rates than mammals and birds. Many of the European reptile species are threatened, with 42% of the reptile species exhibiting a declining population trend. The majority of species in both groups are protected species under European regulation.
>
> "The Panel concludes that exposure of amphibians and reptiles to pesticides does occur, and that this exposure may lead to decline of populations and harm individuals, which would be of high concern. Therefore, a specific environmental risk assessment (ERA) scheme is needed for these groups."

Evidence of effects – f) Mammals

In 2018, the first comprehensive review of the status of 58 British terrestrial mammals found populations of animals such as hedgehog, water vole, common and pygmy shrew had declined by up to 66% over the past 20 years.[70]

Hedgehogs

The 2018 estimated population of 522,000 is 66% lower than the previous estimate of 1,550,000 in 1995. Other reviews based on indices of relative abundance have estimated declines ranging from 1.25% to 40% over 10 years.[71]

Hedgehogs are struggling for a range of reasons including habitat loss, land-use change and because the insects they eat are themselves declining from changes in agricultural practices and pesticide use, including agricultural molluscicides and garden products such as slug pellets.

Fay Vass of the British Hedgehog Preservation Society said:

> "We are concerned about the lack of food in sterile fields where lots of pesticides and chemicals are used – there are also larger scale farms so there are less hedgerows for hedgehogs to use."[72]

A 2016 review of the effects on marine mammals of pollutants, including polychlorinated biphenyls (PCBs) and organochlorine pesticides, stated:

> "This review revealed a systemic suppression of immune function in marine mammals exposed to environmental contaminants. Exposure to immunotoxic contaminants may have significant population level consequences as a contributing factor to increasing anthropogenic stress in wildlife and infectious disease outbreaks."[73]

Evidence of effects – g) Wild plants

The lack of proper environmental monitoring of pesticides makes it hard to attribute the decline or loss of wild plants directly to their use. That said, when fields are sown, grown and treated with herbicides to kill off plants regarded as weeds these treatments will reach non-target plants.

Rising crop production has also meant more farmland is converted for production, often to grow a single crop. In such monocultures, other plants are regarded as a threat to the crop and a drain on profit.

Many species formerly found on croplands and farmland are now rare. The decline in plant species, their richness, abundance and diversity, on cropped fields, and in nearby fields, field margins, hedgerows, woods, ditches and habitats cannot be regarded as mere coincidence. Plantlife, the UK's plant charity, states:

> "The reasons for loss *(of wild plants)* are well known and include increased development, extensive use of herbicides, lack of appropriate woodland management, eutrophication of waterways, nitrogen deposition from the atmosphere, overgrazing and undergrazing and a host of other factors."[74]

Since botanical records began in the 17th century, 80 species (flowering plants, mosses, liverworts and lichens) have become extinct in Britain. At the national level the figures are even higher – England has lost 106, Wales 86 and Scotland 97.

Of the British total, 18 are wildflowers, 10 of which have been lost in the past 60 years:

- Narrow-leaved cudweed
- Summer lady's tresses
- Small bur parsley
- Purple spurge
- Lamb's succory
- Interrupted brome
- Downy hemp-nettle
- Irish saxifrage
- Stinking hawksbeard
- York groundsel

Of a total of 1,346 British wild plants, about a third are of conservation concern and are moving closer to extinction: 45 are Critically Endangered, 101 species are Endangered and 307 are listed as Vulnerable.

In its 2007 report on managing arable land, Plantlife states:

> "Arable flora is the most threatened group of plants in Britain today. From being a commonplace element of the farmed landscape, and indeed the bane of farmers' lives in past decades, modern agricultural techniques have brought many species to the verge of extinction. Fifty-four species are considered rare or threatened, whilst seven species are extinct in the arable setting…The impact of modern farming developments has been severe: of the 30 vascular plant species that have shown the greatest relative decline across Britain between the 1930-69 and 1987-99 recording periods, no fewer than 60% are characteristic of arable

and other cultivated land. These levels of decline are reflected in the new assessment of the threat status of Britain's vascular plant flora and supplementary surveys. It details that no fewer than seven species are regarded as extinct as arable plants in Britain, whilst a further 54 species are considered threatened (Fig 8). In short, arable plants represent the most threatened group of British plant species according to habitat."[75]

Sensitive arable management

Plantlife points to the potential of sensitive management of farmland as a solution:

> "…it is encouraging to note that to note that even the rarest of arable species often respond well to sympathetic management. Over ten thousand plants each of Cotswold Pennycress and Broad-leaved Cudweed appeared in Worcestershire and Kent respectively, within just a few months of sympathetic farming without herbicides: these are amongst our rarest arable species, confined to a handful of UK sites and both fully protected by law. Nature conservation policies now potentially provide the mechanisms through which effective arable plant conservation could be achieved.
>
> "The ability of arable plants to lie dormant in the seed bank means, with correct management in the right place, species rich assemblages can appear within the first year. With targeted action there is no reason why arable plants, the foundation of arable farmland biodiversity cannot return to the British countryside on a large scale."

Such sympathetic management isn't sufficiently widespread and a 2013 study found marked effects of various herbicides on non-target plant species at different stages of growth, from seedling to maturity and potential reproduction, including that:

- Many non-target plants have reached reproductive stages at spray time.
- Delay and reduction in reproduction occurred on plants sprayed as seedlings.
- Reproduction was often reduced by spraying during reproductive periods.
- Reproductive stages often exhibited more sensitivity than at seedling stage.[76]

However, research by the Centre for Ecology and Hydrology in 2017, points to how, counterintuitively, farmers can increase hay yields by planting more wildflowers.[77] Arable areas with wildflowers produced over 40% better hay yield than plots of only a few types of grasses. The hay from these areas was as good or better quality food for cattle in terms of nutrient content. And the benefits lasted and improved over eight years, countering suggestions that this effect is temporary:

> "Why does this seem to go against received wisdom? Work by ourselves and others has shown that the greater variety of species, especially wildflowers, results in a greater range of growth forms and life-styles. Species root to different depths, grow to diverse heights, and develop at different times of the year. This means that, as a whole the diverse plant community uses soil nutrients and energy from the sun more efficiently than can a community with fewer species.
>
> "This effect is especially strong when soil fertility is low. These fields were not fertilised. If they had been we could have achieved about double the hay yield we got and would have largely wiped out the diversity effect, but we would also have lost many species and potentially polluted watercourses with the runoff."

4. Efficacy in farm and food production

Long-held assumptions that pesticide use is essential to farming practices, to the production and protection of crops and for blooming horticulture and domestic gardens are coming into question. This is underlined by growing evidence that widespread over-use of pesticides is leading to rising pesticide resistance in pests.

The UN has challenged claims that pesticide use is essential to food production, crop yields and food security.[78] Its 2017 report linked pesticide use and the self-interest of pesticide businesses with the loss of diverse farming systems, and the decline of natural predators with rising food insecurity and resistance of pests:

> "Evolving technology in pesticide manufacture, among other agricultural innovations, has certainly helped to keep agricultural production apace of unprecedented jumps in food demand. However, this has come at the expense of human health and the environment. Equally, increased food production has not succeeded in eliminating hunger worldwide. Reliance on hazardous pesticides is a short-term solution that undermines the rights to adequate food and health for present and future generations." (para 2, p 3)

> "The assertion promoted by the agrochemical industry that pesticides are necessary to achieve food security is not only inaccurate, but dangerously misleading. In principle, there is adequate food to feed the world; inequitable production and distribution systems present major blockages that prevent those in need from accessing it. Ironically, many of those who are food insecure are in fact subsistence farmers engaged in agricultural work, particularly in lower-income countries." (para 91, p 19)

> "The amount of pesticides needed to protect crops depends on the robustness of the farming system. If crops are cultivated in unsuitable locations, they tend to be more susceptible to pests and diseases. Over the past decades, diversity in farming systems has been greatly reduced in terms of crops and varieties grown in natural habitats. The result is a loss of ecosystem services like natural pest control through predators and a loss of soil fertility. Rather than encouraging resistance, crop breeding in industrial agriculture has focused on high-yielding varieties that respond well to chemical inputs but that are more susceptible to pests and diseases. As most seed companies are now owned by agrochemical companies, there is limited interest in developing robust varieties. In order to succeed with pesticide reduction, it is essential to reintroduce diversity into agriculture and move away from monocultures of single varieties." (para 93, p 20)

> "Despite their widespread use, chemical pesticides have not achieved reduction in crop losses in the last 40 years. This has been attributed to their indiscriminate and nonselective use, killing not only pests but also their natural enemies and insect pollinators. Efficacy of chemical pesticides is also greatly reduced owing to pesticide resistance over time." (para 96, p 20)

The UN's recommendations include:

- Policies to reduce pesticide use and phase out / ban highly hazardous pesticides.
- Placing strict liability on pesticide producers.

- Developing comprehensive national plans, including incentives to support alternatives and initiating binding, measurable and timed reduction targets.
- Establishing systems to enable national agencies responsible for agriculture, public health and the environment to cooperate efficiently to address the adverse impact of pesticides and to mitigate risks from misuse and overuse.
- Establishing impartial and independent risk-assessment and registration for pesticides, with full disclosure required from producers, based on the precautionary principle and accounting for health and environment hazards.
- Use of non-chemical routes first, with chemical use based on proven need only.
- Penalties for companies fabricating evidence and disseminating misinformation on the health and environmental risks of their products.
- Encouraging agro-ecological practices such as crop selection, rotation and soil fertility management suited to local conditions.
- Replacing pesticide subsidies with taxes, import tariffs and use fees.

US study

A study of maize production in Indiana looked at the risk of neonicotinoid residues from treated maize to foraging honey bees and, regarding efficacy, the study authors state:

> "We documented no benefit, in terms of crop yields, of planting neonicotinoid treated maize over three cropping seasons" and "Three years of field experiments spread throughout the most intensive maize production region of Indiana failed to demonstrate a significant benefit of planting treated maize seeds, which parallels recent reports finding no, or inconsistent, benefits in oilseed rape in the EU (Budge et al. 2015), and US soybean production (Seagraves & Lundgren 2012; US EPA, 2014). These reports and our data suggest that the current use levels of insecticidal seed treatments in North American row crops are likely to far exceed the demonstrable need and our results likely reflect a scarcity of target pests."[79]

Regarding wildlife, the study indicates that over 94% of foraging honey bees across Indiana are at risk including to lethal levels of neonicotinoids during the sowing of maize:

> "We demonstrate movement of neonicotinoid residues well beyond planted fields occurs during maize sowing in Indiana. Based on locations of maize fields and apiaries in the state, the likelihood of neonicotinoid exposure for foraging honey bees is high. Other non-target organisms are also likely to encounter neonicotinoid residues; we conservatively estimate that deposition of neonicotinoid residues on non-target lands and waterways will occur on over 42% of the state of Indiana during the period of maize sowing.
>
> "The use of both seed treatments and modern pneumatic sowing equipment is widespread and contaminated dust stands out as an important source of acute exposure to neonicotinoids for honey bees and a wide range of other non-target organisms across areas that far exceed the planted field. However, there is reason for optimism: our work suggests that significant reductions in risks to pollinators and other non-target organisms could be achieved rapidly, and with little or no corresponding reduction in maize production simply by reducing the percentage of maize seed that is treated with neonicotinoid insecticides to levels that more realistically reflect pest pressure."

French study

A study of over 900 non-organic conventional farms in France found that, for the vast majority (94%), reducing pesticide use would not lead to them producing fewer crops. Instead, it found that none would produce less and two-fifths would produce more.[80]

The most startling results were for insecticides, where reduced use would result in more production on 86% of farms. The study authors reported:

> "…we demonstrated that low pesticide use rarely decreases productivity and profitability in arable farms. We analysed the potential conflicts between pesticide use and productivity or profitability with data from 946 non-organic arable commercial farms showing contrasting levels of pesticide use and covering a wide range of production situations in France. We failed to detect any conflict between low pesticide use and both high productivity and high profitability in 77% of the farms. We estimated that total pesticide use could be reduced by 42% without any negative effects on both productivity and profitability in 59% of farms from our national network. This corresponded to an average reduction of 37, 47 and 60% of herbicide, fungicide and insecticide use, respectively. The potential for reducing pesticide use appeared higher in farms with currently high pesticide use than in farms with low pesticide use. Our results demonstrate that pesticide reduction is already accessible to farmers in most production situations. This would imply profound changes in market organization and trade balance."

Rising resistance to herbicides

Resistance to herbicide use is a factor in reduced crop yields. First recorded in the 1960s, by 2015 457 distinct types of resistance had been found in 246 weed species in 86 crop varieties in 66 countries worldwide.[81]

Where some weeds are resistant to herbicides, they can pass on resistance to the next generation. Repeated applications of the same type of herbicide can further increase the population of resistant plants. Indeed, resistance to 22 of the 25 different methods that herbicides use to disrupt plant physiology has evolved.

As an illustration of its growing cost to agriculture, herbicide resistance in black-grass has been confirmed in 35 English counties, involving virtually all of the 20,000 UK farms that spray regularly to control weeds. Losses of wheat yields due to black-grass are reported to be 0.4-0.8 tonnes per hectare (T/ha), with some losses of over 2 T/ha recorded. Resistance also occurs in wild oats (found in 28 counties), rye grass (33 counties) and has recently emerged in poppy (9) and common chickweed (13).[82]

Cropping systems can contribute to the growth of herbicide resistance – one reason for the spread of resistance in black-grass is the tendency for shorter, less diverse rotations of crops. Wheat, barley and oilseed rape account for most (around 81%) of the UK's total arable crop land. If the same crop type is grown in successive seasons, then growth of the same weed species and use of the same herbicides can increase the chance of herbicide resistance. The danger is that a range of herbicides are increasingly unreliable if not ineffective at controlling black-grass. About 80% of black-grass emergence occurs in autumn, when autumn-planted cereals are starting grow through. Without the opportunity to remove these weeds prior to the crop growing, farmers are reliant solely on herbicides for weed control, which increases risks of resistance in black-grass – a vicious, increasingly ineffective cycle.

Rising resistance to insecticides

A 2018 review of evidence of the global use of organophosphates (OPs) finds that:

> "While IPM strategies do not, in principle, forbid the use of OP and other neurotoxic pesticides, these higher-risk materials serve as a last resort and should be applied in a way that protects human and environmental health. That most crops produced with OP pesticides are also produced organically provides compelling evidence that OP pesticides are not essential. Some recalcitrant pests may be difficult to manage with less toxic pesticides, which in some instances may result in lower yields or higher production costs, reducing competitiveness. Recent research, however, indicates that crop yields from organic and other alternative production systems are increasing and in some cases match conventional yields; these approaches additionally would likely reduce external costs to public health and the environment. To ensure that farmers are not threatened with rising costs and thinner profit margins, many agricultural trade and policy organizations recommend increased government support for extension research and outreach needed to support transitions to less toxic materials."[83]

A field experiment replicated in 114 fields across Europe examined ways to improve ecosystem services in intensively cropped landscapes and reported that:

> "…fertilisation had the strongest positive effect on yield, but hindered simultaneous harnessing of below- and above-ground ecosystem services…enhancing natural enemies and pest control through increasing landscape complexity can prove disappointing in fields with low soil services or in intensively cropped regions. Thus, understanding ecological interdependences between land use, ecosystem services and yield is necessary to promote more environmentally friendly farming by identifying situations where ecosystem services are maximised and agrochemical inputs can be reduced."[84]

Rising resistance to pyrethroids and neonicotinoids

Synthetic pyrethroids are widely used insecticides designed to block insects' nerve impulses, causing paralysis and death. Based on the chemistry of pyrethrum daisies in the crysanthemum family, pyrethroids began to be widely deployed in the 1960s and 1970s to replace widely used chemicals such as DDT, which were found to be highly bioaccumulative and persistant in the environment. Pyrethroids can harm beneficial insects such as bees and parasitic wasps and be toxic to fish and aquatic organisms, but were presented as a more effective treatment for a range of insect pests, which farmers could use less of, thereby reducing risks of residues accumulating in the environment.

By the mid 1980s pyrethroids made up a quarter of global insecticide sales with, 33 million hectares of crops being treated every year. Insect resistance to this widespread use started to be detected in the 1990s and 2000s. By the mid-2000s global sales had fallen to about 17% of the pesticides market, reflecting a rise in the use of neonicotinoids, which were promoted as a replacement for “older, dirtier” chemicals such as pyrethroids.

Such claims overlook that some neonicotinoid forumulations include pyrethroids and that pyrethroids remain in general use alongside neonicotinoids. The impression that neonicotinoids have replaced pyrethroids is false, rather like saying a new car has replaced an old one when both remain in use.

Insects develop resistance, especially where insecticides such as DDT and pyrethroids have the same mode of action (way to kill target species) and insects develop “cross-resistance” to both. This is exacerbated where species produce multiple generations in a season or year, where species such as aphids reproduce asexually, and when used in confined areas such as greenhouses.

Resistance also tends to occur with repeated use of insecticides, and trends show that resistance starts to be observed between two and twenty years after a new form of insecticide is introduced to replace the existing generation.

Because treatments are usually promoted as a form of insurance and applied habitually and prophylactically whether or not a crop is vulnerable, this cycle of resistance arising and spreading is almost inevitable.

5. Conclusions and recommendations

Pesticide reduction would benefit wildlife and food production as shown above. Increasing numbers of farmers are recognising the need to work with nature and looking for government support for agroecology and nature-friendly farming.[85]

Friends of the Earth recommends that:

Set ambitious target to reduce pesticide use and impacts

An ambitious target for pesticide reduction is needed to signal the scale of change needed and to allow monitoring of progress.[86] This should be based on frequency of use and toxic load not based on weight of pesticides used.

Targets would also help create a new category of farming adviser for food production and for nature so that farmers and growers who are trying to do the right thing are helped by the right system, not one geared to pesticide industry profits. The core need is to reduce and manage risk rather than just manage pesticides.

Incentivise pesticide reduction and low pesticide use

For years, financial incentives have been deployed to support food production based on rising pesticide use. Such public funding can and should be used to support greater use of cultural agronomic methods. This funding could help reduce pesticides use, such as through payments to farmers and landowners that support adoption of other methods of land and crop management, as well as the application of polluter pays policies.

End prophylactic use

Pesticide use should be a last resort, not a first line of defence. Instead of the current use of chemicals as a prophylactic, where the assumption is that there'll be a problem, other methods of cultivation and control should be adopted, including seeing if problems arise before reaching for the chemical spray, pellet or application.

Prioritising other ways to produce and protect crops and manage land would also bring the benefits of supporting soil health and improving conditions for beneficial creatures which can help to control pests.

If farmers, growers and amenity users never try to operate without prophylactic application of chemicals they won't know how things might be if they reduced or ceased use. They will also remain locked into a system of dependence both on pesticide use and to paying substantial amounts of their costs to the pesticide industry.

Proper monitoring and assessment

Many species aren't adequately monitored for their population numbers, range, abundance and trends in order to know how they're faring and to assess how they may be affected by pesticide and herbicide use.

This is compounded by poor monitoring of pesticide use, making it hard to track how these chemicals behave in the environment after they've been applied, including indirect effects, such as on aquatic species, or to attribute declines or losses of wild plants to the use of pesticides. Lack of proper data presents major barriers to better informed decisions about chemical use by practitioners and by policy makers.

Robust pesticide testing

The way pesticides are tested before they're approved for use has been found wanting. Testing has not adequately assessed how different pesticides behave together, how they affect a wide range of species and how they behave in the environment long after they have been applied.

Improved pesticide testing must cover more species, synergistic effects and long-term impacts, and must be conducted in an open way that's entirely independent from the pesticide industry and its tendency to conduct private testing.

Ongoing product testing

It's assumed that having been approved for use, a product or its active ingredient can never be questioned. That's how the pesticide industry and its supporters often respond to suggestions that its products require re-examination.

That isn't an especially scientific approach, as new evidence about the effects and efficacy of products can arise at any time. Knowledge should not be denied to decision-makers – including product manufacturers – about ongoing use and possible replacement by other, safer products.

Ongoing product information from better use of data would reduce or avoid the need for separate tests when the safety of a product or active ingredient is questioned.

Technological advances mean that it's now possible to track and monitor pesticides in the environment around the clock, which can feed back into closer and more timely reviews of their effects and use, and even reviews of their licensing.

Focus on soil quality and fertility

Many agronomic practices exist which can be deployed more extensively to boost soil quality and fertility. Such techniques and methods need more support, adoption and incentives. Finance streams can be utilised to increase their use.

Farming for multiple benefits

Moving away from agricultural monocultures would start to optimise more desirable, multi-functional land use and activities which can help protect and restore the ecosystems which food and farm production depend on.

That requires a fundamental shift in agriculture practices to support a wider array of social, environmental, and economic benefits from improved management of land-based natural capital.

Research and development into alternatives

The focus of research and development in recent decades has been on increasing crop yields as a way to maintain profitability. This has included more use of pesticides and fertilisers, to take advantage of the potential for increased yields. However, the past decade has seen gross margins eroded by yields levelling off and the rising cost of pesticides and artificial fertilisers. The environmental consequences of this high-yield culture are documented in this paper.

There should be a significant upscaling in the funding that's available for research into farming systems that aid pesticide reduction and the adoption of IPM, including: conventional plant breeding and development of crop varieties tolerant to pests and disease; alternative cultural and mechanical measures to control pest and disease; and the development of novel chemical solutions with a significantly reduced toxicity load.

Friends of the Earth has compiled the views of farmers and agronomists on what support is needed for greater take up of IPM.[87]

Change the structure of research

The links between research, advisory services, and what farmers need have suffered and need to be restored. A failure to research many low-tech, low-input techniques has arisen at the same time as much of the capability to examine holistic approaches has been lost, with the closure of research stations which have farms attached to them.

Meanwhile, due to the university appraisal system (Research Excellence Framework), universities have been forced to focus on academic prowess and publishing in high-impact journals to attract research funding. This has occurred at the expense of research into low-tech solutions that can make a genuine difference to farmers, growers, landowners and managers.

Long-term research into farming systems should be conducted by organisations with strong links to end users, working closely with innovative farmers and having the means to promote their findings and train farmers.

This will require multidisciplinary teams, making use of the latest technologies but also with an appreciation of what's achievable by farmers. Funding must be long-term, flexible and include compensation for farmers if it's carried out on commercial farms, and with the recognition that achieve a truly sustainable farming system will take time.

Boost independent agronomic advice

As farms have grown in size, the use of chemical inputs has become more complex, so many farmers have turned to agronomists for advice on the use of pesticides for different crops and management regimes.

The provision of on-farm agronomy is provided by BASIS-qualified agronomists, many of whom have ties to the agrochemical industry, where the pressure to boost sales of particular products may influence the advice being given. The prevailing culture of pursuing high yields through high farm inputs and risk-aversion reinforces the prophylactic use of pesticides as the norm. Understandably, agronomists would not want their advice to be the cause of crop failure.

Agronomic advice to farmers and growers should be given entirely independently of pesticide industry interests, to ensure that it isn't a barrier to reduction of pesticide use or adoption of IPM as a primary method of control.

The BASIS syllabus should be reviewed to ensure training promotes IPM and deployment of non-pesticide solutions as primary responses to the pests and disease.

Support knowledge transfer

Farmers and growers need help to adopt and apply new practices like IPM. This should be supported with better training through a continuing professional development programme, with priority given to peer-to-peer learning, involvement of regional teams, and consideration of local and regional conditions.

Clear government leadership and guidance

The European Commission has highlighted important shortcomings in EU member states' National Action Plans for pesticides, too many of which fail to specify how the application of IPM can be measured, fail to set targets, nor indicate how implementation will be ensured.

The UK should champion IPM and the practical application of the various techniques it implies and create a system that can be readily understood and practised by farmers, growers and land managers, and promoted by the government and its agencies.

Address inefficiencies in the food supply chain

The increasing gap between producers and users or consumers has been part of growing levels of food loss in production and food waste and profligacy in consumption.

Addressing the food supply chain's inefficiencies would help relieve pressures for more use of harmful chemicals, for agricultural land to be more productive, and for other land to be pressed into production.

Appendix 1: UK pesticide use, trends and toxicity

Limited data on the use of pesticides in the UK is collected by the UK government which conducts annual surveys of a sample of farmers and growers to produce indicative estimates rather than totals of actual usage.

Data is also limited by reflecting only the active ingredients used rather than the products themselves which will be formulated with different concentrations of active ingredients alongside other substances. Data also excludes when pesticides were used and whether they were applied alone or in combination.

Along with the lack of adequate monitoring of pesticides in soils, water and wider environment and lack of data about many wild species, the limitations of pesticides data makes it hard to draw firm conclusion about pesticides, their effects and efficacy and, ultimately, to make well-informed policy.

The total weight of pesticides used fell between 2000 and 2016 but this does not equate to reduced use of pesticides. Indeed, although the total weight of pesticides applied fell substantially between 2000 and 2016 the government does not regard the weight of pesticides applied as a good measure of environmental impact:

> "Reductions explained only in volume applied are meaningless with regard to risk as many new active substances are applied at much lower rates per hectare than the older products they are replacing, bringing about significant reductions in the weight applied, without necessarily resulting in any reduction of use or risk."[88]

What is clear is that overall pesticide use has risen over many decades. In the UK the area treated (spray hectares) has been increasing since 2000 mainly because of trends to grow more cereals and oilseeds and to increase chemical applications per area, and the increases have outweighed decreases in pesticide applications on grassland and beet crops and, by weight only, on potatoes.[89]

In addition, measurements and reduction targets based only on quantity (e.g. treatment frequency index, quantity of active ingredient applied) don't indicate the level of use of pesticides of greatest risk to health and the environment. Several EU countries are switching targets from use reduction to toxicity risk reduction for this reason. Targets should be set for both use and risk reduction. Including a measure of toxicity to humans and wildlife will ensure that the pesticides known to be most directly harmful are reduced first and fastest. Cutting overall use is also needed to ensure that indirect and poorly understood effects from pesticides are reduced. For example, some herbicides may not be categorised as highly toxic but by wiping out wild plants – not just specific problem weeds – they remove important plants bees and other pollinating insects need to visit for pollen and / or nectar.

Acute toxicity of active substances in pesticide products does not automatically result in an increased effect because other factors also have a bearing such as: the dosage (rate of application); the concentration of the active ingredient in each product; the overall formulation of each product with ingredients other than the active ingredient; the persistence of the product in soils, water and the environment.

Making good assessments and policy decisions about toxicity is hampered by the lack of a standard system to assess toxicity because different countries and sectors use different models, for example:

- Germany used SYNOPS to assess farm-scale impacts[90];
- I-Phy evaluates the potential for water and air contamination[91];
- the Netherlands developed an Environmental Yardstick for Pesticides (EYP)[92];
- Norway developed a pesticide risk indicator (NERI)[93]; and,
- Denmark has a Pesticide Load Indicator[94].

These models were either developed for use by agronomists (SYNOPS, I-Phy, EYP) and so require field level information such as soil type, or they're linked to pesticide taxes (NERI, PLI) and so are related to the pesticide formulations used in those countries which will be different from those used in the UK.

The Environmental Impact Quotient (IEQ) hosted by Cornell University was developed to help agronomists make better informed choices for IPM (see Appendix 2) and considers toxicity, persistence, human exposure and contamination, based on data from US universities. Being less detailed than some of the above models IEQ allows use of the averages provided by UK pesticide data although drawbacks remain such as:

- measures of effects on human health may not be valid because assumptions about operator and consumer exposure are based on US regulation and procedures;
- the measure is based on direct toxicity (LD50, LC50) and therefore excludes important sub-lethal effects such as the impact on bee behaviour, or indirect effects, such as loss of habitat caused by broad spectrum herbicides;
- the model assumes that the user has a specific pesticide formulation in mind, and therefore the actual percentage of the active ingredient used, data which is not available; and,
- as with all the models, the results indicate only the *potential* for environmental impact, because impacts may be mitigated in practice by required UK management practices (buffer zones, spray timings etc) that are not taken into account by a US-based analysis.

As can be seen the UK collects different data to those EU countries which have set pesticide reduction targets. Currently the UK has no target for pesticide reduction but it would be possible to adapt the kind of targets being used in other EU countries in the UK or a bespoke system could be developed drawing on the best aspects of them all. There's no technical difficulty in developing risk indicators and use reduction targets for the UK. The barrier is more political than technical.

Appendix 2: Integrated Pest Management (IPM)

IPM is defined in the EU directive 2009/18 on the sustainable use of pesticides as:

> "careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimise risks to human health and the environment. 'Integrated pest management' emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms." (Article 3, para 6)[95]

The European Commission lists the principles for enacting IPM as follows[96]:

The prevention and/or suppression of harmful organisms should be achieved or supported among other options especially by:

- crop rotation,
- use of adequate cultivation techniques (e.g. stale seedbed technique, sowing dates and densities, under-sowing, conservation tillage, pruning and direct sowing),
- use, where appropriate, of resistant/tolerant cultivars and standard/certified seed and planting material,
- use of balanced fertilisation, liming and irrigation/drainage practices,
- preventing the spreading of harmful organisms by hygiene measures (e.g. by regular cleansing of machinery and equipment),
- protection and enhancement of important beneficial organisms, e.g. by adequate plant protection measures or the utilisation of ecological infrastructures inside and outside production sites.

Harmful organisms must be monitored by adequate methods and tools, where available. Such adequate tools should include observations in the field as well as scientifically sound warning, forecasting and early diagnosis systems, where feasible, as well as the use of advice from professionally qualified advisors.

Based on the results of the monitoring the professional user has to decide whether and when to apply plant protection measures. Robust and scientifically sound threshold values are essential components for decision making. For harmful organisms threshold levels defined for the region, specific areas, crops and particular climatic conditions must be taken into account before treatments, where feasible.

Sustainable biological, physical and other non-chemical methods must be preferred to chemical methods if they provide satisfactory pest control.

The pesticides applied shall be as specific as possible for the target and shall have the least side effects on human health, non-target organisms and the environment.

The professional user should keep the use of pesticides and other forms of intervention to levels that are necessary, e.g., by reduced doses, reduced application frequency or partial applications, considering that the level of risk in vegetation is acceptable and they do not increase the risk for development of resistance in populations of harmful organisms.

Where the risk of resistance against a plant protection measure is known and where the level of harmful organisms requires repeated application of pesticides to the crops, available anti-resistance strategies should be applied to maintain the effectiveness of the products. This may include the use of multiple pesticides with different modes of action.

Based on the records on the use of pesticides and on the monitoring of harmful organisms the professional user should check the success of the applied plant protection measures.

Appendix 3: Human effects

Humans can be exposed to pesticides by various routes from the direct exposure of farm workers to pesticides in food. Pesticides have different properties that can be harmful to health including effects on nervous and endocrine systems. A summary is provided by the Pesticides Action Network[97] and below we highlight recent evidence.

A 2012 review of evidence linked pesticide exposure with the incidence of chronic diseases in humans.[98] Genotoxicity (properties of pesticide agents to damage genetic information in cells) and proteotoxicity (impaired cell function from damaged proteins) were identified as the main mechanisms involved. The review recommended better epigenetic knowledge to diagnose relationships and new policies for pesticide use:

> "Along with the wide use of pesticides in the world, the concerns over their health impacts are rapidly growing. There is a huge body of evidence on the relation between exposure to pesticides and elevated rate of chronic diseases such as different types of cancers, diabetes, neurodegenerative disorders like Parkinson, Alzheimer, and amyotrophic lateral sclerosis (ALS), birth defects, and reproductive disorders. There is also circumstantial evidence on the association of exposure to pesticides with some other chronic diseases like respiratory problems, particularly asthma and chronic obstructive pulmonary disease (COPD), cardiovascular disease such as atherosclerosis and coronary artery disease, chronic nephropathies, autoimmune diseases like systemic lupus erythematous and rheumatoid arthritis, chronic fatigue syndrome, and aging. The common feature of chronic disorders is a disturbance in cellular homeostasis, which can be induced via pesticides' primary action like perturbation of ion channels, enzymes, receptors, etc., or can as well be mediated via pathways other than the main mechanism. In this review, we present the highlighted evidence on the association of pesticide's exposure with the incidence of chronic diseases and introduce genetic damages, epigenetic modifications, endocrine disruption, mitochondrial dysfunction, oxidative stress, endoplasmic reticulum stress and unfolded protein response (UPR), impairment of ubiquitin proteasome system, and defective autophagy as the effective mechanisms of action."

More study is needed into how direct and indirect pesticide exposure may be affecting human health such as neurodevelopment. Proper study matters to understand pesticides effects on feotal and children's early development because toxicology differs in early stages of life and exposure to certain chemicals, which may have little or no discernible effects on healthy adults, can affect foetal development at low levels. In 2013, Professor Vyvyan Howard of the University of Ulster told UK MPs:[99]

> "What we are dealing with, with pesticides, is diffuse low-dose mixture and nobody is monitoring who is exposed to what very much, and particularly they are not monitoring what the foetus is getting…I think the main thing that I want to see introduced into regulatory process is a much closer look at subtle functional deficits. Hitherto, developmental toxicity has largely been measured by looking at gross malformations, spina bifida, skeletal malformations-things you can see with the naked eye. It is changing slowly but not fast enough, in my opinion. I will give you examples of these subtleties. One would be, say, a reduced ability to produce sperm. You don't see any deficit by looking at the anatomy; you have to measure the physiology, and neuro-behavioural deficits obviously fall into that as well. The

> subtle deficits are the things that we are finding increasingly following exposure during the foetal period. I think if we get to a stage where we can manage to protect the foetus, then we protect everybody – that is the most vulnerable state."

Neonicotinoids have been found to affect mammalian nicotinic acetylcholine receptors (nAChRs) in a similar way to the effects of nicotine. These receptors are critically important for human brain function, especially during early years' development, and for memory, cognition, and behavior. A 2012 study by Kimura-Kuroda et al said:

> "This study is the first to show that acetamiprid (ACE) and imidacloprid (IMI) and nicotine exert similar excitatory effects on mammalian nAChRs at concentrations greater than 1 μM. Therefore, the neonicotinoids may adversely affect human health, especially the developing brain."[100]

According to a 2017 systematic review of neonicotinoid effects on human health:

> "A distinct aspect of neonic toxicity is the ability to bind to the most prominent subtype of nAChRs in mammals, the α4β2, which is found in the highest density in the thalamus. Alteration of the density of this neuroreceptor subtype has been found to play a role in several central nervous system disorders, including Alzheimer's disease, Parkinson's disease, schizophrenia, and depression. In the developing brain, this subtype is involved in neural proliferation, apoptosis, migration, differentiation, synapse formation, and neural circuit formation. Other studies have found adverse reproductive as well as developmental effects in mammals including reduced sperm production and function, reduced pregnancy rates, higher rates of embryo death, stillbirth, and premature birth, and reduced weight of offspring…."Given the wide-scale use of neonics, more studies are needed to fully understand their effects on human health."[101]

Neonicotinoids are just one type (class) of pesticide. Originally formulated as human nerve gas agents organophosphates (OPs) have been adapted into lower dose insecticides and are regarded as moderately / highly hazardous to human health by the US EPA and WHO.[102] A 2018 review of evidence said: "Widespread use of OP pesticides in agriculture – as well as in homes, parks, schools, and hospitals and on golf courses, right-of-ways, and other public spaces – has led to ubiquitous human exposure."[103]

On OP exposure from the use of chlorpyrifos, the review noted that: "The US EPA concluded in 2016 that the existing epidemiologic literature provided 'sufficient evidence that there are neurodevelopmental effects occurring at chlorpyrifos exposure levels below that required to cause acetylcholinesterase inhibition'. Such chronic, low-level exposures are often overlooked or dismissed as benign because neither the pregnant woman nor the fetus shows clinically visible signs or symptoms. Furthermore, the developmental deficits do not manifest until months or years later."

The review said the evidence: "indicates that OP pesticides can interfere with brain development at levels previously thought to be safe or inconsequential" and recommended: "Governments phase out chlorpyrifos and other OP pesticides, monitor watersheds and other sources of human exposures, promote use of integrated pest management (IPM) through incentives and training in agroecology, and implement mandatory surveillance of pesticide-related illness."

References

[1] Report of the Special Rapporteur on the right to food, United Nations, Human Rights Council Thirty-fourth session, 27 February-24 March 2017, Agenda item 3 www.ohchr.org/en/hrbodies/hrc/regularsessions/session34/pages/listreports.aspx

[2] FAO Stat: www.fao.org/faostat/en/#data/RP

[3] Garthwaite, D, Ridley, L, Mace, A, Parrish, I, Barker, J, G, MacArthur, R. Land Use & Sustainability Team, Fera, Pesticides Usage Survey Report 271, Arable crops in the UK 2018 (2017 data) https://secure.fera.defra.gov.uk/pusstats/surveys/documents/arable2018.pdf

[4] There's something wrong in the countryside: rising pesticides use in the UK, 2019 https://policy.friendsoftheearth.uk/insight/theres-something-wrong-countryside-rising-pesticide-use-uk

[5] Köhler H-R, Triebskorn R (2013) Wildlife ecotoxicology of pesticides: can we track effects to the population level and beyond? Science 341:759–765. doi: 10.1126/science.1237591

[6] Pesticides and biodiversity, European Crop Protection Association and European Landowners' Organisation, (2013) www.ecpa.eu/sites/default/files/7584%2BBiodiversity_V04_bàt.pdf

[7] Katagi, T, Utsumi, T, Miyamoto, M, Sumitomo Chemical Co., Ltd., Environmental Health Science Laboratory, Ecotoxicological Risk Assessment of Pesticides in Terrestrial Ecosystems, (2011) https://www.sumitomo-chem.co.jp/english/rd/report/theses/docs/2011-1E_05.pdf

[8] Prosser, R.S., Anderson, J.C., Hanson, M.L., Solomon, K.R., Sibley, P.K. (2016) Indirect effects of herbicides on biota in terrestrial edge-of-field habitats: A critical review of the literature https://doi.org/10.1016/j.agee.2016.07.009

[9] Ibid page 6, para 32, page 9, UN, 2017

[10] Milner, A and Boyd I.L. Toward pesticidovigilance, *Science* (2017), Vol. 357, Issue 6357, pp. 1232-1234 DOI: 10.1126/science.aan2683 http://science.sciencemag.org/content/357/6357/1232

[11] United Nations Convention to Combat Desertification, Global Land Outlook first edition, Food Security and Agriculture (2017) page 136 https://knowledge.unccd.int/glo#the-bokk

[12] Gibbons, D., Morrissey, C., Mineau, P., A review of the direct and indirect effects of neonicotinoids and fipronil on vertebrate wildlife, Environ Sci Pollut Res Int. 2015 Jan;22(1):103-18. doi: 10.1007/s11356-014-3180-5. Epub 2014 Jun 18. www.ncbi.nlm.nih.gov/pubmed/24938819/

[13] Ségolène Humann-Guilleminot; Łukasz J. Binkowski; Lukas Jenni; Gabriele Hilke; Gaétan Glauser; Fabrice Helfenstein, A nation-wide survey of neonicotinoid insecticides in agricultural land with implications for agri-environment schemes, Journal of Applied Ecology, 2019, doi: 10.1111/1365-2664.13392

[14] Gill, HK and Garg H, (2014) Pesticides: Environmental Impacts and Management Strategies, 2014, Sonia Soloneski, IntechOpen, DOI: 10.5772/57399 www.intechopen.com/books/pesticides-toxic-aspects/pesticides-environmental-impacts-and-management-strategies

[15] Hertz-Picciotto I, Sass JB, Engel S, Bennett DH, Bradman A, Eskenazi B, et al. (2018) Organophosphate exposures during pregnancy and child neurodevelopment: Recommendations for essential policy reforms. PLoS Med 15(10): e1002671. https://doi.org/10.1371/journal.pmed.1002671

[16] Anu Kalia & S. K. Gosal (2011) Effect of pesticide application on soil microorganisms, Archives of Agronomy and Soil Science, 57:6, 569-596, DOI: 10.1080/03650341003787582

[17] Montanarella, L., Pennock, D. J., McKenzie, N., Badraoui, M., Chude, V., Baptista, I., Mamo, T., Yemefack, M., Singh Aulakh, M., Yagi, K., Young Hong, S., Vijarnsorn, P., Zhang, G.-L., Arrouays, D., Black, H., Krasilnikov, P., Sobocká, J., Alegre, J., Henriquez, C. R., de Lourdes Mendonça-Santos, M., Taboada, M., Espinosa-Victoria, D., AlShankiti, A., AlaviPanah, S. K., Elsheikh, E. A. E. M., Hempel, J., Camps Arbestain, M., Nachtergaele, F., and Vargas, R.: World's soils are under threat, SOIL, 2, 79-82 (2016) https://doi.org/10.5194/soil-2-79-2016

[18] United Nations Convention to Combat Desertification, Global Land Outlook first edition, Food Security and Agriculture (2017) page 43 https://knowledge.unccd.int/glo#the-bokk

[19] United Nations Convention to Combat Desertification, Global Land Outlook first edition, Food Security and Agriculture (2017) page 55 https://knowledge.unccd.int/glo#the-bokk

[20] Victor Limay-Rios; Luis Gabriel Forero; Yingen Xue; Jocelyn Smith; Tracey Baute and Arthur Schaafsma, Neonicotinoid insecticide residues in soil dust and associated parent soil in fields with a history of seed treatment use on crops in south western Ontario, 2015, Department of Plant Agriculture, University of Guelph, Ridgetown Campus, Ridgetown, Ontario, and Ontario Ministry of Agriculture, Food and Rural Affairs, Ridgetown, Ontario, Canada *Environ Toxicol Chem.*, DOI: 10.1002/etc.3257

[21] Petersen, S. O. et al Pesticide Interactions with Tillage and N source. Effects on fauna, microorganisms and selected ecosystem services. Pesticide Research No. 162 (2016) Department of Agroecology and Department of Bioscience at Aarhus University with the Danish Environmental Protection Agency. http://dca.au.dk/en/current-news/news/show/artikel/the-effects-of-pesticides-on-soil-organisms-are-complex/

[22] Ockelford. C et al, Scientific Opinion addressing the state of the science on risk assessment of plant protection products for in-soil organisms, EFSA (2017) www.efsa.europa.eu/en/efsajournal/pub/4690

[23] Pelosi, C., Barot, S., Capowiez, Y. et al. Agron. Sustain. Dev. (2014) 34: 199. Pesticides and earthworms. A review https://doi.org/10.1007/s13593-013-0151-z
https://link.springer.com/article/10.1007%2Fs13593-013-0151-z

[24] Frampton, GK., Jänsch, S., Scott-Fordsmand, JJ., Römbke, J., van den Brink, PJ. (2009), Effects of pesticides on soil invertebrates in laboratory studies: A review and analysis using species sensitivity distributions using species sensitivity distributions https://setac.onlinelibrary.wiley.com/doi/abs/10.1897/05-438R.1

[25] Nicolas Givaudan, N., Claudia Wiegand, C., Le Bot, B., Renault, D., Pallois, F., Llopis, S., Binet, S. (2014). Acclimation of earthworms to chemicals in anthropogenic landscapes, physiological mechanisms and soil ecological implications. Soil Biology and Biochemistry; 73: 49 DOI: 10.1016/j.soilbio.2014.01.032

[26] Pesticides make the life of earthworms miserable, (2014), ScienceDaily www.sciencedaily.com/releases/2014/03/140325113232.htm

[27] Van Hoesel W, Tiefenbacher A, König N, Dorn VM, Hagenguth JF, Prah U, Widhalm T, Wiklicky V, Koller R, Bonkowski M, Lagerlöf J, Ratzenböck A and Zaller JG, 2017, Single and Combined Effects of Pesticide Seed Dressings and Herbicides on Earthworms, Soil Microorganisms, and Litter Decomposition. *Front. Plant Sci*. 8:215.
www.frontiersin.org/articles/10.3389/fpls.2017.00215/full

[28] Individual and combined effects of herbicide tribenuron-methyl and fungicide tebuconazole on soil earthworm Eisenia fetida, (2018), Jiqiang Chen, Muhammad Saleem, Caixia Wang, Wenxing Liang, Qingming Zhang, Scientific Reports volume 8, Article number: 2967 www.nature.com/articles/s41598-018-21288-y

[29] Guiling Yang, Chen, Yijun Yu, Huiyu Zhao, Wen Wang, Yanhua Wang, Leiming Cai, Yueping He, Xinquan Wang, (2018), Combined effects of four pesticides and heavy metal chromium (Ⅵ) on the earthworm using avoidance behavior as an endpoint www.sciencedirect.com/science/article/pii/S0147651318302562

[30] Ndakidemi, B., Mtei, K. and Ndakidemi, P. (2016) Impacts of Synthetic and Botanical Pesticides on Beneficial Insects. *Agricultural Sciences*, **7**, 364-372. doi: 10.4236/as.2016.76038

[31] Woodcock, B.A., Harrower, C., Redhead, R., Edwards, M., Vanbergen, A.J. (2013) National patterns of functional diversity and redundancy in predatory ground beetles and bees associated with key UK arable crops https://doi.org/10.1111/1365-2664.12171

[32] Basley, K, Davenport, B, Vogiatzis, K, Goulson , D, (2018) Effects of chronic exposure to thiamethoxam on larvae of the hoverfly *Eristalis tenax* (Diptera, Syrphidae) www.ncbi.nlm.nih.gov/pmc/articles/PMC5775755/

[33] Sir David Attenborough, Saving butterflies and moths for 50 years (2028) https://butterfly-conservation.org/news-and-blog/saving-butterflies-and-moths-for-50-years

[34] Populations of grassland butterflies decline almost 50% over two decades, (2013), European Environment Agency www.eea.europa.eu/highlights/populations-of-grassland-butterflies-decline

[35] Gilburn, A.S.; Bunnefeld, N.; Wilson, J.M.; Botham, M,S.; Brereton, T.M.; Fox., R; Goulson, D. (2015). Are neonicotinoid insecticides driving declines of widespread butterflies? PeerJ 3:e1402 https://doi.org/10.7717/peerj.1402

[36] Braak, N; Neve, R; Jones, A. H; Gibbs, M; Breuker, C. J. The effects of insecticides on butterflies – A review (2018) www.sciencedirect.com/science/article/pii/S0269749118320943

[37] Labruyere, S., Ricci B., Lubac, A., Petit, S. (2006) Crop type, crop management and grass margins affect the abundance and the nutritional state of seed-eating carabid species in arable landscapes https://doi.org/10.1016/j.agee.2016.06.037

[38] Di Vitantonio, C; Depalo, L; Marchetti, E; Dindo, M. L.; Masetti, A; (2018) Response of the European Ladybird *Adalia bipunctata* and the Invasive *Harmonia axyridis* to a Neonicotinoid and a Reduced-Risk Insecticide. *Journal of Economic Entomology*, Volume 111, Issue 5. https://doi.org/10.1093/jee/toy206

[39] Hallmann CA, Sorg M, Jongejans E, Siepel H, Hofland N, Schwan H, Stenmans, W., Müller, A., Sumser, H., Hörren, Goulson, D., de Kroon, H. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PLoS ONE 12(10): e0185809. https://doi.org/10.1371/journal.pone.0185809

[40] Warning of 'ecological Armageddon' after dramatic plunge in insect numbers, (2017), The Guardian www.theguardian.com/environment/2017/oct/18/warning-of-ecological-armageddon-after-dramatic-plunge-in-insect-numbers

[41] Seibold, S., Gossner, M.M., Simons, N.K. *et al.* Arthropod decline in grasslands and forests is associated with landscape-level drivers. *Nature* **574,** 671–674 (2019) doi:10.1038/s41586-019-1684-3 www.nature.com/articles/s41586-019-1684-3

[42] 'Alarming' loss of insects and spiders recorded, BBC, 2019 www.bbc.co.uk/news/science-environment-50226367

[43] S. Henrik Barmentlo et al. Environmental levels of neonicotinoids reduce prey consumption, mobility and emergence of the damselfly *Ischnura elegans*, Journal of Applied Ecology (2019) https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/1365-2664.13459

[44] Van Swaay, C. A. M., Bos, G., van Grunsven, R.H.A., Kok, J., Huskens, K., van Deijk, J. R., & Poot, M. (2008) Vlinders en libellen geteld. Jaarverslag 2017. Rapport VS2018.006. De Vlinderstichting, Wageningen

[45] Nakanishi, K., Yokomizo, H. & Hayashi, T.I. Were the sharp declines of dragonfly populations in the 1990s in Japan caused by fipronil and imidacloprid? An analysis of Hill's causality for the case of *Sympetrum frequens,* Environ Sci Pollut Res (2018) 25: 35352. https://doi.org/10.1007/s11356-018-3440-x

[46] Marshall, E.J.; Brown, V.; Boatman, N.D.; Lutman, P. The impact of herbicides on weed abundance and biodiversity, A report for the UK Pesticides Safety Directorate, HSE, PN0940 (2001) www.hse.gov.uk/pesticides/topics/publications/research-reports/the-impact-of-herbicides-on-weed-abundance-biodiversity.htm

[47] UK Biodiversity Indicators (2018), JNCC, http://jncc.defra.gov.uk/page-4229

[48] Agri-environmental indicator – population trends of farmland birds, Eurostat (2017) https://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_population_trends_of_farmland_birds

[49] Wild Bird Populations in England, 1970 to 2017, Department for Environment, Food and Rural Affairs, (2018), www.gov.uk/government/statistics/wild-bird-populations-in-england

[50] Declines in insectivorous birds are associated with high neonicotinoid concentrations, Hallmann, CA., Foppen, RPB., van Turnhout, CAM., de Kroon, H., Jongejans, E. (2014), Nature volume 511, pages 341–343 www.nature.com/articles/nature13531

[51] François Chiron., F., Chargé., R., Julliard, R., Jiguet, F.,Muratet, A., (2014), Pesticide doses, landscape structure and their relative effects on farmland birds www.sciencedirect.com/science/article/pii/S0167880913004350

[52] Where have all the farmland birds gone?, (2018), French National Center for Scientific Research (CNRS) https://news.cnrs.fr/articles/where-have-all-the-farmland-birds-gone

[53] Morrissey et al., 2015; Van Dijk, Van Staalduinen & Van der Sluijs, 2013; Samson-Robert et al., 2014; Main et al., 2014; Schaafsma et al., 2015.

[54] Sánchez-Bayo, F., Goka, K., Hayasaka, D. 2016. Contamination of the Aquatic Environment with Neonicotinoids and its Implication for Ecosystems. Front. Environ. Sci. 4:71. www.frontiersin.org/articles/10.3389/fenvs.2016.00071/full

[55] Kreuger, J., Graaf, S., Patring, J., Adielsson, S. (2010) Pesticides in surface water in areas with open ground and greenhouse horticultural crops in Sweden 2008. p. 49. www.researchgate.net/publication/259113442_Detection_and_analysis_of_neonicotinoids_in_river_waters_-_Development_of_a_passive_sampler_for_three_commonly_used_insecticides

[56] Starner, K., Goh, K.S. (2012) Detections of the neonicotinoid insecticide Imidacloprid in surface waters of three agricultural regions of California, USA, 2010–2011. Bull Environ Contam Toxicol 88:316–321 www.ncbi.nlm.nih.gov/pubmed/22228315

[57] Hoyle, S., Code, A. (2016) Neonicotinoids in California's Surface Waters, A Preliminary Review of Potential Risk to Aquatic Invertebrates. Xerces Society, Oregon. https://xerces.org/neonicotinoids-and-surface-waters/

[58] Hladik, M.L., Kolpin, D.W., Kuivila, K.M. (2014). Widespread occurrence of neonicotinoid insecticides in streams in a high corn and soy bean producing region, USA. Environ. Pollut. 193,189–196. www.ncbi.nlm.nih.gov/pubmed/25042208

[59] Main, A.R., Headley, J.V., Peru, K.M., Michel, N.L., Cessna, A.J., Morrissey,C.A. (2014) Widespread use and frequent detection of neonicotinoid insecticides in wetlands of Canada's prairie Pothole region. PLoS One 9(3):e92821 http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0092821

[60] Székács, A., Mörtl, M., Darvas, B. (2015) Monitoring Pesticide Residues in Surface and Ground Water in Hungary: Surveys in 1990–2015. Journal of Chemistry Volume, Article ID 717948 http://dx.doi.org/10.1155/2015/717948. www.hindawi.com/journals/jchem/2015/717948/

[61] Van Dijk T,C., Van Staalduinen M,A., Van der Sluijs J,P. (2013). Macro-invertebrate decline in surface water polluted with Imidacloprid http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0062374

[62] Hallmann, CA., Foppen, RPB., van Turnhout, CAM, de Kroon, H., Jongejans, E., Declines in insectivorous birds are associated with high neonicotinoid concentrations, *Nature* volume 511, pages 341–343, (2014) www.nature.com/articles/nature13531

[63] Wood., TJ, and Goulson., D. (2017). The environmental risks of neonicotinoid pesticides: a review of the evidence post 2013 https://link.springer.com/article/10.1007/s11356-017-9240-x

[64] Neonicotinoid insecticides in British freshwaters, (2017), www.buglife.org.uk/news-and-events/news/heavy-neonicotinoid-insecticide-contamination-damaging-british-rivers

[65] Salmon & Trout Conservation www.salmon-trout.org/category/riverfly-census/page/2/

[66] Ibid, page 12

[67] Yamamuro, M; Komuro, T; Kamiya, H; Kato, T; Hasegawa, H; Kameda, Y. Neonicotinoids disrupt aquatic food webs and decrease fishery yields, *Science*, (2019) https://science.sciencemag.org/content/366/6465/620

[68] Fishery collapse confirms 'Silent Spring' pesticide prophesy, The Guardian, 2019 www.theguardian.com/environment/2019/oct/31/fishery-collapse-confirms-silent-spring-pesticide-prophecy

[69] Ockleford, C, et al. Scientific Opinion on the state of the science on pesticide risk assessment for amphibians and reptiles, (2018) European Food Safety Authority (EFSA) Panel on Plant Protection Products and their Residues (PPR). www.efsa.europa.eu/en/efsajournal/pub/5125

[70] Mathews F, Kubasiewicz LM, Gurnell J, Harrower CA, McDonald RA, Shore RF. (2018) A Review of the Population and Conservation Status of British Mammals: Technical Summary. A report by the Mammal Society under contract to Natural England, Natural Resources Wales and Scottish Natural Heritage. Natural England, Peterborough www.mammal.org.uk/science-research/mammal-review-2018-technical-summary/

[71] Roos et al., 2012, Hof and Bright, 2016

[72] At least fifth of British mammal species could be wiped out within a decade, (2018), The Independent www.independent.co.uk/environment/mammals-uk-extinction-hedgehogs-water-voles-squirrels-nature-farming-pesticides-a8395581.html

[73] Desforges, JPW. Sonne, C., Levin. M., Siebart, S., De Guise, S., Dsietz, R. (2016). Immunotoxic effects of environmental pollutants in marine mammals https://doi.org/10.1016/j.envint.2015.10.007 https://www.sciencedirect.com/science/article/pii/S0160412015300738

[74] Plantlife (2012) Our vanishing flora – how wild flowers are disappearing across Britain www.plantlife.org.uk/uk/our-work/publications/our-vanishing-flora

[75] Still, A and Andrew Byfield, A, Plantlife, (2007) ISBN:1 904749-71-2 New Priorities for Arable Plant Conservation https://messicoles.org/files/fichierressource_Still_2007_england.pdf

[76] Boutin, C., Strandberg, B., Carpenter, D., Mathiasse, S.K., Thomas, P.J., Herbicide impact on non-target plant reproduction: What are the toxicological and ecological implications? (2013) https://doi.org/10.1016/j.envpol.2013.10.009

[77] Bullock, J and Pywell, R, Centre for Ecology & Hydrology (2017) https://nerc.ukri.org/planetearth/stories/142/

[78] Ibid page 4

[79] C. H. Krupke; J. D. Holland; E. Y. Long; B. D. Eitzer, 2017, Planting of neonicotinoid-treated maize poses risks for honey bees and other non-target organisms over a wide area without consistent crop yield benefit, Journal of Applied Ecology doi: 10.1111/1365-2664.12924

[80] Lechenet, M, Dessaint, F, Py, G, Makowski, D, Munier-Jolain, N. Reducing pesticide use while preserving crop productivity and profitability on arable farms, (2017), *Nature Plants* volume 3, Article number: 17008 www.nature.com/articles/nplants20178

[81] International Survey of Herbicide Resistant Weeds www.weedscience.com/

[82] Hull, R., et al, (2014), Aspects of Applied Biology, 127: 261-272

[84] Gagic, V; Kleijn, D; Báldi, A; Boros, G; Jørgensen, H.B.; Elek, Z; Garratt, M.P.D.; de Groot, G.A.; Hedlund, K; Kovács-Hostyánszki, A; Marini, L; Martin, E; Pevere, I; Potts, S.G.; Redlich, S; Senapathi, D; Steffan-Dewenter, I; Świtek, S; Smith, H.G..; Takács, V; Tryjanowski, P; van der Putten, W.H..; van Gils, S; Bommarco, R. (2017) Combined effects of agrochemicals and ecosystem services on crop yield across Europe, In: Ecology Letters, Vol. 20, No. 11, 01.11.2017, p. 1427-1436. www.ncbi.nlm.nih.gov/pubmed/28901046

[85] Nature Friendly Farming Network www.nffn.org.uk/

[86] Driving pesticide reduction – why the government must set ambitious targets, 2019
https://policy.friendsoftheearth.uk/insight/driving-pesticide-reduction-why-government-must-set-ambitious-targets

[87] Cutting pesticides use and promoting integrated pest management in UK agriculture – a farmer's perspective, 2018
https://cdn.friendsoftheearth.uk/sites/default/files/downloads/cutting-pesticide-use-farmers-perspective_1.pdf

[88] Thomas MR (undated) *Guidelines for the Collection of Statistics on the Usage of Plant Protection Products within Agriculture & Horticulture* EUROSTAT Pesticides Statistics Taskforce. p.4
https://secure.fera.defra.gov.uk/pusstats/surveys/documents/guide.pdf

[89] There's something wrong in the countryside: rising pesticides use in the UK, 2019
https://policy.friendsoftheearth.uk/insight/theres-something-wrong-countryside-rising-pesticide-use-uk

[90] Gutsche, V. & Rossberg, D. 1997. SYNOPS 1.1: A model to assess and to compare the environmental risk potential of active ingredients in plant protection products *Agriculture, Ecosystems and Environment* Vol. 40

[91] van der Werf, H.M.G., Zimmer, C., 1998. An indicator of pesticide environmental impact based on a fuzzy expert system. *Chemosphere* 36, 2225–2249.

[92] Reus, J.A.W.A., Leendertse, P.C., 2000. The environmental yardstick for pesticides: a practical indicator used in the Netherlands. *Crop Protection* 19, 637–641.

[93] Stenrød, M., Heggen, H.E., Bolli, R.I., Eklo, O.M., 2008. Testing and comparison of three pesticide risk indicator models under Norwegian conditions—a case study in the Skuterud and Heiabekken catchments. *Agriculture Ecosystems & Environment.* 123, 15–29.

[94] Kudsk P et al, 2018. Pesticide Load – A new Danish pesticide risk indicator with multiple applications *Land Use Policy* 70 pp 384–393

[95] EU directive 2009/18 on the sustainable use of pesticides https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:02009L0128-20091125

[96] European Commission, Integrated Pest Management (IPM)
https://ec.europa.eu/food/plant/pesticides/sustainable_use_pesticides/ipm_en

[97] PAN-UK: www.pan-uk.org/health-effects-of-pesticides/

[98] Mostafalou S and Mohammad A, Pesticides and human chronic diseases: evidences, mechanisms, and perspectives (2013) https://doi.org/10.1016/j.taap.2013.01.025

[99] House of Commons Environmental Audit Committee (2013) Insects and Insecticides,
https://publications.parliament.uk/pa/cm201213/cmselect/cmenvaud/668/130130.htm

[100] Kimura-Kuroda, J., Komuta, Y., Kuroda, Y., Hayashi, M., Kawano, H. (2012). Nicotine-Like Effects of the Neonicotinoid Insecticides Acetamiprid and Imidacloprid on Cerebellar Neurons from Neonatal Rats
https://doi.org/10.1371/journal.pone.0032432
http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0032432

[101] Cimino. AM., Boyles, AL., Thayer, KA., Perry. MJ. (2017). Effects of neonicotinoid pesticide exposure on human health: a systematic review. Environ Health Perspect 125:155–162; http://dx.doi.org/10.1289/EHP515 and www.ncbi.nlm.nih.gov/pmc/articles/PMC5289916/

[102] Roberts J, Reigart J. Chapter 5. Organophosphates. Recognition and Management of Pesticide Poisonings. Sixth ed. Washington, D.C.: U.S. Environmental Protection Agency, Office of Pesticide Programs; (2013). www2.epa.gov/pesticide-worker-safety
World Health Organization International Programme on Chemical Safety. The WHO Recommended Classification of Pesticides by Hazard and Guidelines to Classification 2009. Geneva, Switzerland: (2009)
www.who.int/ipcs/publications/pesticides_hazard_2009.pdf?ua=1

[103] Ibid page 9