
Pesticides and the loss of biodiversity

How intensive pesticide use affects wildlife populations and species diversity



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Pesticide Action Network Europe

PAN Europe is a network of NGO campaign organisations working to minimize the negative impacts of pesticides and replace the use of hazardous chemicals with ecologically sound alternatives

Our vision is of a world where high agricultural productivity is achieved through sustainable farming systems in which agrochemical inputs and environmental impacts are minimised, and where local communities control food production using local varieties.

PAN Europe brings together consumer, health and environmental organisations, trades unions, women's groups and farmer associations. Our formal membership includes 32 organisations based in 19 European countries.



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Biodiversity loss and the use of pesticides

Pesticides are a major factor affecting biological diversity, along with habitat loss and climate change. They can have toxic effects in the short term in directly exposed organisms, or long-term effects by causing changes in habitat and the food chain.

What is biodiversity?

Charles Darwin and Alfred Wallace were among the first scientists to recognise the importance of biodiversity for ecosystems. They suggested that a diverse mixture of crop plants ought to be more productive than a monoculture (Darwin & Wallace 1858). Though there are exceptions, recent studies confirm the idea that an intact, diverse community generally performs better than one which has lost species (Chapin *et al* 2002). Ecosystem stability (resilience to disturbance) seems to arise from groups of connected species being able to interact in more varied positive and complimentary ways (Tilman 2002). Biological diversity manifests itself at different levels. It includes the diversity of ecosystems, species, populations, and individuals. In an ecosystem, interdependent populations of various species deliver 'services' such as the supply of food and soil resources, or the retention and cycling of nutrients, water and energy. Although it seems that the average species loss can affect the functioning of a wide variety of organisms and ecosystems, the magnitude of effect depends on which particular species is becoming extinct (Cardinale *et al* 2006).

- Communities of different animal and plant species perform vital functions within ecosystems. In general, communities which have higher diversity tend to be more stable.

Why conserve threatened species?

Rachel Carson provided clear evidence of the far-reaching environmental impact of pesticides in her pioneering work 50 years ago. In 'Silent spring' she showed that organochlorines, a large group of insecticides, accumulated in wildlife and the food chain. This had a devastating effect on many species. Only a decade after the 'green revolution' began it became obvious that large-scale spraying of pesticides was causing serious damage. In 1963, Rachel Carson emphasised human dependence on an intact environment: "But man is a part of nature, and his war against nature is inevitably a war against himself", (CBS 1963). Human well-being depends on the services delivered by intact ecosystems. While biodiversity loss is in itself a cause for concern, biodiversity conservation also aims to sustain humanity. People's livelihoods ultimately depend on biological resources. Thus lacking progress towards the target of the Convention on Biological Diversity, "to achieve by 2010 a significant reduction of the current rate of biodiversity loss" could undermine achievement of the Millenium Development Goals and poverty reduction in the long term (Sachs *et al* 2009). The 2010 target has inspired action but will not be fully attained. Biodiversity loss and degradation of ecosystems have increasingly dangerous consequences for people, and may threaten some societies' survival (IUCN 2010).

When EU cereal yield was doubled it resulted in the loss of half the plant species and one-third of carabid beetles and farmland bird species. Of the components of agricultural intensification, pesticide use, especially insecticides and fungicides, had the most consistently negative effects on species diversity, and insecticides also reduced the potential for biological pest control (Geiger *et al* 2010). In the EU, up to 80% of protected habitat types and 50% of species of conservation interest now have an unfavourable conservation status. Much greater effort is needed to reverse the decline in threatened species or habitats on a larger scale (EC 2008). A 'business-as-usual' scenario would mean that the current decline of biodiversity will continue and even accelerate, and by 2050 a further 11% of natural areas which existed in 2000 will be lost, while 40% of land currently under low-impact agriculture could be converted to intensive agricultural use (TEEB 2008).

- Human survival is inextricably linked to the survival of numerous other species on which intact ecosystems depend.

Increasing pressure of agriculture on habitats and biodiversity

The use of pesticides (particularly herbicides) and synthetic fertilisers has increased dramatically over the past 60 years. In industrialised countries, farming practices have fundamentally changed. In the UK and many other places, mixed agriculture has been lost and farms have become increasingly specialised. Arable farming (field crops) and pastoral grassland are now largely separated as traditional crop rotation has been abandoned. In the British lowlands, field sizes have risen and field margins have shrunk. Harvesting has become more efficient and hedgerows have been lost. There has been a marked population decline of many species living on farmland (Boatman *et al.* 2007).

Worldwide humans are estimated to use about 20% of the net primary production (plant organic matter produced in photosynthesis). In South America and Africa, humans use about 6% and 12%, respectively, of the regional net primary production, while the fraction consumed by humans is 72% in western Europe and 80% in south central Asia (Imhoff *et al.* 2004). The proportion of plant organic matter consumed by humans varies enormously between regions. For example, consumption of regionally-produced plant matter per inhabitant is nearly five times higher in North America than in south central Asia. Changes of habitat and biodiversity have been due both to changing climate and people's increasing use of plant and animal resources.

- Heavy pesticide input has been a key feature of agricultural intensification. This is closely linked to changes in farming practices and habitat destruction or loss.
- Between 1990 and 2006, the total area treated with pesticides increased by 30% in the UK, and the herbicide-treated area increased by 38% (Fera 2009).
- In farmland habitats, population declines have occurred in about half of plants, a third of insects and four-fifths of bird species (Robinson & Sutherland 2002).

Impact of pesticides on wildlife populations and species diversity

Many pesticides are toxic to beneficial insects, birds, mammals, amphibians, or fish. Wildlife poisoning depends on a pesticide's toxicity and other properties (eg water-soluble pesticides may pollute surface waters), the quantity applied, frequency, timing and method of spraying (eg fine spray is prone to drift), weather, vegetation structure, and soil type. Insecticides, rodenticides, fungicides (for seed treatment) and the more toxic herbicides threaten exposed wildlife. Over the past 40 years, the use of highly toxic carbamate and organophosphate has strongly increased. In the south, organochlorines such as endosulfan, highly persistent in the environment, are still used on a large scale. With habitat change, pesticide poisoning can cause major population decline which may threaten rare species.

Agricultural pesticides can reduce the abundance of weeds and insects which are important food sources for many species. Herbicides can change habitats by altering vegetation structure, ultimately leading to population decline. Fungicide use has also allowed farmers to stop growing 'break crops' like grass or roots. This has led to the decline of some arable weeds (Boatman *et al.* 2007). In Canada, losses among 62 imperilled species were significantly more closely related to rates of pesticide use than to agricultural area in a region. Species loss was highest in areas with intensive agriculture (aerial spraying). The authors concluded that either pesticides, or other features of intensive agriculture linked to pesticide use in Canada, played a major part in the decline of imperilled species (Gibbs *et al.* 2009).

- Pesticides affect wildlife directly and indirectly via food sources and habitats.
- Wildlife poisoning by highly toxic insecticides, rodenticides, fungicides (on treated seed) and toxic herbicides can cause major population decline.

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- Pesticides accumulating in the food chain, particularly those which cause endocrine disruption, pose a long-term risk to mammals, birds, amphibians, and fish.
 - Broad-spectrum insecticides and herbicides reduce food sources for birds and mammals. This can produce a substantial decline in rare species populations.
 - By changing vegetation structure, herbicides can render habitats unsuitable for certain species. This threatens insects, farmland birds, and mammals.

Bird species decline owing to pesticides

In western Europe the number of farmland birds is now just half that of 1980, even among formerly abundant species. While average populations of all common and forest birds declined by about 10% in Europe between 1980 and 2006, populations of farmland birds have fallen by 48%. This figure is based on surveys in 21 EU countries (EBCC 2008). Forest birds have declined less than have specialist birds living on farmland. A recent survey found that in the USA one in three bird species is endangered, threatened, or of conservation concern (NABCI *et al* 2009). Forty percent of grassland and arid-land birds are affected by population decline. Populations of raptors and other birds recovered after DDT and other toxic pesticides were banned in Europe. In North America between 1980 and 1999, populations of grassland species declined more than species living in shrubland. In 78% of species there was at least one association between population trend and change in agricultural land-use, and for most species this factor accounted for 25-30% of the variation in trend among states (Murphy 2003).

In Europe, the population decline among farmland birds was far greater in countries with more intensive agriculture, and in a statistical analysis 'cereal yield' explained over 30% of the trend in population change (Donald *et al* 2001). The authors of this study predicted that introducing EU agricultural policy into accession countries will result in a major decline in key bird populations. This occurred in the German state of Saxony-Anhalt. After 1990, farming in this region shifted from rotational cultivation (eg root-crops) to oilseed rape and winter cereals, which led to a reduction in grassland area and increased insecticide and herbicide use. In the same period, red kite (*Milvus milvus*) numbers fell by 50% from over 40 nesting pairs to about 20 pairs per 100 km² (Nicolai *et al* 2009).

Important Bird Areas (IBAs) include agricultural areas with important bird populations. Although IBAs are appointed as priority conservation sites, they have no official protected status (Heath & Evans 2000). Agricultural expansion and intensification threaten half of IBAs in Africa and one-third in Europe. It is estimated that worldwide bird populations have declined by 20% to 25% since pre-agricultural times. Altogether, 1,211 bird species (12% of the total) are considered globally threatened, and 86% of these are threatened by habitat destruction or degradation. For 187 globally threatened bird species, the primary pressure is chemical pollution, including fertilisers, pesticides and heavy metals entering surface water and the terrestrial environment (BLI 2004).



Bird poisonings caused by pesticides

In the UK, the volume of seeds eaten by many bird species is large enough to pose a potential risk if the seeds are treated with one of the more toxic fungicides (Prosser & Hart 2005). Organophosphate insecticides, including disulfoton, fenthion, and parathion are highly toxic to birds. These have frequently poisoned raptors foraging in fields (Mineau 1999). Field studies have led to the conclusion that given the usual amounts of insecticide used, “direct mortality of exposed birds is both inevitable and relatively frequent with a large number of insecticides currently registered” (Mineau 2005). In the USA, some 50 pesticides have killed songbirds, gamebirds, raptors, seabirds and shorebirds (BLI 2004). In a small area of the Argentine pampas, monocrotophos, an organophosphate, has killed 6,000 Swainson’s hawks. Worldwide, over 100,000 bird deaths caused by this chemical have been documented (Hooper 2002).

The number of birds found killed by pesticides, in the UK was at least 60 in 2006, and 55 in 2007. Pesticides were investigated as a possible cause of death in another 90 cases (80, in 2007). The affected species included buzzard, red kite, raven, crow, peregrine falcon, golden eagle, gull, barn owl, tawny owl, magpie, pheasant, rook, marsh harrier, dove, jackdaw, and chaffinch (PSD & Defra 2007; ACP 2008). The following pesticides were identified as a cause of fatal bird poisoning: carbamates (aldicarb, bendiocarb, carbofuran), organophosphates (chlorpyrifos, diazinon, isofenphos, malathion, mevinphos, phorate), anticoagulant rodenticides (bromadiolone, brodifacoum, difenacoum), and alphachloralose.

In 2005, from 20 dead barn owls and ten kestrels that contained one or more anticoagulant rodenticides, six barn owls and five kestrels had residues in the potentially lethal range. It was concluded that rodenticides may have contributed to the death of one barn owl and two kestrels, based on the circumstances of death and examination of carcasses (Walker *et al* 2007). Residues in five of 23 red kites found dead would be potentially lethal to barn owls, while 17 of these had residues of at least one rodenticide, and ten had residues from two or three rodenticides (Walker *et al* 2008). From dead tawny owls collected under the Predatory Bird Monitoring Scheme, 20% (and 33% of owl livers) contained residues of one or more rodenticides (Walker *et al* 2008).

Negative impacts of pesticides on food sources of birds

Herbicides and avermectin residues (used as worming livestock agents) affect birds indirectly by reducing food abundance (Vickery *et al* 2001). Lower availability of key invertebrates and seed food for farmland birds in northern Europe was likely due to insecticides and herbicides, intensification and specialisation of farmland, loss of field margins, and ploughing (Wilson *et al* 1999). Insecticides generally had a negative effect on yellowhammer when spraying occurred during the breeding season. Spraying at this time may cause more damage than repeated use throughout the year (Morris *et al* 2005). Spraying insecticides within 20 days of hatching led to smaller brood size of yellowhammer, lower mean weight of skylark chicks, and lower survival of corn bunting chicks (Boatman *et al* 2004). More frequent spraying of insecticides, herbicides, or fungicides was linked to a considerably smaller abundance of food invertebrates. This resulted in lower breeding success of corn buntings and may have contributed to their decline (Brickle 2000). In Sussex, herbicides were a major cause of the decline of grey partridge populations by removing weeds which are important insect hosts (GCT 2004).

Pesticide use trends (measured by the percentage of treated area) was linked to periods of rapid bird decline (Campbell & Cooke 1997). Bird species at risk from indirect effects caused by pesticides in the UK include grey partridge, corn bunting, yellowhammer, red-backed shrike, skylark, tree sparrow, and yellow wagtail (CSL *et al* 2005). The main causes of farmland bird decline have been (1) pesticides and weed-control with herbicides, particularly, (2) change from spring-sown to autumn-sown cereals, (3) drainage and intensified management of grassland, and (4) increased

cattle or sheep density (Newton 2004). Sublethal effects on the nervous system can cause changes in behaviour. In an orchard, parent birds made fewer feeding trips after azinphos-methyl, an organophosphate, had been sprayed (Bishop *et al* 2000).

- Bird populations are directly affected by poisoning from organophosphate or carbamate insecticides and anticoagulant rodenticides. Sublethal poisoning of birds by organophosphates can lead to detrimental changes in behaviour.
- Broad-spectrum herbicides threaten rare and endangered bird species by reducing the abundance of weeds (eaten by birds) and insects hosted by weeds. Insecticides reduce the number of insects which are important food sources for birds.

Risk to mammals of hazardous pesticides

Pesticides and other chemicals have caused population declines in Britain's wild mammals. Mostly bats and rodents (and 38% of species) were affected (Harris 1995). Certain pesticides can gradually accumulate in the food chain. This is of concern to vertebrates, particularly species in higher orders and top predators such as mammals or raptors. Anticoagulant rodenticides are highly toxic and some can bioaccumulate. Non-target predatory mammals (eg dogs and foxes) and raptors frequently suffer 'secondary poisoning' by eating rats or mice which are poisoned by rodenticides. In France, foxes were poisoned by residues of bromadiolone in prey tissue (Berny *et al* 1997). In the UK, following rat control with rodenticides, local wood mice, bank vole, and field vole populations of declined significantly (Brakes & Smith 2005).

At least 25-35% of small mammal predators (polecats, stoats, and weasels) sampled had been exposed to rodenticides and this may be an underestimate (Shore *et al* 1999). However, it is not well-known how frequently rodenticides cause secondary mammal poisoning, and what the impact on their populations might be.

Herbicide use can affect mammals such as the common shrew, wood mouse and badger by removing plant food sources and changing the microclimate (Hole *et al* 2005). Hares prefer a more diverse habitat. They are thus likely to benefit from increased fallow land (Smith *et al* 2004). On organic farms, foraging activity by bats was significantly higher than on conventional farms, which may be due to a larger abundance of prey insects (Wickramasinghe *et al* 2004). Less intensive farming systems may help to reverse bat decline.

- Anticoagulant rodenticides often indirectly poison predatory mammals and raptors.
- Herbicides can cause changes in vegetation and habitat which threaten mammals, while insecticides may reduce the availability of important food insects.



Impact of pesticides on butterflies, bees, and natural enemies

Broad-spectrum insecticides (eg carbamates, organophosphates and pyrethroids) can cause population declines of beneficial insects such as bees, spiders, or beetles. Many of these species play an important role in the food web or as natural enemies of pest insects. Since 1970, insect numbers in cereal fields in Sussex have dropped by half (GCT 2004). Numbers of bugs, spiders and beetles were considerably higher in untreated fields (Moreby & Southway 1999). On British organic farms, numbers and species richness of butterflies was greater than on conventional farms (Feber *et al* 2007). The number of carabid beetles and spiders was usually higher on organic farms. Conventional management practice appeared to affect natural enemies far more than other insects or target pests (Bengtsson *et al* 2005). Moths were considerably more abundant on organic farms and species richness was higher (Wickramasinghe *et al* 2004). In arable fields, insecticide use was an important factor influencing communities of epigeic spiders (Drapela *et al* 2008). On sites with an increased pesticide input, communities of bugs, wild bees, and spiders were more uniform, indicating less exchange between communities in areas with intensive agriculture (Dormann *et al* 2008).

Bees perform essential pollination. Honey bees are under pressure from parasitic mites, viral diseases, habitat loss and pesticides. Intensified agricultural practices, habitat loss, and agrochemicals are considered to be among the chief environmental threats to Europe's honey and wild bees. Agricultural policy must reduce these pressures to ensure adequate pollinator populations (Kuldna *et al* 2009). On organic farms in the USA, near natural habitat, diverse native wild bee communities provided full pollination services, while diversity and numbers of native bees were greatly reduced on other farms (Kremen *et al* 2002). In the UK, of the 95 incidents of bee poisoning (where the cause could be identified) between 1995 and 2001, organophosphates caused 42%, carbamates 29%, and pyrethroids 14% of cases (Fletcher & Barnett 2003). In the last decade in the UK, insecticides which poisoned bee colonies included bendiocarb (a carbamate) and three pyrethroids: cypermethrin, deltamethrin and permethrin (PSD 2001-7). Synergistic effects between pyrethroids and EBI fungicides (imidazole or triazole fungicides) can increase the risk to honeybees (Pilling & Jepson 2006).

Clothianidin, and to a lesser extent, imidacloprid are highly toxic to bumble bees and other wild bees (Scott-Dupree *et al* 2009). These two neonicotinoid insecticides are used to treat corn and sunflower seeds. In 2008, clothianidin caused many bee poisonings and colony deaths in southern Germany (Spiegel 2008). The product has since been withdrawn. When imidacloprid-treated seed is grown, a large enough amount can enter the environment to poison bees (Greatti *et al* 2003). Residues of imidacloprid in maize pollen grown from treated seed can be a high risk to bees owing to sublethal effects (Bonmatin *et al* 2005). Even at low doses of imidacloprid, bees' foraging behavior was negatively affected (Yang *et al* 2008). Exposure to low doses of imidacloprid over a longer period led to reduced learning capacity among bees (Decourtye *et al* 2003). In alfalfa, imidacloprid affected the number and species diversity in communities of arthropods (natural enemies such as spiders) more strongly than among target pest insects (Liu *et al* 2008). Imidacloprid has been banned in France. Field margins without use of pesticides (herbicides in particular) had a positive effect on the number of Lepidoptera (such as moths or butterflies), bugs, and staphylinid beetles at the edges of arable fields (Frampton *et al* 2007). In organic plots, average numbers of spiders and carabid or staphylinid beetles were almost twice as high as those in conventional plots (Mäder *et al* 2002).

- Pesticides which are highly toxic to bees, bumblebees and other beneficial insects: carbamates (eg aldicarb, benomyl, carbofuran, methiocarb), organophosphates (eg chlorpyrifos, diazinon, dimethoate, fenitrothion), pyrethroids (eg cyfluthrin, cyhalothrin), and neonicotinoids (imidacloprid, thiamethoxam, clothianidin).
- Recently, clothianidin used in seed treatments have caused widespread bee poisoning. Imidacloprid residues in plants can negatively alter bee behaviour.

Pesticides affecting amphibians and aquatic species

One-third of 6,000 amphibian species worldwide are threatened. Besides habitat loss, over-exploitation or introduced species, amphibians are affected by the pollution of surface waters with fertilisers and pesticides from agriculture (IUCN 2009). In the USA, spray drift of hexazinone, a triazine herbicide, was considered "likely to adversely affect" the endangered red-legged California frog and its habitat (US EPA 2008). Atrazine is moderately toxic to some fish species. It can indirectly affect aquatic ecosystems by damaging aquatic plants. A review concluded that further study is needed on the potential hormonal effects of atrazine on frogs or fish (US EPA 2006). In Europe, the authorisation for atrazine has been withdrawn due to health and environmental risks (EC 2003). Urea herbicides such as isoproturon and diuron often contaminate rivers, lakes, and groundwater. Most breakdown products of diuron were more toxic to cellular microorganisms than the parent compound (Bonnet *et al* 2007). Fungicides based on copper are highly toxic to aquatic organisms. In fish and some other aquatic organisms, the risk of copper accumulating may be high (EFSA 2008). The EU aims eventually to eliminate copper in organic vineyards and apple orchards (REPCO 2007).

A major study investigating amphibian communities in the USA found that, among other factors, agricultural fields near surface water and pesticides (at sufficiently high concentrations to affect insects or plants) will harm amphibian species richness. In particular, if water contains herbicides at concentrations which substantially reduce populations of aquatic plants this is likely to be associated with low numbers of amphibians relative to predator populations, and increased numbers of trematode parasites in amphibians (Beasley *et al* 2002). Parasitic nematodes were more abundant in agricultural wetlands during the growing season. Agricultural activity may intensify the infection of frogs by harmful nematodes (King *et al* 2008). Atrazine suppressed the immune system of tiger salamanders by causing reduced numbers of white blood cells. The rate of infection by pathogenic viruses was higher in salamanders which were exposed to atrazine (Forson & Storfer 2006). In field studies, atrazine affected the immune system of tadpoles of northern leopard frogs, a declining species. Atrazine and phosphate fertiliser were the main factors linked to numbers of larval trematodes in frogs (Rohr *et al* 2008). In California, tadpoles of the Pacific treefrog in areas with a poor population status had reduced levels of the enzyme cholinesterase, indicating exposure to organophosphates and/or carbamates (Sparling *et al* 2001). Endosulfan was highly toxic to the declining yellow-legged frog. The insecticides chlorpyrifos and endosulfan have the potential to cause serious damage to amphibians at concentrations occurring in the environment under normal conditions of use (Sparling & Feller 2009). In laboratory tests, the survival of juvenile Great Plains toads and New Mexico spadefoot toads was reduced after exposure to certain formulations of the herbicides glufosinate and glyphosate (Dinehart *et al* 2009).



Circumstances for pesticide use which present a high risk to communities of aquatic species include spray drift for insecticides and run-off from fields for herbicides (Verro *et al* 2009). However, in a study of the risks of 261 pesticides to aquatic ecosystems in field ditches, about 95% of the predicted risk was caused by only seven pesticides (De Zwart 2005). More selective pesticides (with no or minimal impact on non-target organisms) should clearly be preferred. Surface water is frequently contaminated with insecticides through normal use at levels above those known to affect fish and aquatic invertebrates such as daphnia or shrimp. For example, this was observed for levels of azinphos-methyl, chlorpyrifos, and endosulfan in the aquatic environment (Schulz 2004). Similarly, chlorpyrifos and endosulfan were rated as 'chemicals of potential ecological concern'. An assessment concluded that adverse effects of endosulfan on fish and invertebrates are a concern when this insecticide is used near aquatic ecosystems (Carriger & Rand 2008). In field tests, the insecticide carbaryl affected the composition of an aquatic community of amphibians and insects by changing colonisation of pools and numbers of eggs laid (Vonesch & Klaus 2009).

- Insecticides and herbicides in surface waters (from spray-drift or run-off) can alter the species composition of aquatic communities and affect fish and invertebrates.
- Insecticides (organophosphates, carbamates) have toxic effects on the nervous systems of amphibians which may alter their behaviour. Herbicides (eg atrazine) can impair the immune system of frog tadpoles, which can make amphibians more susceptible to harmful parasitic nematodes. Indirect effects can be fatal.
- Urea herbicides such as diuron frequently contaminate surface and ground water. Copper-based fungicides are highly toxic to fish and have a potential to accumulate.

Effect of pesticides on plant communities

In recent decades, the use of herbicides has dramatically increased. Today, some non-crop plants (or 'weeds') are threatened with extinction in Britain (Preston 2002). Although the total volume of herbicides applied in the UK decreased slightly between 1990 and 2006, the herbicide-treated area increased by 38% (Fera 2009). Diversity of wild plants in agricultural fields and field margins is declining, especially in infertile grassland and hedge bottoms. A slight increase in plant diversity in arable fields in 1998 may have been due to the introduction of set-aside (Defra 2008). The number of plants providing food for butterfly caterpillars decreased in Britain between 1998 and 2007. Field margins created within agri-environment schemes supported a higher number of plant species than crop areas, but plant cover and species richness are still low (on average 11 species per plot and 21% cover) when compared to other habitats (eg horticultural land) and set-aside (CS 2007). By providing an unsprayed field margin at least three metres wide, the diversity and number of arable plants and insects hosted by them increased substantially (De Snoo 1999). Over five years, harmful weed cover did not increase in field margins (Musters *et al* 2009).

On European farms using IPM methods (and an average of half the herbicides), the seed bank of weeds in soil doubled in autumn-sown crops. This was considered acceptable, while in spring-sown crops the seed bank increased more than threefold for certain weeds (EN 2005). In lowland areas in England, species diversity and abundance of plants, birds, bats, invertebrates, and plants were typically higher on organic farms than conventional ones. Positive effects were strongest for plants. It was estimated that organic fields held up to twice as many plant species and, on average, a weed cover twice as large (Fuller *et al* 2005). Flora in Britain is changing as arable plants such as the corn marigold introduced long ago are decreasing. This could be due to intensive agriculture and a decline in mixed farming (Preston 2009).

Some herbicides are highly toxic to plants at very low doses, eg sulfonylureas, sulfonamides and imidazolinones. Tribenuron-methyl affected growth of algae and activity of microalgae at very low concentrations (Nystrom *et al* 1999). In a study on the effects of sulfonylurea herbicides on phytoplankton it was concluded that these herbicides present a potential hazard to aquatic systems even at low environmental concentrations (Sabater *et al* 2002). Sulfonylureas have replaced other herbicides which are more toxic to animals. In potatoes, sulfometuron-methyl caused major yield losses even when used at rates below the recommended dose (Pfleeger *et al* 2008). Experts have warned that the wide-spread use of sulfonylureas "could have a devastating impact on the productivity of nontarget crops and the makeup of natural plant communities and wildlife food chains", (Fletcher *et al* 1993).

Hexazinone is a persistent triazine with high leachability (Footprint 2009). In the USA, at all application rates the EPA's levels of concern for aquatic and terrestrial non-target plants were exceeded. Aquatic ecosystems within or next to hexazinone-treated areas could be altered by the effects on aquatic plants (US EPA 1994). Other triazines affect aquatic plants similarly, eg terbutylazine and atrazine. In field tests, the herbicide glyphosate altered the composition of freshwater microbial communities by decreasing the abundance of microbial phytoplankton and increasing cyanobacteria (Pérez *et al* 2007).

- Many plants which were previously common on British farmland are declining owing to the abandonment of mixed farming and increased herbicide use.
- Large-scale use of sulfonylurea herbicides, and presumably also sulfonamides and imidazolinones, poses a risk to non-target plants, algae, and ecosystems.
- Triazine herbicides may present a risk to non-target and aquatic plants.

Are pesticides diminishing soil fertility?

What is soil fertility? A fertile soil provides the nutrients needed to promote growth of plants, is a habitat of an active and diverse community of organisms, and exhibits a structure which is characteristic of the location, and which enables a continuous decomposition of organic residues (Mäder et al 2002).

In South Africa, the feeding activity of soil organisms was higher in soil from organic vineyards than from conventionally treated sites (Reinecke *et al* 2008). The number of earthworms was 1.3-3.2 times higher in organic compared to conventional plots, and the length of plant roots colonised by mycorrhizae was 40% higher in organic than in conventional systems (Mäder *et al* 2002). Triclopyr, a herbicide, caused a major reduction in the growth of mycorrhizae at levated soil levels (Chakravarty 1987).

The sulfonylurea herbicides metsulfuron and (to a lesser extent) chlorsulfuron caused a reduction in the growth of *Pseudomonas* soil bacteria (Boldt & Jacobsen 2006). In laboratory tests, a combination of two sulfonylurea herbicides, bensulfuron-methyl (B) and metsulfuron-methyl, caused a considerable reduction in soil microbial biomass over the first 15 days (El-Ghamry *et al* 2001). In bacterial communities in soil, bromoxynil (a nitrile herbicide) caused major changes in species composition and diversity. Bromoxynil inhibited the growth of bacteria capable of degrading chemicals in soil (Baxter *et al* 2008). Also captan (a fungicide) and the herbicide glyphosate caused a shift among species in bacterial communities in soil (Widenfalk *et al* 2008). Certain organophosphate insecticides (eg dimethoate) can decrease the activity and biomass of soil microorganisms, while others (such as fosthiazate) may actually result in an increase in microbial biomass (Eisenhauer *et al* 2009). How pesticides affect long-term soil fertility is not well understood as this depends on many factors.

- Pesticides affect earthworms, symbiotic mycorrhizae, and other organisms in soil.
- Composition and activity of bacterial communities can be changed by pesticides.



Policies and methods for biodiversity conservation

In the EU, national policies set targets for biodiversity conservation (EC 2009). The Convention on Biological Diversity provides national strategies and action plans for conserving species at national level. These include the establishment of national targets. For example, the UK Biodiversity Action Plan (BAP) currently lists 1,150 species and 65 habitats with a priority for conservation. In 2002, of 78 farmland priority species, 39% were declining, 21% had unknown or unclear status, 18% were stable, 15% on the increase, and 7% had been lost. From the total area of one million hectares of nationally-important wildlife sites ('Sites of Special Scientific Interest') in the UK in 2003, about 380,000 hectares, or 38%, were in an unfavourable condition owing mainly to agriculture. Only 47% of important wildlife sites on farmland were in a favourable condition (Defra 2003). One of the BAP's targets is to reverse the decline in farmland birds in Britain by 2020. In winter, farmland bird density is much higher on stubble (rotational set-aside) than on cereal fields. However, EU policy recently changed and set-aside is no longer compulsory. Ornithologists have warned that this could have serious negative impacts on farmland biodiversity across the EU (Gillings *et al* 2009).

Maintaining an appropriate population of weed species to support farmland wildlife is a challenge. It may be achieved by providing conservation headlands, by developing much more selective herbicides, and through their selective use (IACR 2001). In England between 1978 and 1990, plant diversity on arable land was declining. Between 1998 and 2007, plant diversity in main plots increased by 36%. This was due to increases in the area of set-aside or fallow land, driven by agri-environment schemes (CS 2009). On plots with reduced herbicide input, farmland birds used winter cereal stubble more often than on conventional plots (Bradbury *et al* 2008). To reverse the decline of birds, farming needs to change substantially and incorporate appropriate practices (Newton 2004). Species diversity is usually higher in non-crop areas than in grassland or fields. Unsprayed headlands of fields contain rare weed species and the highest diversity of invertebrates. As a feeding area for birds, the headland is most important. Weeds on the ground provide refuge and host many food insects. Using more selective herbicides in winter cereals could benefit farmland bird species which feed their chicks weed seeds eg linnets or finches (Moreby & Southway 1999). In the EU on arable or mixed farms which use integrated management practices, on average the use of herbicides was reduced by 43%, use of insecticides or molluscicides by 55%, and fungicide use was 50% lower when compared to conventional farms. On farms using IPM, the number of arthropods (such as beetles, spiders, springtails or sawflies), plants and earthworms increased significantly. Similar positive effects were observed for soil organisms, birds, and mammals such as wood mice (EN 2005).

National systems for pesticide authorisation aim to limit of the harm pesticides inflict on non-target species. But measures for reducing risks from pesticides are still being developed. Regulatory controls alone will not eliminate the impact on non-target species. Additional initiatives are needed which mitigate the effects of pesticides on biodiversity. The EU's Sixth Environment Action Programme identified biodiversity conservation as a high priority (EC 2002). Areas protected under the Birds and Habitats Directives are connected in the 'Natura 2000' network. The proposed strategy on sustainable pesticide use in the EU aims to minimise risks to health and the environment from pesticides. Member states must eliminate or reduce the use of pesticides as far as possible in Natura 2000 sites, and promote farming with low pesticide input, particularly integrated pest management (IPM), and establish the necessary conditions for implementing IPM techniques (EC 2009a).

One of the leading organisations in the development of IPM standards is the International Organisation for Biological and Integrated Control of Noxious Animals and Plants (IOBC). Its principles for integrated production emphasise the importance of biodiversity.

According to the IOBC, integrated production is a farming system which produces high quality food and other products by using natural resources and regulating mechanisms to replace polluting input and to secure sustainable farming (IOBC 2004).

Agri-environment schemes in the EU provide payments to farmers taking measures to preserve the environment and countryside. But spending on these measures are to date marginal. Farmers who practise less intensive farming and who conserve nature need to be rewarded (Donald *et al* 2002). The UN Convention on Biological Diversity requires that countries develop national strategies and action plans for conserving biodiversity, and define national or sub-national targets and indicators (CBD 2008). The number and quality of conservation targets vary strongly between countries (EPBRS 2009). Incentive schemes should be continuously evaluated and adapted (Berendse 2004). To assess the effectiveness of measures for conserving threatened species such as farmland birds, quantitative and measurable goals are needed, plus monitoring of species (Donald *et al* 2007). Extensive farming may need to stretch over larger connected areas to achieve substantial gains (Whittington 2007). Organic farms, together with agri-environment schemes to some degree, have positive effects on the diversity of plants and beetles in the EU, while bird species were not significantly more diverse. This may be due to widespread chemical pollution. So a shift towards farming with minimal pesticide use over large areas is urgently needed (Geiger *et al* 2010).

Corn, sugar cane and palm oil are increasingly being used to produce biofuels. These crop plants are linked to a high input of pesticide and fertiliser. Their use as biofuels is threatening biodiversity. Corn-based bioethanol is the worst among the alternatives currently available, so alternatives to corn as a biofuel source must be urgently pursued (Groom *et al* 2008). In the EU, to produce energy from plant biomass in an environmentally-friendly way, the proportion of environmentally-orientated farming would need to increase to about 30 % of the Utilised Agricultural Area in most Member States by 2030, except for the most densely-populated countries (EEA 2007).

The need for a biodiversity rescue plan

The UN Convention on Biological Diversity requires the EU's 27 Member States to develop national policies to set biodiversity conservation targets. Not all Member States are equally ambitious, meaning that the 2010 objectives to halt further biodiversity loss need a new quantitative rescue plan for 2020, setting clear quantitative and qualitative targets, timetables and requiring ambitious monitoring. They also need to ensure coherence and better targeting, on these and a number of other EU policies (for sensitive 'Natura 2000' areas and water), the establishment of new EU policies (on soil and bio-waste). However, the success of the biodiversity rescue plan will also to a large extent depend on the EU's implementation of the new 'Regulation on the Placing of Plant Protection Products on the Market', as well as on how seriously member states implement the new framework directive on the sustainable use of pesticides. An important tool would be for member states to use this new opportunity to set dependency/use pesticide reduction targets and clear timetables.

A biodiversity rescue plan also needs to be accompanied by further reform of the EU's Common Agricultural Policy (CAP), departing from the current model where farmers receive income support for up-keep of their land into a model where farmers receive funding to provide public benefits, which includes paying farmers to use sustainable agricultural practices based on prevention first, also called integrated production, whereby the more farmers provide environmental and health services, the greater the public funding they receive.

In the International Year of Biodiversity 2010, we should fight together for reform of the CAP to encourage better agricultural practices. We should start by encouraging more mixed agriculture, crop rotation and pastoral grassland and lower field size. Even more so, we should encourage the development of practices such as bigger field margins and the re-establishment of hedgerows. We should put prevention first, in a dynamic system, encouraging front-runners who are willing to make environmental improvements, and incorporate a policy of making truly integrated agricultural production the basis of the post-2013 CAP.

Such an approach would be a step in the right direction in reversing the decline of birds, bees, bats, arthropods and earthworms, which thrive best in association with organic farming. It is also the best way to re-establish communities of different animal and plant species which perform vital functions within ecosystems, bringing higher diversity which tends to be more stable, and as a result will also help ensure greater long-term food security.



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agroBiodiversity (international network for research). www.agrobiodiversity-diversitas.org/

Assessing Large Scale Risks for Biodiversity (EU project). www.alarmproject.net

EU Biodiversity Action Plan. <http://ec.europa.eu/environment/nature/biodiversity>

European Learning Network on Functional AgroBiodiversity. www.eln-fab.eu

European Platform for Biodiversity Research Strategy. www.epbrs.org

European Topic Centre on Biological Diversity. <http://biodiversity.eionet.europa.eu>

The Economics of Ecosystems and Biodiversity (TEEB) study. www.teebweb.org

UN Convention on Biological Diversity. www.cbd.int

UN Environment Programme: Biodiversity. www.unep.org/themes/biodiversity

World Conservation Union. www.iucn.org/what/biodiversity

World Wildlife Found. Reducing impacts: farming. www.panda.org/what_we_do/footprint/agriculture



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