INSECT ATLAS

Facts and figures about friends and foes in farming 2020

HEINRICH BÖLL STIFTUNG

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2020

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INTRODUCTION

If we were to count them, we would have around 1.4 billion insects from an estimated 5.5 million species for each person alive today. We share our world with an incredible number and variety of six-legged animals. Some we find beautiful; others, with huge fangs, are perhaps a little scary. Insects fly, crawl, tunnel, sting and bite. They are experts at hiding. And they are at home in almost every ecosystem on Earth.

But they are facing massive threats. Maybe it is because of their seemingly infinite numbers that we humans have for so long failed to recognize the scale of the danger that insects face. Or because there is little long-term research on their population status. Such studies are especially scarce in the southern hemisphere.

A very big chunk of the plant world depends on diligent pollination by insects. Bees must visit around 10 million plants to collect enough nectar to make half a kilogram of honey. In doing so, they carry pollen from flower to flower. Insects also clean up our world. They decompose manure as well as dead plants and animals, so improving the quality of the soil.

The public reacted all the more clearly to the alarming scientific findings on insect mortality that emerged in 2017. Because policymakers are not responding fast enough, citizens, environmental groups, farmers and political parties have joined

> ” A very big chunk of the plant world depends on diligent pollination by insects.

forces and launched initiatives to protect insects in several EU countries. For example in the German region of Bavaria, where 1.75 million people supported a referendum for more nature conservation. Or in the UK the Bee Cause in 2012 aiming to reverse bee decline. A European citizens' initiative, appropriately named "Save Bees and Farmers", was launched in October 2019.

Industrial agriculture, with its ever-bigger fields, its reliance on pesticides and its monotonous landscapes, poses one of the biggest challenges to the world of insects. There is no alternative: to protect insects, farming must become part of the solution. Not just for the sake of society, but also for the sake of farming itself – because it, too, needs insects. Nevertheless, since autumn 2019, tractors have blocked the streets of Berlin, Paris, Amsterdam, and Madrid, as thousands of farmers have voiced their displeasure at stricter environmental protection regulations. Their anger is a result of decades of failure in agricultural policy.

At the 1992 Earth Summit in Rio de Janeiro, the EU committed itself to protecting biodiversity. Way back then, policymakers could have set a course in the right direction.

But nothing happened. Farmers deserve a better set of policies: one that sets the right incentives and policy frameworks for the future. An insect-friendly type of farming has to be promoted. In practical terms, that means financial support.

We do not pay enough attention to protecting insects. And farmers do not get paid for doing it either. But this is exactly what must happen. The European Union should use the nearly 60 billion euros it allocates to agriculture each year in a targeted manner to support climate- and insect-friendly farming practices. In the long term, we can only justify spending such sums if this money is used for projects that are important to us as a society.

It is not enough to merely keep watch on the fields outside our own front doors. Much of the fodder that feeds the millions of animals that supply our demand for cheap meat is imported from South America. There, in one of the richest areas of the globe in terms of biodiversity, millions of hectares of forest are being cleared to make way for soybeans and cattle ranching. The European Union is negotiating a free-trade agreement with the Latin American Mercosur bloc. This will allow even more cheap farm products to enter Europe without any trade restrictions – and harm Europe's farmers as well as the world of insects.

That is why policymakers must be active internationally. A course of action can be

> „We do not pay enough attention to protecting insects. And farmers do not get paid for doing it either.

agreed on during the 15th UN Biodiversity Conference in China in 2020, where the EU could play an important role and put the protection of insects right at the top of the agenda.

By presenting the facts and figures in this Atlas we want to contribute to a lively debate on agriculture and insects. At the same time, we want to illustrate how diverse, colourful and worthy of protection the world of insects is. Our intention is to show that agriculture and insect conservation need ambitious policies, not only in the European Union, but also worldwide. The challenges are large, and to meet them, we must seek solutions together.

Barbara Unmüßig
Heinrich Böll Foundation

Jagoda Munić
Friends of the Earth Europe

12 BRIEF LESSONS

ON INSECTS, AGRICULTURE AND THE WORLD

1. Around 90 percent of all animal species in the world are insects. They are the **MOST NUMEROUS GROUP** of all living things and are at home in all the world's ecosystems.

2. Insects pollinate three-quarters of the most important crops and **BOOST** their yields, but also **THREATEN** crop harvests and stored food.

3. Agriculture and food production are intimately connected to the presence of insects. They improve the **QUALITY OF SOILS,** help decompose dead material from plants and animals, and **POLLINATE** crops worldwide.

4. Intensive farming, **MONOCROPS** and pesticides threaten insects: both their diversity and their absolute numbers are declining, especially in agricultural areas.

5. It is difficult to combine farming and the protection of insects. But **IT IS WORTH IT.** Worldwide, pollination by insects is valued at hundreds of billions of dollars.

6. **ORGANIC FARMING** avoids using pesticides and artificial fertilizers, but relies on crop rotations that control insect numbers while providing them with a range of suitable habitats.

7 Humans in over 130 countries eat insects. They contain **MANY NUTRIENTS** that are effective against malnutrition.

8 Around the world, insects serve as a **SOURCE OF INCOME FOR POOR WOMEN.** Those that have no land often collect insects in the forest. If the market is profitable, men often take over the marketing.

9 **EATING LESS MEAT** protects insects. Much of the soybean used to feed intensively kept livestock comes from South America, where species-rich landscapes are being turned into monocultures.

10 Insects can be used as livestock feed, but this is not yet common. Feeding insects to **CHICKENS** and **PIGS** will depend on whether this is found to be ecologically sustainable.

11 **CLIMATE CHANGE** harms insect habitats especially in hot regions. In temperate areas, the balance between beneficial and harmful insects will shift, threatening harvests.

12 The international community decades ago committed itself to protecting insects. But little has happened on the ground, and all the **INTERNATIONAL TARGETS** set so far have been missed.

SIX FEET ON THE GROUND

They are on the land, in the water and in the air; they eat and are eaten; they pollinate plants, aerate soil and clean up leaves: insects are an integral part of ecosystems.

The world of insects is amazing and diverse. No other group of animals has developed such an enormous array of species. We encounter them in the widest range of shapes and sizes, and they shimmer in a rainbow of hues. They may be as big as your hand, or microscopically small. All of them have three pairs of legs: hence the scientific name "Hexapoda", or "six feet", the zoological subphylum that covers insects along with a few other, less-common creatures.

Insects are often confused with other creepy-crawlies, such as mites, ticks and woodlice. The same is true of centipedes and millipedes, although their names ("hundred" or "thousand feet") indicate that they cannot possibly be insects. Spiders are also sometimes lumped together with insects, though they have eight legs. Nor are crabs, which have ten legs (including a pair of pincers) counted as hexapods.

Apart from all having six legs, insects have various other features in common. Their bodies consist of three segments: the head with the mouth parts and thousands of individual lenses clustered into compound eyes; the thorax that bears three pairs of legs, and in flying insects, the wings; and the abdomen, which houses the digestive and reproductive organs. Insects have no skeleton. Their bodies are encased within a thin, horny layer of chitin that protects the animal from water and gives its body stability along with flexibility. Insects do not have lungs; they breathe via a system of tubes and sacs known as trachea that run throughout the whole body.

Their hairlike sensory organs, which are distributed around the body, allow insects to detect odours, vibrations, temperature and humidity. They smell, taste and feel with their antennae. They have a simple nervous system, and their internal organs are bathed in blood. The mouthparts are very varied, depending on the species and the types of food it eats. The Heteroptera (bugs) and beetles have a sharp apparatus that they use to stab other animals or pierce the epidermis of plants so they can suck out the juices. Butterflies, on the other hand, have a long, coiled proboscis that they use to sip liquid food from fruits or water from puddles.

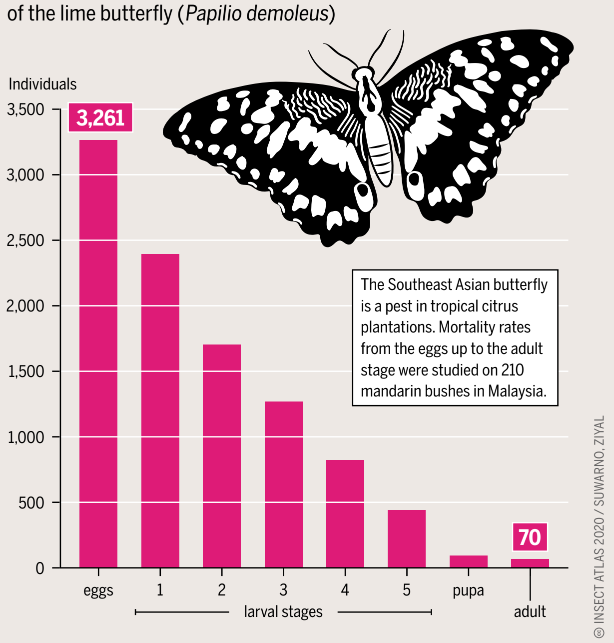
Science has so far described around 1.8 million species of animals, plants and fungi. Half of them are insects. They make up around 70 percent of the world's animal species, and as such comprise the largest group of all living things. Most insect species have not yet been discovered. In addition to the million already catalogued, an estimated 4.5 million more still await discovery, including 1.5 million beetles alone. For example, three-quarters of Germany's animal species are insects: over 33,300 species in all, including bees, beetles, butterflies, dragonflies, grasshoppers, ants and flies.

The lifestyles and requirements of individual species vary widely in terms of habitats, climate and food. There are the so-called generalists that are flexible in their diet, alongside specialists that are much fussier: they depend on a particular type of plant, animal or habitat. The viper's bugloss mason bee (*Osmia adunca*), for example, collects pollen only from plants of the genus *Echium* (including the viper's bugloss, *Echium vulgare*). Other insect species are closely adapted to certain types of trees, or live on dead wood. Insects are to be found from the seaside right up into the high mountains. They are absent only in the open sea.

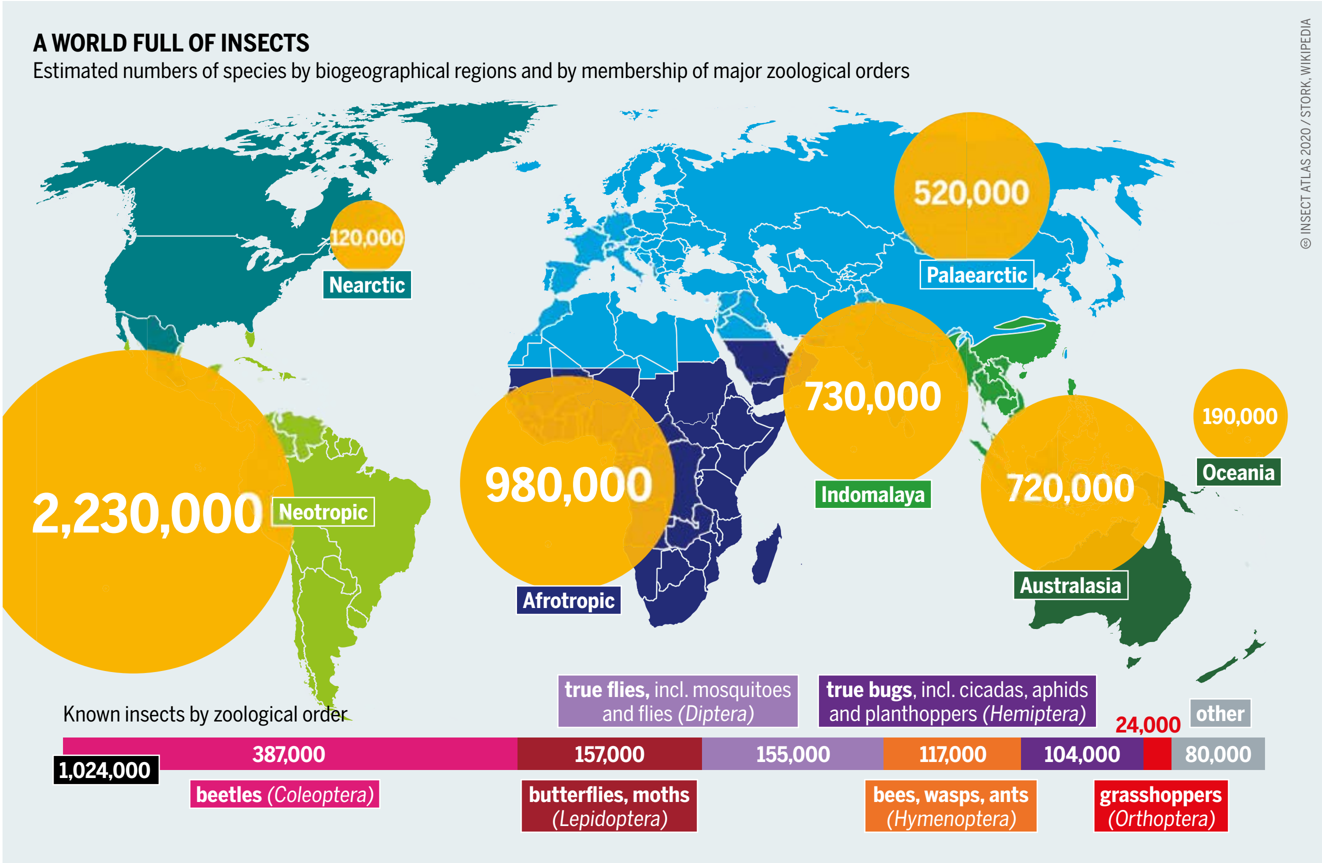
Insects pass through several stages of development, some of which may make completely different demands on their habitat – both in terms of their structure, features and interrelationships, and in their food sources. Most insects lay eggs that hatch and pass through several larval stages, perhaps along with a pupal stage. Some types of insects, including dragonflies, crickets and bugs, do not undergo a pupal stage; others, such as bumblebees, butterflies and beetles, must pupate to produce an adult.

Insects play various roles in the ecosystem. This is also

QUICK DEATHS
Development stages and typical population losses of the lime butterfly (*Papilio demoleus*)



Only between one and four percent make it to adulthood. Rain, spiders, mantises and birds decimate the eggs, larvae and pupae of the lime butterfly



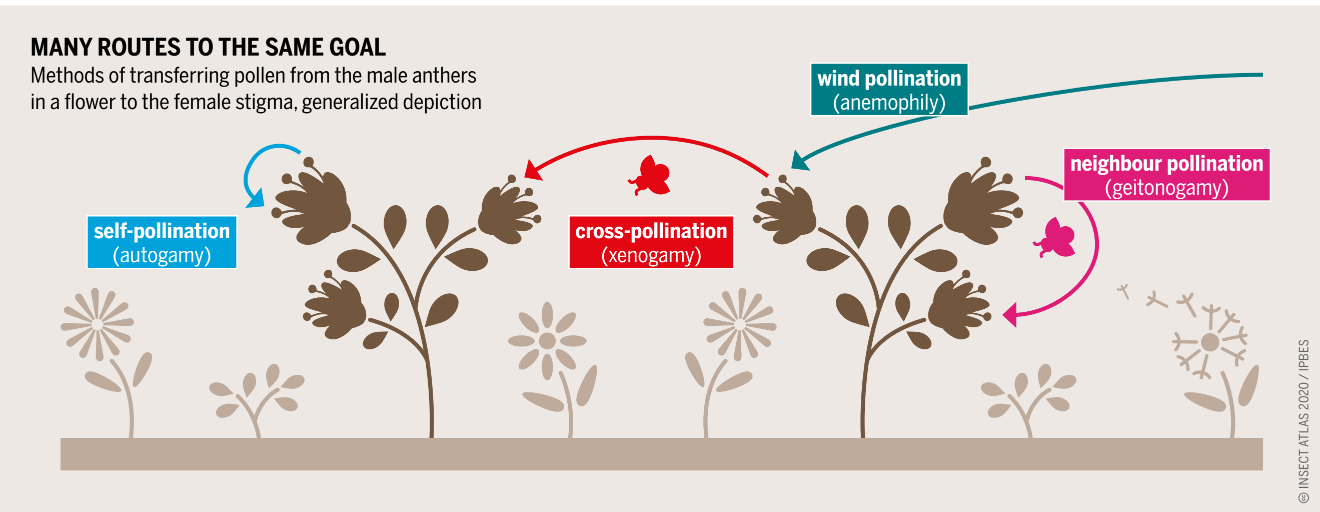
true for cultural landscapes – those that have been created or adapted by humans – as many species perform important services in agriculture. A bumblebee, for example, may pollinate up to 3,800 flowers in a single day. Insects combat pests: almost 90 species are used in biological crop protection. Insects also form the food source of other animals, decompose organic material, clean up water supplies, and maintain soil fertility.

Insects feed on both animal and plant food. Almost all butterfly caterpillars eat plants, and are therefore unwelcome in arable farming, where they are regarded as pests. Predators such as beetles and lacewings that eat other insects can be helpful as beneficial insects in crop fields.

Some groups of insects, including ants, termites and crickets, form huge communities. An ants' nest in Jamaica may contain up to 630,000 individual animals. Over 3 million individuals were found in one South American termite nest, and swarms of locusts may consist of over a billion insects. ●

There may be over 5 million species of insects, but only 1 million have been described. Many species are threatened with extinction before they have even been named

Pollinators also include bats, birds and reptiles – but of all animals that help fertilize plants, insects are by far the most important



AGRICULTURE

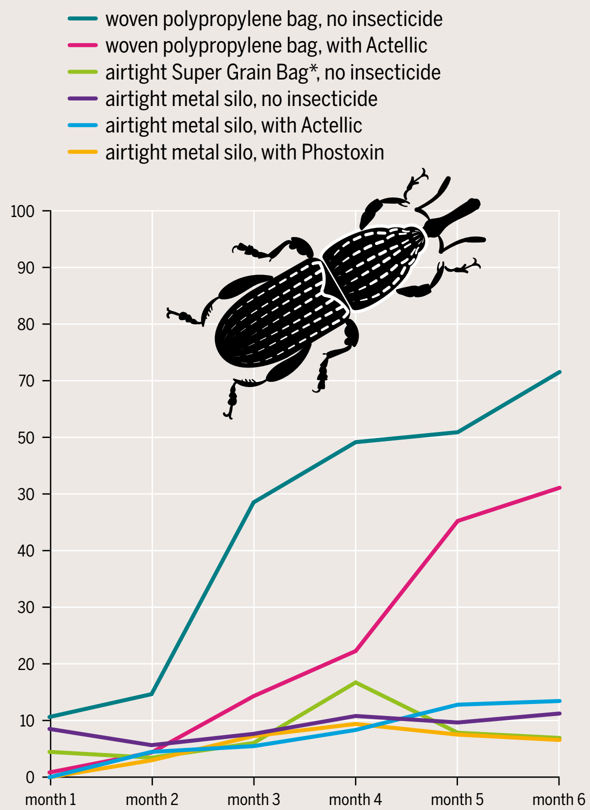
BALANCING PRODUCTION AND SUSTAINABILITY

Their services in pollination and soil management make insects vital for agriculture. But farming also poses grave threats to them. We need to better maintain and restore biodiversity in farmed landscapes.

Ecosystems depend on insects to function properly. Plant eaters, which chew on leaves or suck plant sap, are just as important as predators that feed on herbivores, or – like parasitic wasps – lay their eggs in a host insect, where their larvae hatch and consume their hosts from the inside. Carrion-scavengers and dung-eaters consume dead organisms. Litter-decomposers break down dead plants, making it easier for microbes to work.

GOBBLING THROUGH GRAIN

Infestation by the grain weevil *Sitophilus granarius*, a global pest of stored grain, in a maize store in Homa Bay, western Kenya, by storage type and with or without use of the insecticide Actellic Super Dust and Phostoxin (aluminium phosphide, a gas), in percent of the damaged grains of maize



* made from patented film, air pressed out, enclosed in a polypropylene bag

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Pollinators are an important part of many agricultural systems. By carrying pollen from one plant to another, insects enhance seed set and facilitate the mixing of genes in both crops and non-cultivated plants. Three-quarters of the world's most important crops exhibit a yield benefit from pollinators: they contribute directly to around one-third of global food production. Promoting wild bees – which are usually more important pollinators than honeybees – can double the yields of strawberries and cherries.

Insects can be harmful as well as helpful. If they eat crops, instead of weeds, they can cause huge amounts of damage. Worldwide, insects are responsible for between 17 and 30 percent of crop-yield losses, especially in countries already afflicted by hunger and poverty. Insects also cause a lot of damage to crops after the harvest: postharvest losses may be as high as 40 percent in developing countries.

Just as insects affect agriculture, so too does agriculture affect insect populations. Alongside climate change and light pollution, the spread and intensification of farming is by far the most important cause of the global decline in insect numbers. Intensified production makes agricultural landscapes structurally much simpler. Overfertilization leads to monotonous communities of plants that provide habitats for only a few species.

Pesticides kill insects both directly and indirectly. The frequent use of herbicides to control weeds reduces the diversity of plants and impoverishes the food webs of the insects. Insecticides usually kill insects directly. But even if they are not lethal at first, they can still prove deadly – by reducing insects' vitality and reproductive ability, by harming their ability to find their resources, and by increasing their susceptibility to diseases. Plant protection using chemicals has increased steadily since the 1930s in many industrialized countries, as well as in Latin America, Asia and Oceania. In the 1960s, the crop-protection industry was valued at less than 10 billion US dollars, and farmers could choose among products based on around 100 different active ingredients. Today the sector is worth over 50 billion US dollars, and customers worldwide have a choice of about 600 different active ingredients.

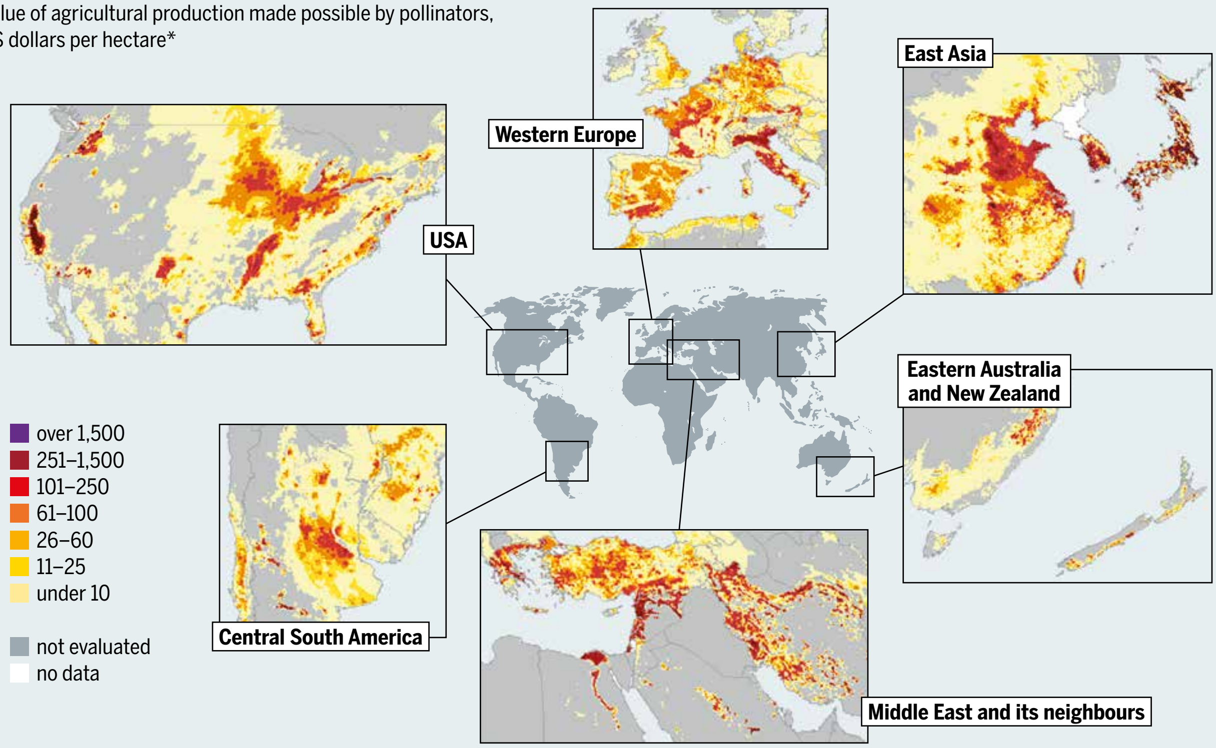
What is more, the number of chemical products in use around the world continues to increase. And, their negative effects on the insect world are also becoming more and more evident. This is not just because a growing number of chemicals are being applied; the formulations are also increasingly effective and can be used more selectively.

The nature of agricultural production and the structure

To reduce postharvest losses during grain storage, the important thing is not insecticides but biteproof and airtight containers

GLOBAL SERVICE PROVIDERS

Value of agricultural production made possible by pollinators, US dollars per hectare*



* corrected for inflation and purchasing power, standardized for year 2000

Using cold, hard cash to measure the value of pollination services by animals – mostly insects – shows that even costly protection measures may well be profitable

of the agriculture landscapes can be optimised to hinder harmful insects and promote those that are beneficial. Pests benefit from monocultures and from the fact that the same crop is planted season after season. A diverse range of crop types, long rotations (planting different crops each season) and small fields all help to sustain a diverse insect population and make it easier for farmers to maintain a balance between pests and beneficial insects.

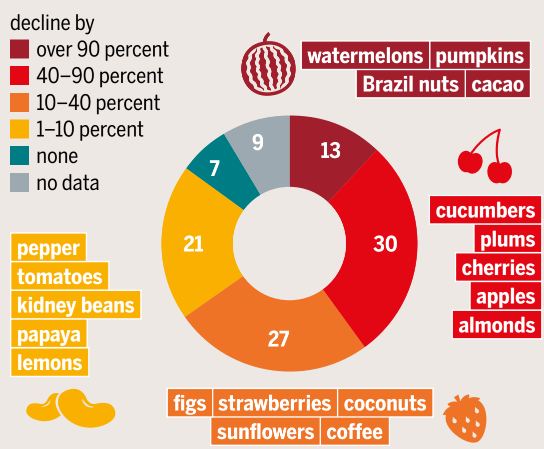
A comparison of eight regions in Europe and North America shows that smaller fields lead to a marked increase in species diversity. This is because insects, birds and plants can take advantage of the wider range of resources that are available. The edges of the fields are especially important, as they enhance dispersal across landscapes. Reducing the average field size from around 5 to 2.8 hectares in a landscape has the same positive effect on biodiversity as increasing the proportion of near-natural habitats from 0.5 percent to 11 percent.

It is not just how individual fields are managed, but even more so, it is the makeup of the whole landscape that is important for maintaining insect diversity. This is because most insect populations are not confined to small locations, but range over a wide area. For example, chalk heathlands are home to one-third more species if they are surrounded by a high percentage of near-natural habitats instead of predominantly arable fields. Efficiency of management is higher in monotonous, cleared landscapes, because introducing hedges and wildflower strips have a significantly greater positive effect on insect diversity than in colourful, variegated landscapes where such structural elements are common. Further, conservation measures are necessary across all regions, because the composition of insect populations may be radically different from one region to another. ●

About one-eighth of humanity's most important plant foods depend to a large degree on pollinators

NO MORE CHOCOLATE

Threatened decline in production of 107 plant foods* in absence of pollination by animals, numbers of food types and examples



* used for human consumption and traded on the world market

GLOBAL INSECT DEATHS

A CRISIS WITHOUT NUMBERS

The decline in both insect populations and in the number of species is well documented, though the evidence is patchy outside Europe and North America. Scientists agree that agriculture has a negative influence. Both the expansion and intensification of farming seem to be to blame.

Compared to plants, mammals, birds and fish, insects are little researched. Only a small fraction has even been classified. Particularly little research has been done on the long-term occurrence and population dynamics of insects outside Europe and the US.

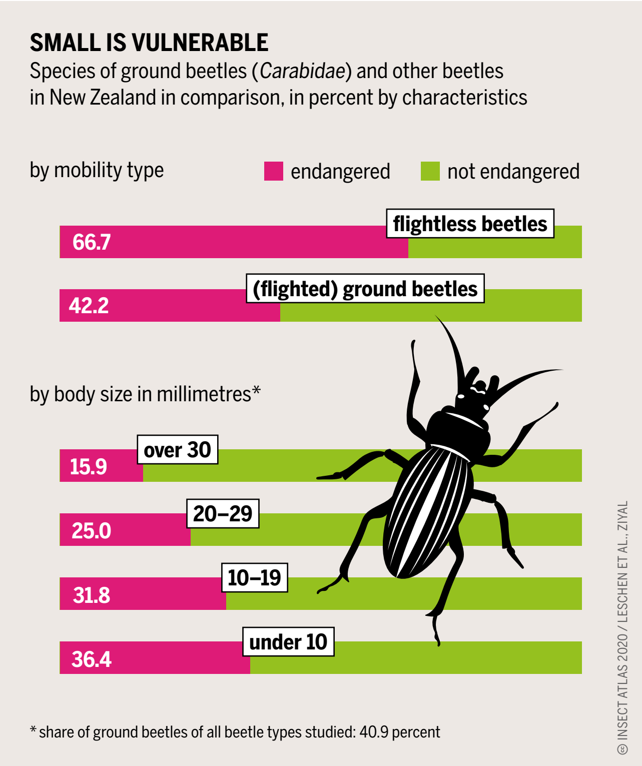
Scientists agree that several well-studied species, such as monarch butterflies, some groups of moths and butterflies, and some species of bees and beetles are in decline – especially in Western Europe and North America. There is also consensus that insect biodiversity is decreasing in many parts of the world, while the numbers and biomass of the animals vary greatly depending on the region, climate change and land use, as well as the adaptability of each species.

There is no scientifically confirmed figure for the global decline in insects. A first review by the University of Sydney in 2018 compiled information from research studies in various regions. It found that the populations of 41 percent of species are in decline, and one-third of all insect species are threatened by extinction. While cautioning that the available evidence is relatively thin, the researchers estimated that total insect biomass is declining by 2.5 percent a year. Most of the research studies they included in their review came from Europe, some from North America and only a few from Asia, Africa or Latin America. The existence of these gaps has been met with criticism. Some critics pointed out that the researchers had paid too little attention to studies that showed positive changes in insect numbers. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) says the proportion of insect species worldwide that are endangered is unknown. But based on the available data, this international organization cautiously estimates that 10 percent of species are endangered.

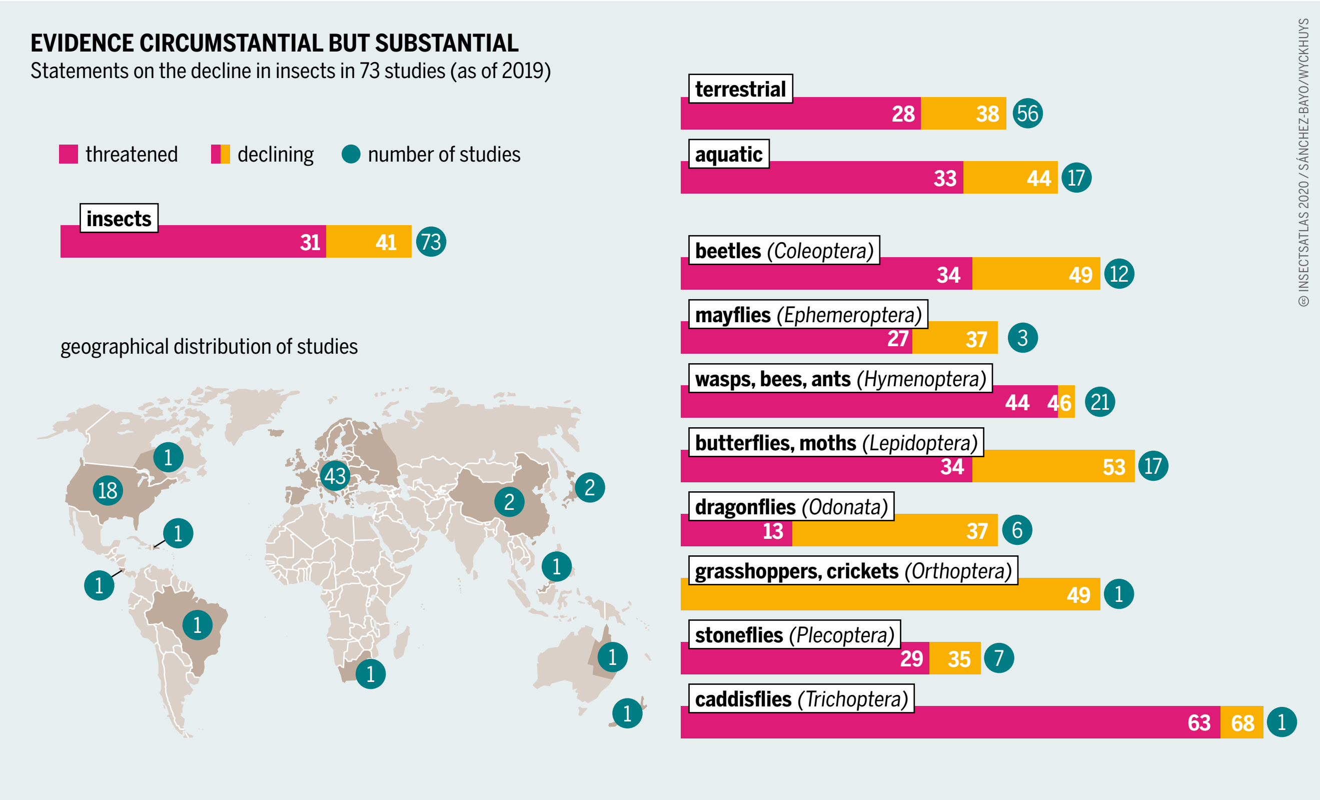
In Europe and North America, research shows that the numbers and diversity of moths, butterflies, beetles, wild bees and other insects are clearly dwindling, though at different rates in each region. Individual analyses in other parts of the world reveal the same trend. A study on the Caribbean island of Puerto Rico over a period of 36 years found that the biomass of arthropods in the rainforest fell by between 78 and 98 percent (arthropods include insects along with creatures such as spiders, scorpions and millipedes). Studies in Madagascar and New Zealand, and the Red List of Threatened Species compiled by the International Union for Conservation of Nature (IUCN), show that insect species are at risk throughout the world. At the same time, research in colder regions has found that insect numbers there are rising. Research in Russia revealed that the population of springtails in the tundra has increased as temperatures there rise.

Insects are disappearing mainly from cultivated land and intensively used pastureland. Since the early 1960s in New Zealand, the population of moths in grasslands has fallen by 60 percent, and in intensively used areas with a high livestock density by as much as 90 percent. The Academy of Sciences Leopoldina, in the city of Halle, states that the frequency of species in agricultural landscapes in Germany has fallen by around 30 percent. In woodland, marshland and settlements, by contrast, numbers have remained stable or have even risen.

The scientific consensus is that agriculture has a negative influence on insects. Farmland throughout the world is being used more and more intensively. Applications of fertilizer and pesticides have risen significantly in an attempt to squeeze out higher yields per hectare. Above all, though, the type of land use has been changing. In just 300 years, between about 1700 and 2007, the areas of arable land and pastureland both increased fivefold, with big expansions especially in the 19th and early 20th centuries. Humans



Ground beetles in New Zealand are threatened mainly by the expansion of cattle pastures for dairying



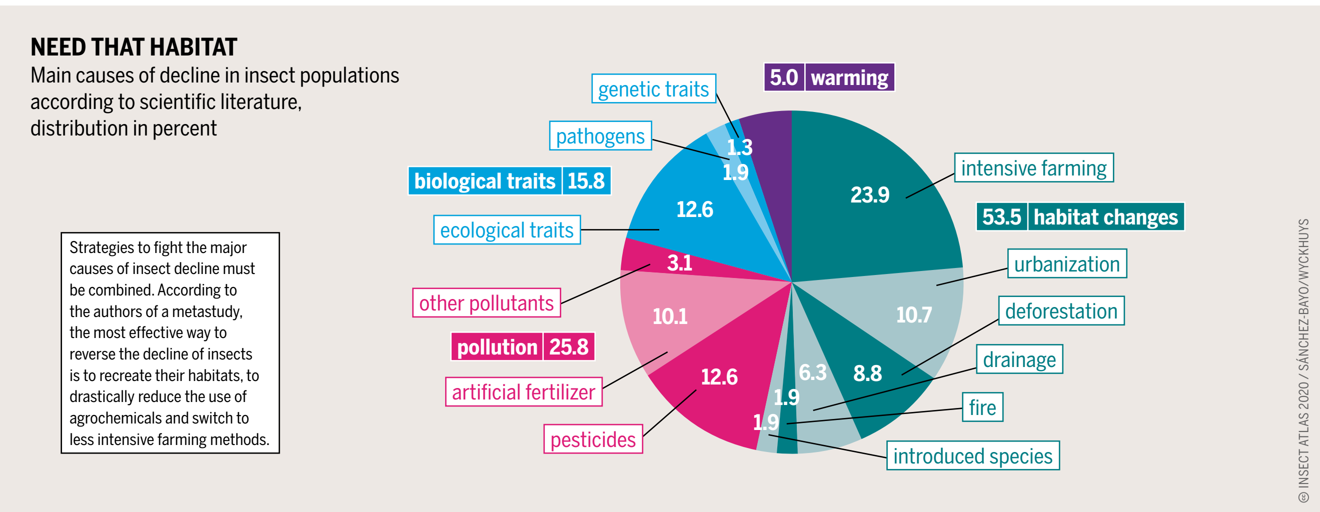
A great deal of research on insects focuses on particular species, groups and geographical areas. Global statements are often useless. But it is still possible to see some trends

cleared forests, drained swamps, and converted steppes and savannas to fields and pastureland. Wild animal and plant species that require undisturbed habitats declined or disappeared.

Between 1980 and 2000, over half of the new agricultural land in the tropics was created by clearing forests. Between 2000 and 2010, the figure was 80 percent. Two countries, Indonesia and Brazil, were responsible for over half of this tropical forest loss. But it is precisely in the tropical countries of Latin America and Asia that the numbers and diversity of insects are especially high. The most important reasons for deforestation are to clear pastureland for cattle, establish oilpalm plantations, and opencast mining of minerals.

The demand for farm products is rising across the globe: the Food and Agriculture Organization of the United Nations predicts a 60 percent increase by 2050. That will go hand in hand with an expansion in agricultural land – depending on rising yields per unit area – of up to 100 million hectares. But these developments can be averted. If the developed world were to consume less meat and if agricultural products were no longer used as fuel, the pressure on the land areas could be reduced considerably. ●

More than half of all specialized publications point to changes in habitat as the most important factor in the decline in insect populations



POLLINATOR DECLINE IN EUROPE

KILLING FIELDS

Europe's fields and meadows used to be abuzz with insects, all busily flitting from flower to flower in search of nectar and pollen. With the spread of chemical-intensive farming, the insects are disappearing and the fields are falling silent.

In Europe, the main pollinators are bees, hoverflies, butterflies and moths, plus some beetles and wasps. Around 84 percent of crop species and 78 percent of wildflower species in the EU depend at least in part on animal pollination, and up to almost 15 billion euros of the EU's annual agricultural output is directly attributed to insect pollinators. This ecological and economic importance makes the current considerable decline in pollinators worrying. Decreases in wild bees and hoverflies have been clearly documented in parts of Europe. At least one out of ten bee and butterfly species is threatened with extinction.

The lack of data makes it difficult to determine how many species are actually at threat: is it possible to count those species for which no (or inadequate) data exist? Of the 2,000 wild bee species in Europe, 9.2 percent are thought to be threatened with extinction, according to the European Red List. A further 5.2 percent, or 101 species, are considered "near threatened". However, for more than 55 percent of all species not enough data is available to evaluate their risk status. As more data become available, many of the currently unclassified bees may prove to be threatened as well.

Europe's most widely managed pollinator is the honeybee. Most of its wild and feral colonies are already lost, and existing colonies are managed by beekeepers. For some years, honeybee losses were severe and widespread throughout much of Europe, but since 2004 the number of hives has increased steadily. In 2018, there were more than 17 million hives in the EU.

Intensive agricultural production is considered one of the most important drivers for the decline in pollinators. Land-use changes for agriculture and agricultural intensification result in the loss and degradation of habitats, and less crop diversity in the fields. This results in a loss of diversity in flora, reducing food supplies and nesting opportunities. Exposure to insecticides poses an additional threat to pollinators.

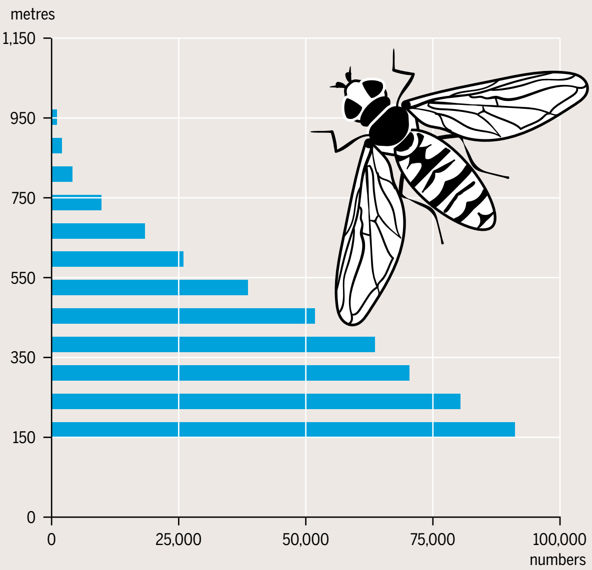
Research in Sweden shows that there is not only a decrease in abundance – there is also a reduction in diversity. Bumblebee populations there started changing in the 1960s. Two generalist species have increased in relative abundance: they now completely dominate the bee community at the expense of other specialized species. This may be related to the loss and fragmentation of key bumblebee habitats in the agricultural landscape, such as hay meadows and semi-natural pastures.

The butterfly's status is equally endangered. Of the 482 different species found in the EU, 7 percent are threatened with extinction, and another 11 percent are considered as "near threatened". About a third of Europe's butterfly species are declining, with a 39 percent drop since 1990. Researchers also attribute this decrease to agricultural intensification, which leads to uniform, almost sterile grasslands for butterflies. The use of fertilizer reduces plant diversity on the pasture, while high frequency mowing and haymaking are particularly detrimental for pollinators.

Agrochemicals such as fertilizers and pesticides have a significant negative impact on pollinators. They do not just affect the local area where they are applied, as once thought, but influence the occurrence of pollinators on a large scale across Europe. Even though the EU's regulatory system for pesticides is widely regarded as the most rigorous in the world and the EU has been promoting reduced pesticide use and the adoption of integrated pest management practices, the amount of pesticides used in the EU is not decreasing.

FREEDOM OF MOVEMENT DESPITE BREXIT

Flight altitude in metres and number of hoverflies (e.g., *Episyrphus balteatus*) during flight from the European continent to southern England

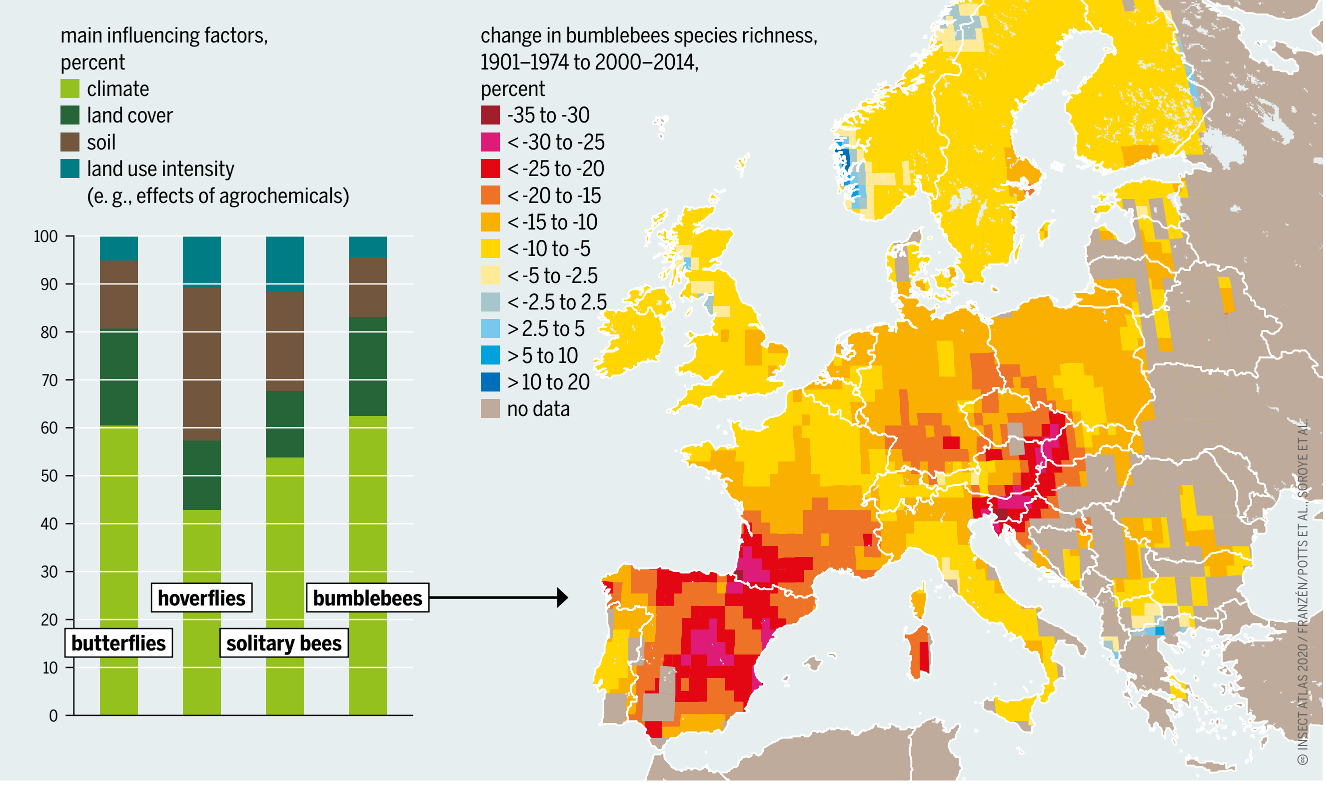


Between one and four billion hoverflies with a biomass of 80 tonnes, including many marmalade hoverflies *(Episyrphus balteatus)*, fly each year from the European Continent to southern England. They and their larvae eat up to 10 trillion aphids, pollinate billions of plants, before returning to the Continent as a new generation, 1 billion stronger and with 28 tonnes more biomass. By riding the wind, they can travel long distances and may fly up to 1,000 metres high, according to radar measurements.

Billions of Episyrphus balteatus hoverflies transport pollen across the Channel every year in either direction, helping maintaining biodiversity on both sides

TEMPERATURES UP, NUMBERS DOWN

Most important drivers for European pollinators including bumblebees, and climate change-related change in bumblebee species richness, model calculation based on thermal and precipitation positions



Not just threatened, but already gone – in some parts of Europe, one-third of the bumblebee species have disappeared

Neonicotinoid insecticides have been proven to be particularly harmful to bees. A report presented by the European Food Safety Authority in 2018 confirmed that most uses of neonicotinoids pose a risk to wild bees and honeybees. This was based on a review of more than 1,500 studies. A study covering 2,000 hectares across three EU countries, found evidence of harm to honeybees and wild bees. It concluded that in bumblebees and solitary bees, higher concentrations of neonic residues found in nests led to fewer queens. Another study shows that honeybee colonies that were chronically exposed to neonicotinoids performed worse in the short-term: the number of adult bees fell (–28%), as did the amount of brood (–13%), honey production (–29%) and pollen collection (–19%). There is also evidence that the use of neonicotinoids is a factor in the decline of farmland butterflies in England.

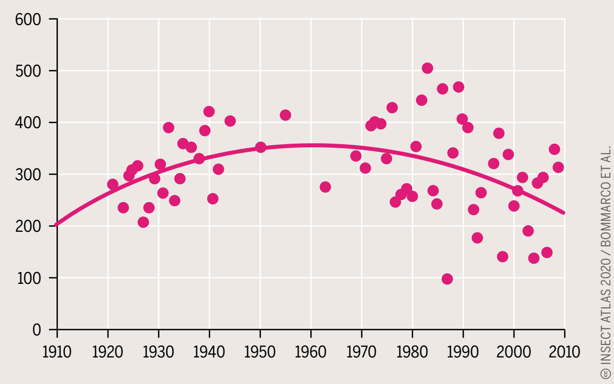
As a result of overwhelming scientific evidence, the EU has banned and restricted the use of some neonicotinoids. Member states can still apply for emergency use. This authorization is only meant for a plant-protection crisis where other means of protecting the crop are not available – but it has been used more widely. Seven countries have been investigated for inappropriate use of this authorization process. In addition, new neonicotinoids – such as Sulfoxaflor – have been approved by the EU.

Farming subsidies from the Common Agriculture Policy need to be shifted to support high nature value farming, organic farming, and agroecological systems. Stricter regulations for pesticide approvals are also needed. These measures will help strike a balance between agriculture, habitats and insects in the EU. Since political decision makers have not yet acted appropriately, the EU-wide citizen initiative “Save Bees and Farmers” is now needed to show decision makers how important this issue is to European citizens.

No red clover seeds without bumblebees – the transformation of hay meadows and pastures into cropland has deprived the pollinators of their habitat

LIKE A HUNDRED YEARS AGO

Seed yields in red clover fields in Sweden, in kilograms per hectar



INSECT NUMBERS IN GERMANY

ON THE WAY DOWN

Long-term research, individual studies and the Red Lists all tell the same story: the numbers and diversity of insects are heading downhill. Plugging the gaps in the data will do nothing to change this conclusion.

Entomological research – the study of insects – is not normally the stuff of headlines. But one finding hit the news around the world: in parts of Germany, more than 75 percent of the flying insects have disappeared. The study, published in October 2017, is based on data from the Entomologischer Verein Krefeld (Krefeld Entomological Society). Members of this society had studied the occurrence of flying insects over a period of 27 years in over 60 locations, mostly in protected areas in the state of North-Rhine Westphalia. Although the study has been criticized for methodological shortcomings, it provides long-term data on the populations of whole groups of insects – data that had never before been collected anywhere. The data came from various parts of Germany and show a clear trend.

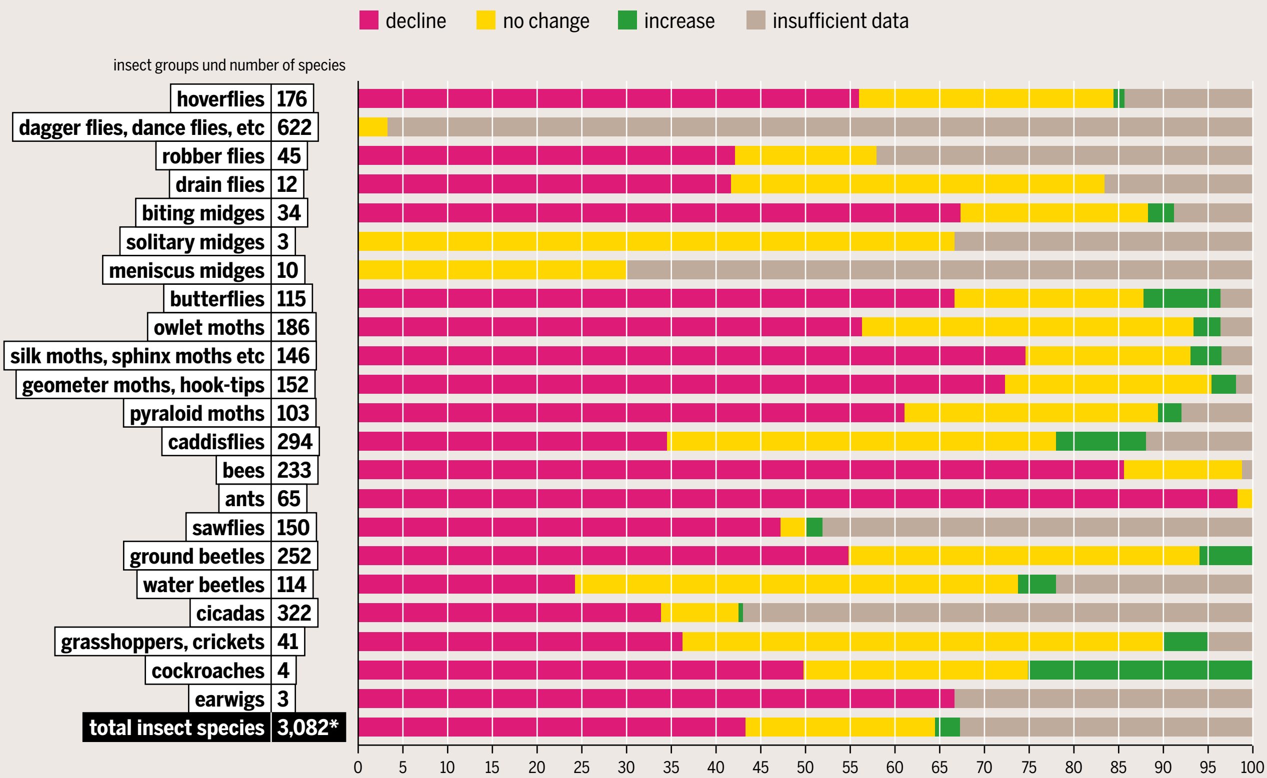
Apart from the Krefeld research,other long-term studies have been conducted in Germany on the populations of butterflies, wild bees and cicadas. They all show a decline in the number of species, and partly also a dramatic fall in the population density of the insects enumerated. In the case of butterflies, this mostly affects the specialist species. These include butterflies whose caterpillars depend on particular food plants. Long-term counts in several parts of Germany reveal permanent losses in over 70 percent of such species.

Almost half of the 561 wild bee species are in decline. Apart from habitat loss, the widespread use of highly effective neonicotinoid insecticides may have contributed to the marked drop in these bee populations. On the Swabian Jura, a range of hills in southern Germany, the number of nests of the common furrow-bee, Lasioglossum calceatum, shrank by 95 percent over a period of 46 years. In the Isar River floodplains in Dingolfing, Bavaria, three-quarters of wild-bee species have disappeared in just 10 years. Other

Among those insect groups whose numbers have fallen over the long term (50 to 150 years), almost half have also declined over the short term (in the last 10 to 25 years)

ON THE WAY DOWN ALMOST EVERYWHERE

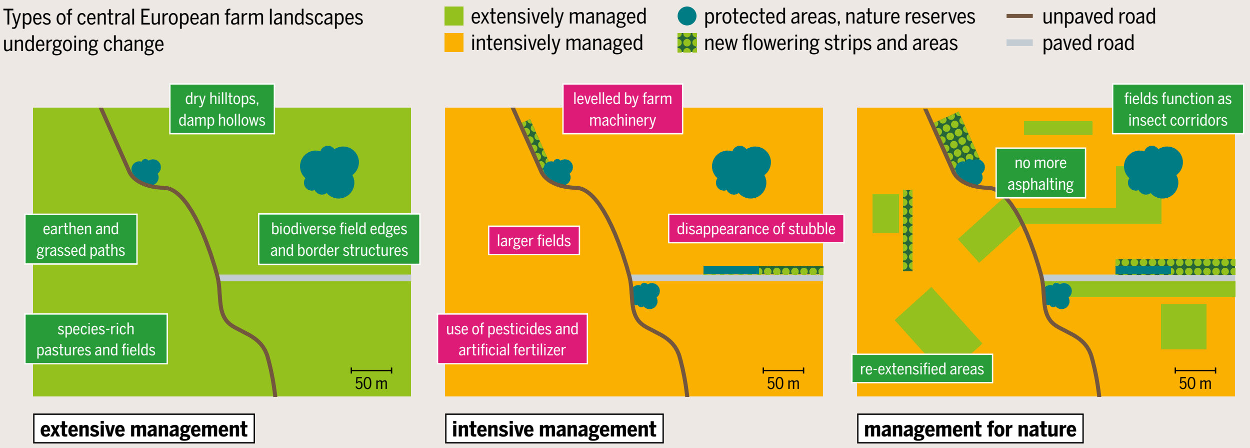
Red Lists of insects in Germany, acute trends in insect groups declining in the long term, distribution by percent of species



* without invasive species, wasps, phantom midges (Chaoboridae) and thrips (Thysanoptera)

ALTERNATIVE REALITIES

Types of central European farm landscapes undergoing change



Maintaining and restoring insect populations requires many changes, large and small, both in the fields and outside them

groups of insects have also been decimated. Populations of cicadas on dry grasslands in eastern Germany have declined by 54 percent over a timeframe of 40 to 60 years. In wet grasslands in Lower Saxony, losses were as high as 78 percent.

Overall, the research in Germany shows that losses are not confined to particular localities but occur across the country. Species with widely differing lifestyles and habitats are affected. By far the highest insect losses are in open parts of the landscapes. Such areas include arable land and meadows. According to an international team of researchers led by the Technical University of Munich, the insect biomass in grassland areas fell by two-thirds between 2008 and 2017. During the same period, forests lost 40 percent of their insect biomass.

The Red Lists are the most comprehensive collections of information on the threat status of individual species. The German Federal Agency for Nature Conservation has compiled them for the last 40 years. Continually expanded, they portray the population developments of around 15,000 insect species over a period of 50 to 150 years. That means they cover the situation of just under half the 33,000 insect species in Germany. The gaps that exist in the data are because many species are difficult to identify, and there are not enough specialists to document their numbers on a continuous basis. The Red Lists show that one in every two species covered is in decline. Only a small fraction of species – around two percent – are on the increase. The past few decades have seen particularly striking losses among ant species. More than 90 percent of the 107 species found in Germany are decreasing.

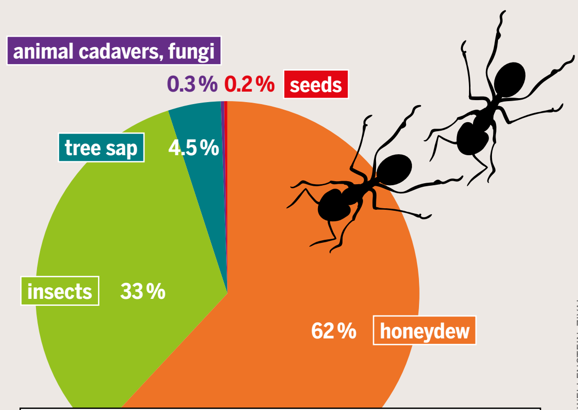
A large number of beetles have now been placed under protection because they are threatened. The lack of dung beetles can be determined from the condition of cow dung on the fields. In many locations they no longer degrade, leading to the formation of “concrete cowpats”. One of the causes is the presence of insecticide residues in animal-feed concentrate, which the livestock excrete along with their dung. These residues go on to kill the beneficial beetles that rely on the dung.

In a new study, experts from Krefeld analyse the decline in terms of individual insect groups and species. For hoverflies – the most important pollinators besides bees – the number of specimens in a protected area in North-Rhine Westphalia sank from nearly 17,300 to around 2,700 between 1989 and 2014: a loss of 84 percent. Of the former 143 species, only 104 were found 25 years later. The project Diversity of Insects in Nature protected Areas, or DINA, launched in 2019, is looking at the causes: over a period of four years, the scientists will study as closely as possible the factors that give rise to insect mortality. They will try to determine how important these factors are. The results will help set priorities so as to reverse the current trends.

It’s not a lack of food, it’s the disappearance of their habitat: ants are the most threatened group of insects in Germany

INVENTOR OF LIVESTOCK FARMING

Diet of wood ants (*Formica*) by components, in percent



Farming is one threat to ants in Germany, in part because of overfertilized grazing land. But ants were keeping livestock long before humans: they cultivate aphids, protect them from predators, and milk them for the honeydew they produce. A colony with a million ants harvests around 200 litres of honeydew a year, supplemented with some 11 million insects weighing 28 kilograms.

PESTICIDES

TO THE LAST BREATH, OR AS A LAST RESORT

Agrochemicals are used to control many organisms that might reduce crop yields. They are becoming ever more precise in their workings. Despite this, more and more of them are being applied on the fields.

The quantity of pesticides applied on crops has risen fivefold since 1950. Even though organic farms make do without them wherever possible, conventional farms apply over 4 million tonnes of chemical pesticides a year worldwide. Global turnover in 2018 for these materials totalled 56.5 billion euros. By 2023, according to estimates, it may climb to as much as 82 billion euros.

Four chemicals giants share two-thirds of the global market: BASF and Bayer in Germany, Syngenta in Switzerland (but Chinese-owned), and Corteva, a newcomer formed out the agrochemicals divisions of DowDuPont. The OECD, a club of developed countries, says that in 2017 the pesticide sales of Bayer alone totalled 11.2 billion US dollars, followed by Syngenta at 9.4 billion, and BASF and DowDuPont at between 7 and 8 billion US dollars each. Including seeds sales, the figures are even higher.

Pesticides are one of the main causes of insect mortality because they affect the entire ecosystem. Depending on their target organisms, they can be classified as insecticides, herbicides, fungicides and others. Insecticides eliminate pests on crops, but other plants are inevitably also affected. Neonicotinoids, for example, now the world's most widely used type of pesticide, harm many species, including bees and bumblebees. They damage the insects' nervous systems, causing the bees to lose their sense of navigation. Bumblebees even lose their sense of smell.

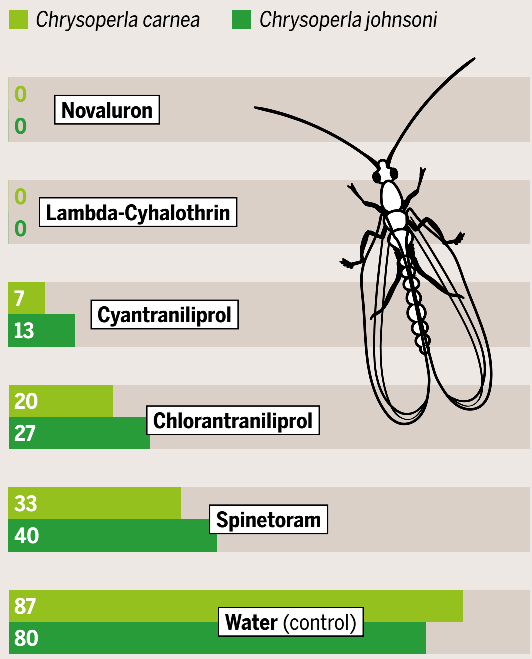
Herbicides are targeted against weeds. Selective herbicides are effective against specific types of plants, while non-selective herbicides, or "total weedkillers", kill almost all plants. The most widely used non-selective herbicide globally is glyphosate. Its sales have risen sharply because it is used in combination with genetically modified crops, especially soybeans. These plants are designed to withstand the pesticide, which kills all the other plants nearby. As a result, insects find fewer flowers and lose their source of food. The herbicides may also harm insects directly. Experiments by the University of La Plata in Argentina show that glyphosate can kill lacewings, beneficial insects that prey on aphids.

The highest applications of pesticides are in Asia, especially in China, India and Japan. Chinese farmers now apply three times more than the global average. The Americas come next, with North America, Brazil and Argentina consuming the largest quantities of pesticides in absolute terms. Africa consumes only about two percent of the global total.

There is a lack of long-term research on the effects of pesticides on biodiversity and insects in Africa and Latin America. Pesticides could have a big impact on insect mortality in areas where applications are high and where registration is poorly regulated. Pesticides banned decades ago in the European Union are still used in South African vineyards and in vegetable production in Kenya. As discussed at the company's annual shareholders' meeting in 2019, Bayer sells twelve active ingredients in Brazil that are no longer permitted in the EU, including the insecticide Thiodicarb, which is effective against harmful butterfly species.

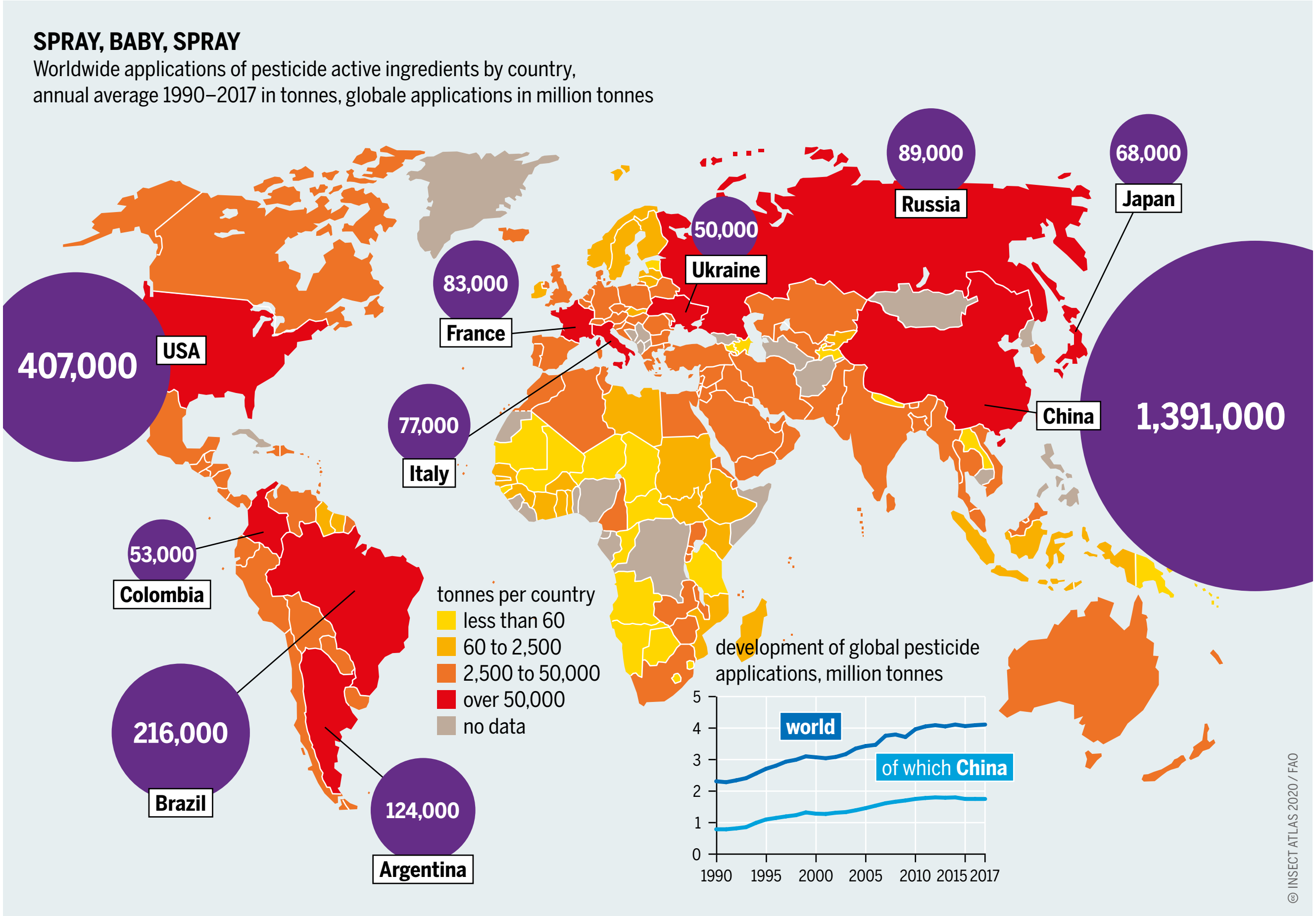
GOOD GUYS CAUGHT IN THE CROSSFIRE

Survival rates of two species of green lacewings of the genus *Chrysoperla* with applications of various pesticides, larva to adult, in percent



The larvae of the *Chrysoperla* lacewings are sometimes called "aphid lions" because they consume large numbers of pests. In the USA, two of the species that are typically found in fruit and walnut orchards were exposed to five common active ingredients of pesticides. The consequences were so serious for the lacewings that secondary pest outbreaks occurred because there were too few beneficial insects to prey on the pests. As a result, farmers have to apply yet more pesticides, which then kill even more beneficials.

Pesticides that kill beneficials along with pests often worsen pest problems. The solution is integrated pest management, which uses as few chemicals as possible

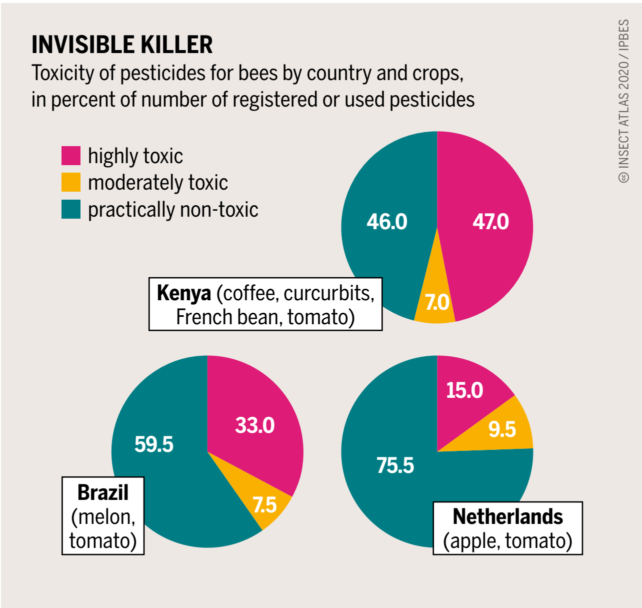


China consumes about one-third of the world's pesticides. Syngenta, a Swiss-based company that is one of the world's top three agrochemicals companies, is in Chinese hands

Nongovernment organizations in Europe are demanding that synthetic pesticides, which are banned in the European Union because of their negative effects on the environment may not be exported to the developing world. The Rotterdam Convention, which came into force in 2004, is an international treaty governing the import and export of dangerous chemicals, including pesticides. It permits the import of such substances if the country of destination has been informed about the risks they entail for human health and the environment, and if it has consented to the import. The Convention has been ratified by 160 countries. It lists a total of 36 pesticides, but gaps remain. By no means all the signatory parties have banned the import of the listed substances. China, for example, has not banned DDT.

Debates on insect mortality and the loss of biodiversity are increasing and are putting the agroindustrial manufacturers under pressure. The interactions between pesticides and insects were ignored for a long time. There was not enough information on the long-term impacts of pesticides or the effects of pesticide combinations. In the past, the manufacturers often commissioned the evaluations themselves, while independent scientific investigations did not have to be taken into account in approval procedures.

In 2019, a change in European Union law made the registration of all research results compulsory – including those that reveal problems. That means these results may no longer be withheld but must be considered in the approval process. The risks posed by pesticides can now be better assessed, and protecting humans and the environment is being given higher priority.

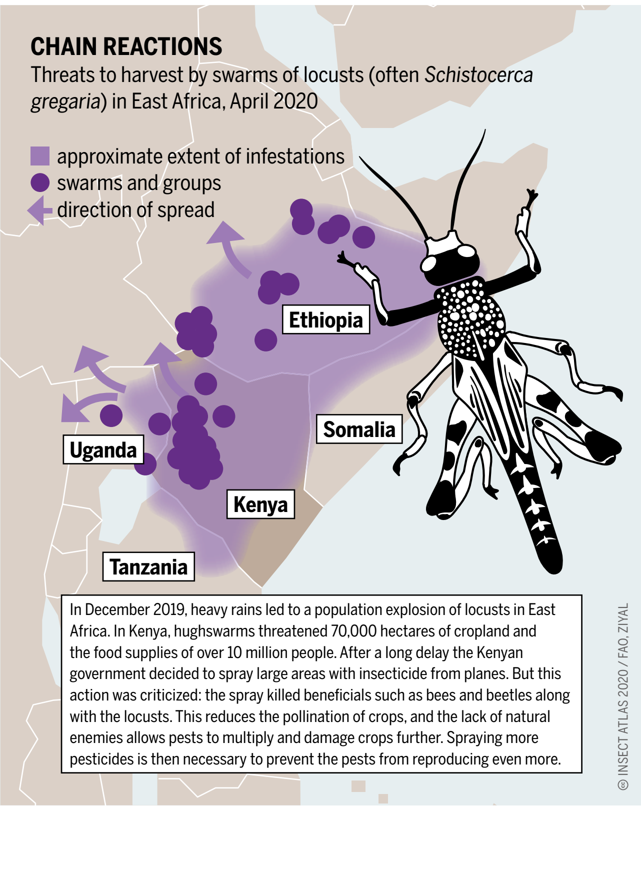


In poorer countries such as Kenya and Brazil, the types of pesticides used are more toxic for bees than in the wealthy Netherlands

BANNED IN EUROPE, COMMON IN KENYA

The developed world is waking up to the risks associated with the use of pesticides. The situation is different in the developing world: chemicals that are banned in Europe and North America are still used routinely to control pests. Stricter controls are needed, along with better information for farmers.

Agriculture in Kenya accounts for about 26 percent of Kenya's GDP with an estimated 75 percent of the population (mostly small-scale and subsistence farmers) working directly or indirectly in the farming sector. The country's agricultural economy promotes conventional, high-input farming. For this reason, the demand for pesticides is high compared to other African countries. However, the pesticide sale market in Africa still accounts for less than 6 percent of the global pesticide market. There are no local manufacturing facilities on the continent. Most of the pesticide products used in Kenya are imported from China (42 percent) and Europe (30 percent). With a market share of more than 30 percent, the EU is the largest exporter of pesticides in terms of monetary volume. Kenya's spending on pesticides increased from 36 million US dollars in 2000 to 114 million in 2017.



In December 2019, heavy rains led to a population explosion of locusts in East Africa. In Kenya, hughswarms threatened 70,000 hectares of cropland and the food supplies of over 10 million people. After a long delay the Kenyan government decided to spray large areas with insecticide from planes. But this action was criticized: the spray killed beneficials such as bees and beetles along with the locusts. This reduces the pollination of crops, and the lack of natural enemies allows pests to multiply and damage crops further. Spraying more pesticides is then necessary to prevent the pests from reproducing even more.

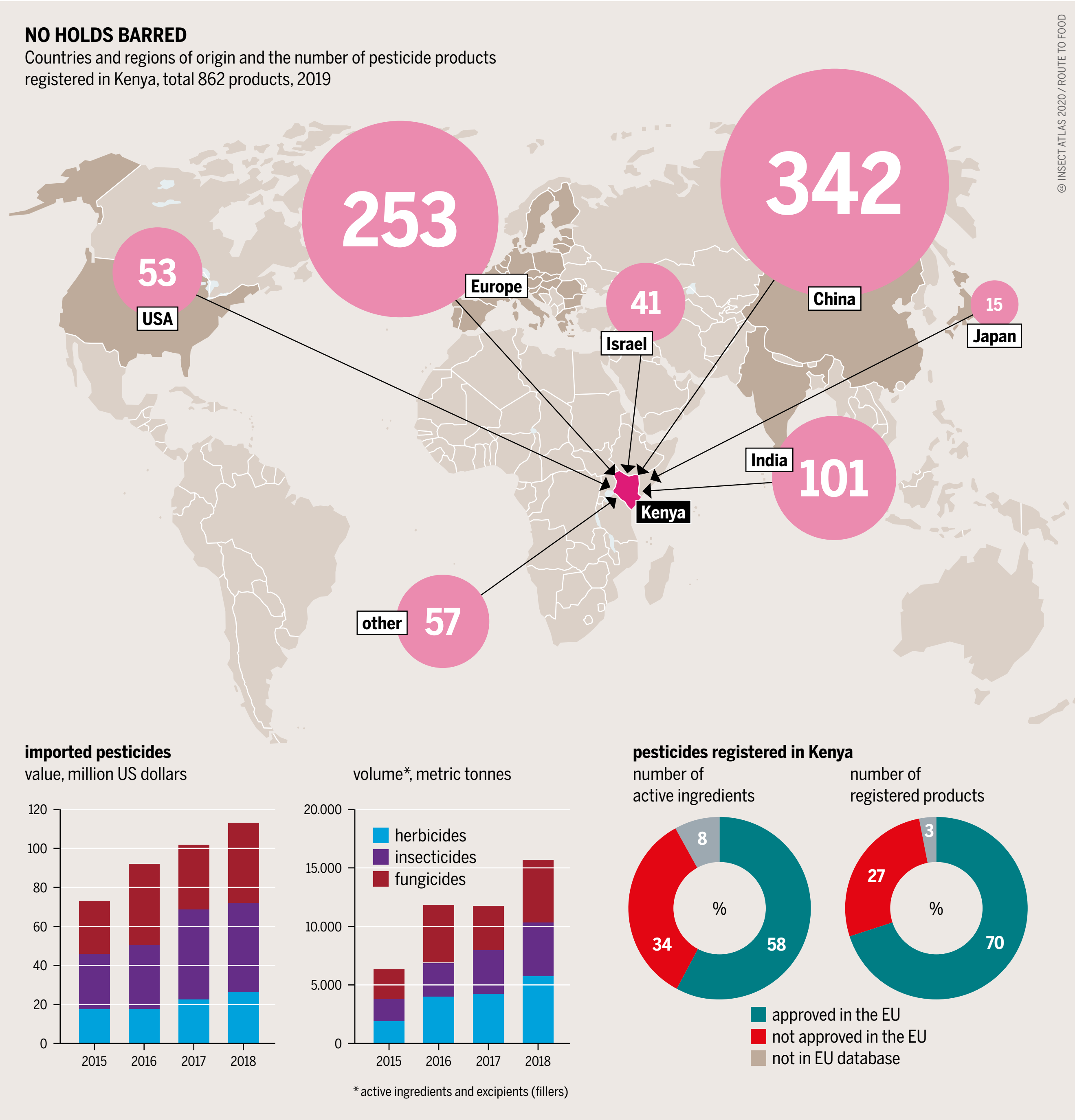
Studies on the impact of pesticides on African insect diversity are limited and geographically dispersed. One study in eastern Kenya found pesticide use was negatively related to pollinator abundance in fields. Kenyan authorities have approved 862 products for use in horticulture, 275 of which (32 percent) are toxic or highly toxic to bees. Kenya is not unique: in South Africa, 298 of 1,355 products (22 percent) are toxic or highly toxic to bees. In Europe, by contrast, 49 percent of the pesticides classified as toxic or highly toxic have been withdrawn from the market or have been restricted to greenhouse use only, because they are toxic to bees. Licenses for many active ingredients have not been renewed because of potentially harmful effects on the environment and human health. No such restrictions or withdrawals are being considered in Kenya.

This is of particular concern with regard to active ingredients classified as neonicotinoids, a pesticide group that includes imidacloprid and thiamethoxam. These are commonly used in Kenya to control thrips, aphids and whiteflies, but often without caution or safety measures. Imidacloprid (developed by Bayer) is an ingredient in 42 products used in Kenya, but is restricted to greenhouse applications only in Europe. Thiamethoxam (from Syngenta) is present in 13 products in Kenya; its registration has been withdrawn in Europe. A lot of the seeds used in Kenya are pre-coated with neonicotinoids, affecting not only pollinators but also soil microbial and insect activity, which in turn affects soil fertility.

The intensive use of neonicotinoids is evident in the residue levels in honey, pollen, surface water and sediments. The African beekeeping business, an important source of income for many rural communities, is more vulnerable to the loss of bee populations than its European or North American counterparts. Most of the bees used for honey in Africa are wild, not kept in hives as in Europe. This makes it more difficult for farmers to replace bees lost due to pesticide use or for other reasons. Unless all pollinators are protected, food and livelihood security and critical biodiversity are in danger.

Farmers are often oblivious to the fact that certain products are toxic to pollinators and other insects. As a result, they do not use precautions when handling and using them. For example, they are unaware that spraying close to a river will allow runoff and spray-drift to enter the water; nor do they know that spraying when pollinators are active will expose them to the pesticide. Such measures are often the preconditions for successful registration in Europe. But this

Hormone traps are effective at preventing plagues of locusts. But they are expensive, so governments still rely on chemical controls



information does not reach farmers in Kenya due to a lack of training, inadequate labelling and insufficient regulations.

In December 2019, a locust invasion threatened Kenya and neighbouring countries in East Africa. The biggest swarm covered an area of over 20 by 40 kilometres, with up to several million locusts per square kilometre. It was a severe threat to agriculture and food security in the region. Scientists think that this invasion could have been prevented if the first outbreaks had been dealt with in 2018.

Today, large quantities of pesticides are needed to manage the crisis. These pesticides are sprayed from planes over large areas, harming other insects, the soil, water and human health. The active ingredients of these pesticides are Malathion, which is highly toxic to fish and bees, and Fenitrothion, which is toxic to bees and soil arthropods and is not approved for use in Europe.

Chinese and European firms are the worst offenders: in countries with weak controls, they sell chemicals with abandon

Although the scale of the crisis warrants special measures to avoid total crop destruction, it is equally important to monitor the soil and water of the treated areas after the invasion subsides. The unprecedented scale of the locust invasion is a stark reminder that such natural disasters are becoming more frequent and more extreme in their effects due to climate change. It is therefore ever more important that the countries most affected by such disasters be better prepared to avoid and manage them. To safeguard their natural resources, biodiversity and food security, alternative mitigation strategies should be part and parcel of such preparations. ●

FROM FOREST TO PASTURE, FROM PASTURE TO FEEDLOT

Worldwide demand for meat sparks a chain reaction of deforestation, monocultures and chemical sprays. Nature is being destroyed fastest in those areas that are especially rich in insects.

Each year, the world's production of meat rises. The Food and Agriculture Organization of the United Nations (FAO) calculates that global output in 2018 was 335 million tonnes. In 1970, it was just one-third of that figure. Demand for meat has huge ecological consequences, also for insects. Livestock farming practices determine agricultural landscapes, plant diversity, the soil and water quality, and thus the habitat for insects. No other type of farming has more influence on ecosystems than intensive livestock farming.

Meadows, pastureland and savannahs make up between 22 and 26 percent of the world's land surface free of ice. They are home to an enormous variety of plants that in turn offer insects a wide range of habitats. Grasslands often harbour a greater variety of insect species and larger populations than cultivated fields. But intensively used meadows have lower diversity: high-yielding grasses, excessive fertilization, frequent mowing and intensive grazing all take their toll. Shorter grass growth and denser vegetation rob insects of their habitats. Extensive grazing, on the other hand, prevents bushes and trees from growing on an area, but it also promotes plant diversity and thereby boosts insect wealth.

Globally, livestock farming has changed fundamentally in the last 50 years. Fewer and fewer animals are now grazed on pastureland. Most animals are stall-fed or raised in huge factories or in feedlots, where they are crammed into small, open-air paddocks. Such dense stocking eliminates any grasses in the paddock. The higher numbers of animals boosts the demand for feed manufactured from cereals and oilseeds. Intensive livestock farming has thereby become one of the most important causes of changes in land-use: forest is cleared for grazing or to grow crops that will end up as livestock feed, and pasture is ploughed up to sow feed crops. The habitat for insects shrinks further.

Soya is the most important source of protein for intensively kept livestock. It is now grown on 123 million hectares worldwide, an area 3.5 times the size of Germany. Just three countries – the United States, Argentina and Brazil – together produce around 80 percent of the world's soybeans. In 1990, soybeans covered 11 million hectares in Brazil; in 2018, Brazil became the world's largest soybean producer – the surface had increased to 36 million hectares.

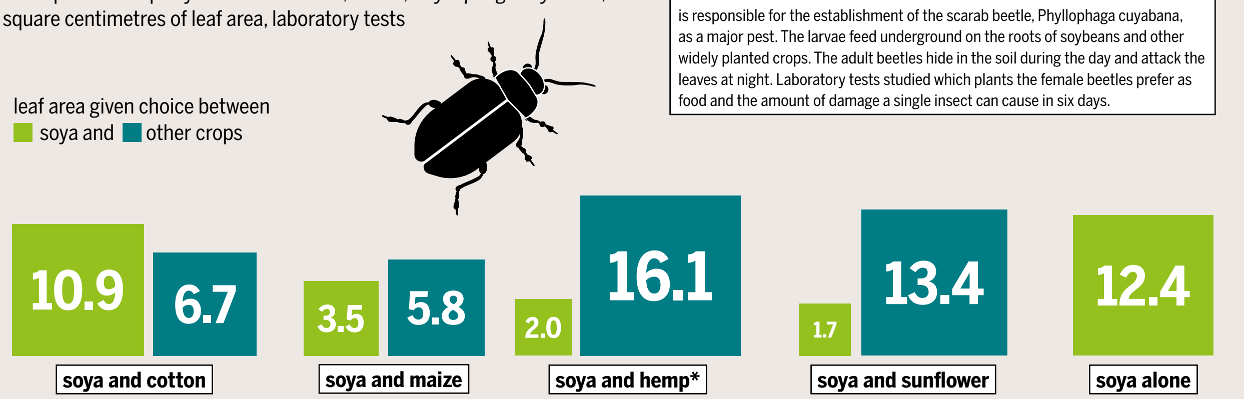
Brazil is also one of the most insect-rich countries in the world, but soybean production there is affecting its biodiversity. Brazil is home to around nine percent of the nearly 1 million insect species that have so far been classified. Specialists estimate that as many as half a million insect species may actually be native to Brazil. The tropical and subtropical parts of the country, as well as the Cerrado – the most extensive forest savannah in South America – are home to the world's greatest diversity of insects. While several protected areas exist in the Amazon region, the Cerrado is virtually left to the mercy of an expanding agroindustry. Farm-

A few decades ago, Phyllophaga cuyabana was just one beetle among many. Then along came clear-cutting and monocultures, and its career took off

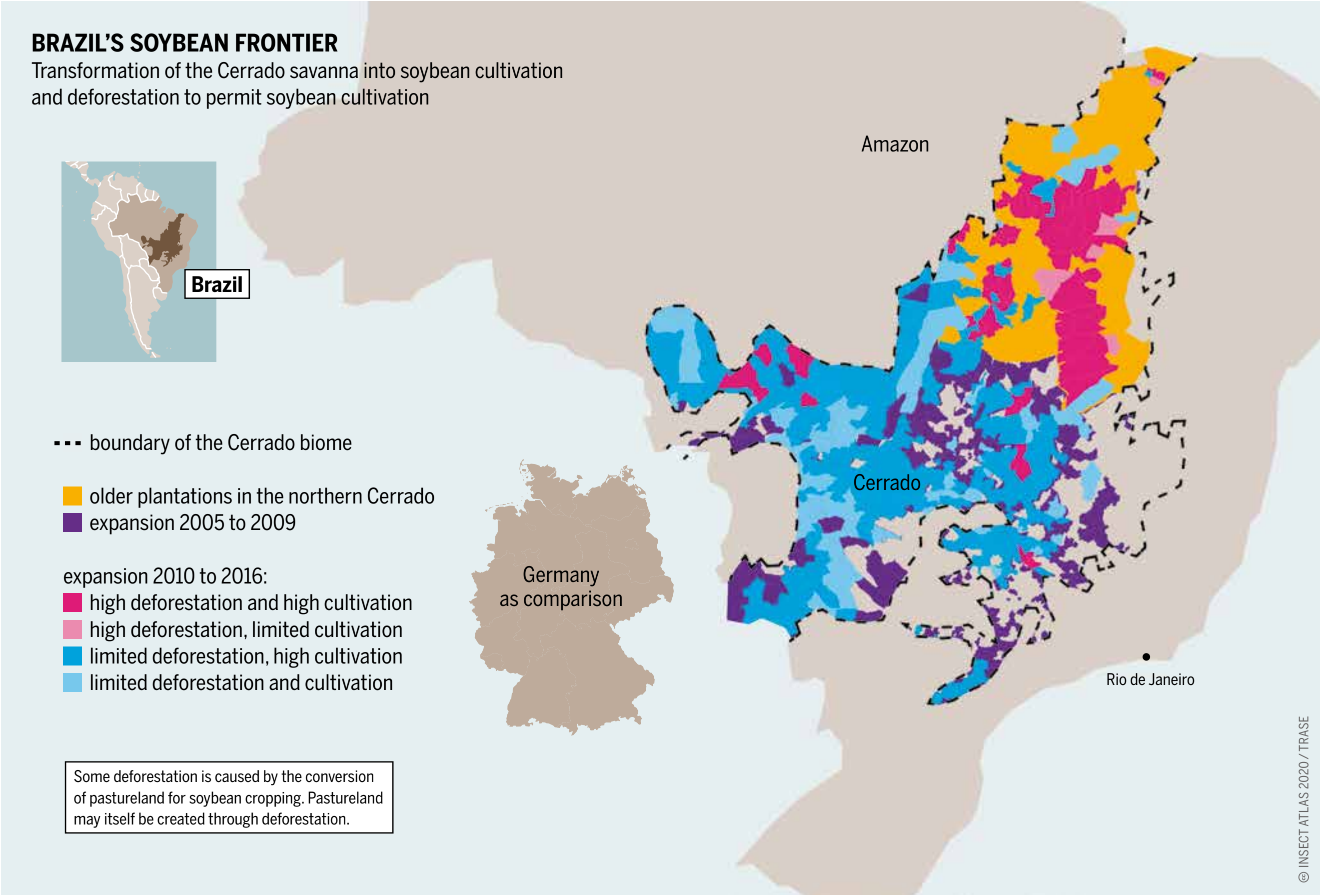
THANKS FOR THE MEAL

Consumption of crops by the scarab beetle, beetle, *Phyllophaga cuyabana*, in square centimetres of leaf area, laboratory tests

The transformation of the Brazilian Cerrado savannas into enormous monocultures is responsible for the establishment of the scarab beetle, Phyllophaga cuyabana, as a major pest. The larvae feed underground on the roots of soybeans and other widely planted crops. The adult beetles hide in the soil during the day and attack the leaves at night. Laboratory tests studied which plants the female beetles prefer as food and the amount of damage a single insect can cause in six days.



* plantation crop used e.g., as source of oil



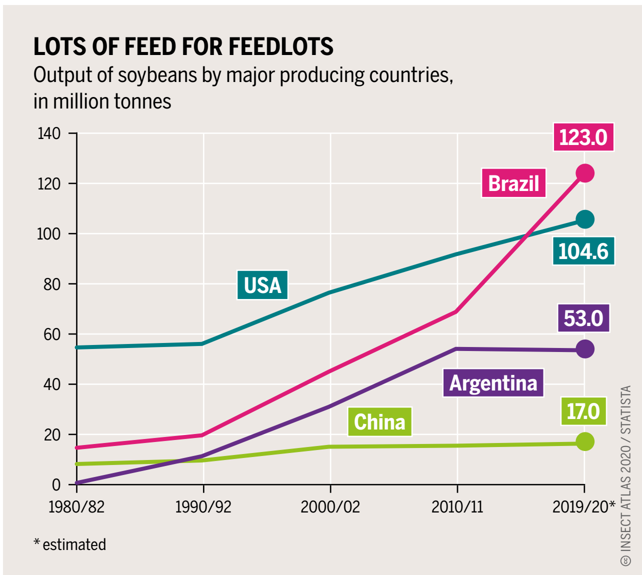
Forests are disappearing in the Cerrado even more quickly than in the neighbouring Amazon. With them, a species-rich ecosystem is being lost

ing continues to spread in both ecosystems, with the help of legal as well as illegal means.

The soya boom goes hand in hand with the increased use of pesticides. Both Brazil and Argentina grow mainly genetically modified types of soya. These plants are resistant to glyphosate, a herbicide that kills any weeds growing in the field without harming the actively growing soybean plants. Brazil is now the world's second-largest consumer of herbicides. Since the approval of genetically modified soybeans in 1996, Argentina, too, has also relied increasingly on pesticide use. In the 1990s, it applied around 40 million litres; in 2017, the latest year for which data are available, it sprayed 196 million litres. Market analysts predict a boom in spraying in the coming years, with annual increases of over five percent. Both Argentina and Brazil use pesticides that are banned in the European Union because of their negative effects on the environment.

Intensive livestock farming in Europe would not be possible without feed bought on the global soybean market. That is one reason why the European Union has spent 20 years trying to reach a trade agreement with the countries in the Mercosur bloc – Brazil, Argentina, Paraguay and Uruguay – which would turn the two blocs into the world's biggest free-trade area. This initiative has been met with massive criticism from a broad network of more than 340 civil society groups in both Latin America and Europe. The negative ecological consequences of new meat exports from Brazil even hit the headlines in the European media. Less well-known is that the agreement also encompasses the wide-ranging liberalization of trade in chemicals. The biggest pesticide producers in the world – the German firms Bayer and BASF, along with Swiss-based Syngenta – will be delighted. Insects in the Mercosur region will be less enthused.

Brazil's soybean output has risen steeply because the area planted has increased and especially because yields per hectare have gone up



CLIMATE CHANGE

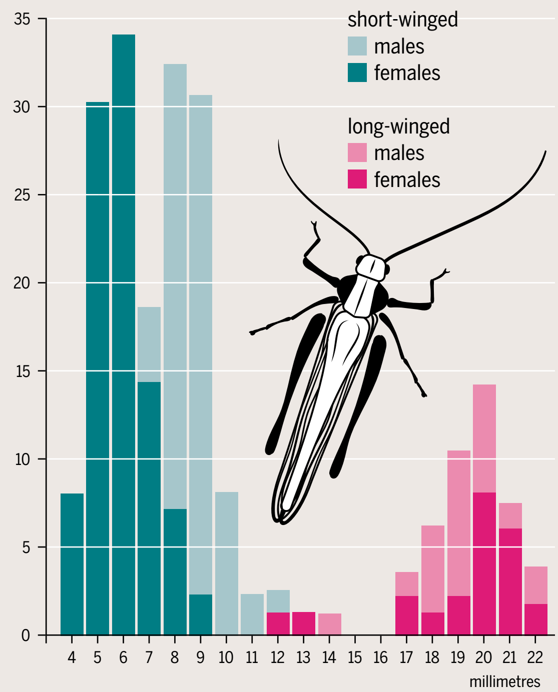
TOO FAST TO KEEP UP

A warming planet harms many species of insects. But it is good for a few species, and some of these are making themselves all too visible in the fields. Experts warn that pests will cause greater damage in the future.

Climate change currently poses the third-biggest threat to species diversity – right behind changes in land use, such as forest clearing, and the direct exploitation of organisms like fishing. Rising temperatures and extreme weather events such as droughts, storms and floods equally damage insects and their habitats. Increases in insect populations can often easily be attributed to climate change. The causes of population declines, on the other hand, may be harder to discern because changes in land use may also be a factor. Most statements about the effects of climate change have so far been based on forecasts and experimental studies. On this basis, it is possible to identify some general trends for some well-researched insect groups.

HAVE WINGS, WILL FLY

Growth of long wings in Roesel's bush-cricket (*Metrioptera roeselii*), wing length in millimetres and numbers, total 210 individuals



Roesel's bush-crickets normally have short wings. Their population increases in warmer years. Some are stressed by crowding, and they grow wings that are two to three times longer than normal. That enables these individuals to fly away to a new area.

Dragonflies and grasshoppers have been studied intensively for a long time. Many species respond positively to higher temperatures. Despite the loss of large areas of insect habitat, and the fragmentation of that habitat into isolated islands, many dragonfly and grasshopper species in Central Europe have been spreading since the end of the 1980s. Few have been negatively affected. Experts estimate that in North Rhine-Westphalia, a state in western Germany, climate change has a positive effect on 40 percent of dragonfly species and 55 percent of grasshopper species. Only 14 percent of dragonfly species and 10 percent of grasshoppers are subject to decline.

The situation is very different for butterflies. They make significantly more complex demands on their environment. Many species live close to the plants that their caterpillars are particularly fond of, and they depend on a network of suitable habitats in the immediate vicinity. In North Rhine-Westphalia, 34 percent of butterfly species are classified as winners in the climate-change game, while as many as 20 percent are losers.

The loss and fragmentation of habitats – mainly as a result of agricultural use – mean it is not possible for many species simply to move elsewhere as conditions alter. Even highly mobile insect species such as dragonflies cannot keep up with the speed of climate change. Some species can adapt at least partially to ongoing instability. But extreme events, such as heatwaves and heavy rains that are occurring more frequently due to climate change, can kill off local populations completely. Without corridors between biotopes, these populations cannot be restored through recolonization from neighbouring areas.

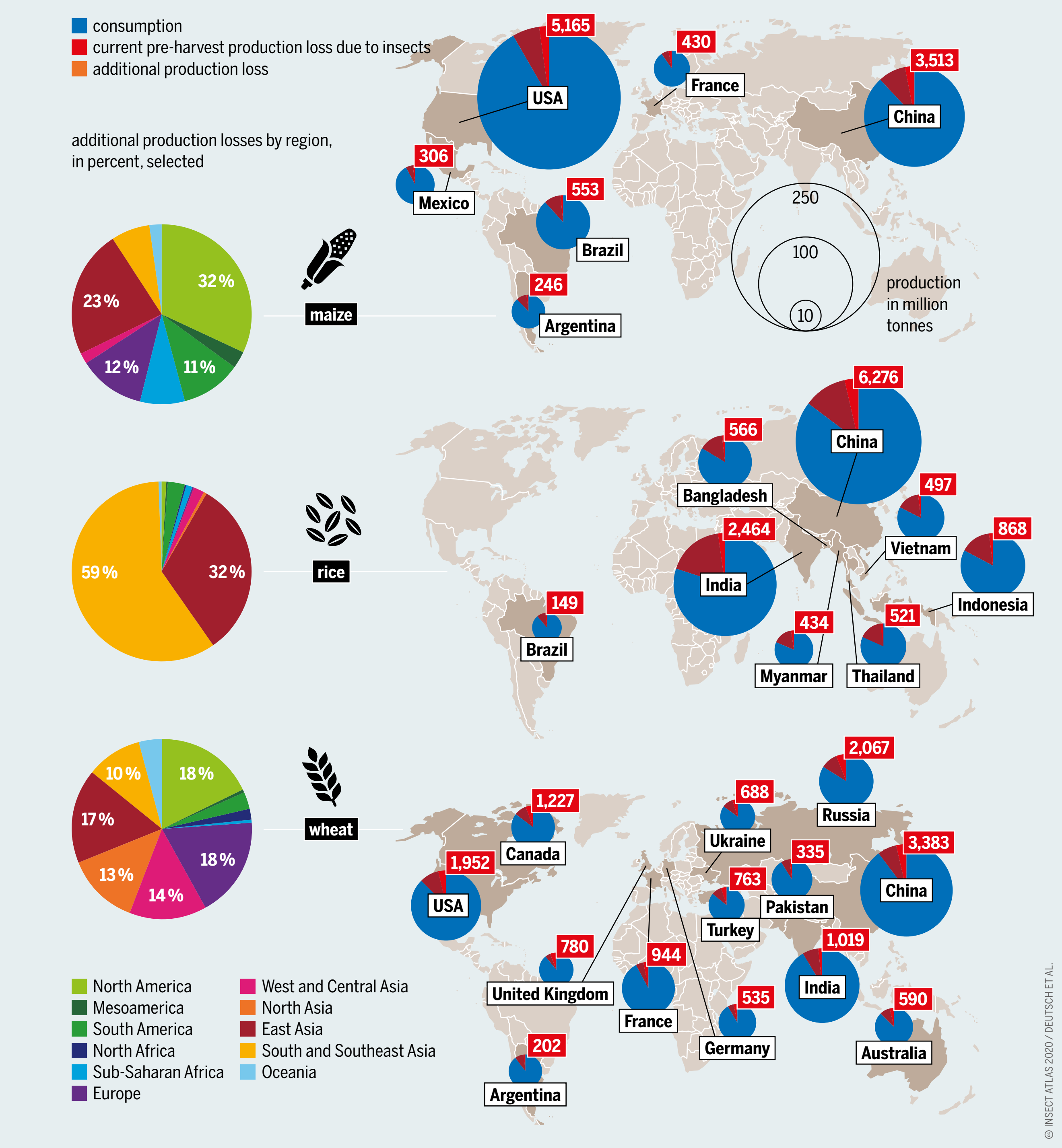
The main beneficiaries of climate change are thermophile (heat-loving), mobile insect species that are capable of thriving in a broad range of situations – the so-called habitat generalists. The losers are those species that are less mobile, that require damp or cool conditions, and that are therefore dependent on specific niches – the habitat specialists. The latter are limited in their response to climate change because of the scarcity of available habitat. Little research has been done on how the changing climate will affect these species and how this, in turn, will affect agricultural yields.

The expected yields of major crops have been calculated for various climate scenarios, but often without taking the crucial role of insects into account. A research team at the University of Seattle in the United States has calculated that harvests of rice, maize and wheat will decrease by between 10 and 25 percent per degree of global warming as a result of changes in insect populations. Such figures are alarming as these three staples together provide 42 per-

Female Roesel's bush-crickets normally have shorter wings than the males. But if they need to seek out new habitats, the wings of both sexes grow much longer

BIGGER APPETITES IN WARMER WEATHER

Predicted production losses of crops due to insect damage with a global temperature increase of 2 degrees Celsius, in 1,000 tonnes



cent of the calories consumed by humans worldwide.

Such crop losses are due to various causes. Climate change alters the relationship between pests and beneficial organisms. Climate stress reduces the tolerance of crop plants to pest attacks. Pollinators are also subject to the same stress. They become diseased more readily, and their populations shrink. And then there is the risk of non-simultaneity: climate change enables plants to flower earlier in the year, at a time when many insect pollinators are not yet active. But it is precisely at the start of the season that other pollinators are not available to make up for the usual species. Researchers at the University of Würzburg in Germany have discovered that the development of the pasqueflower, a wildflower that grows on calcareous grasslands but which is now rare, outpaces that of the bees that pollinate it. There is the risk that the first pasqueflower blooms will have died off before the bees that use them as food have had a chance to pollinate them. ●

With climate change, another 50 million tonnes of the three most important cereal crops could be lost to pest damage

MAINTAINING A BALANCE

To limit the damage that insect pests cause to crops, we call on their natural enemies – mostly other insects. Biological pest control is all the more successful if diversity is higher.

Cereals, potatoes and roses: all types of crops, vegetables and ornamental plants, in fields, greenhouses and gardens, may be attacked by insects. They gnaw away at leaves, stems and roots, suck out sap, and transmit diseases. They may cause huge losses in yields. For the three most important cereals – maize, rice and wheat – losses due to insects are estimated at between 5 and 20 percent worldwide, depending on the region and crop type. While the damage in Europe and North America tends to be lower, hotter regions in Africa and Asia are more seriously affected. Wheat is less vulnerable than maize or rice. In Nigeria, for example, maize famers suffer losses of up to 19 percent, while their counterparts in the United States lose only 6 percent of their crop. These figures may rise in the future: climate change may allow pests to reproduce more quickly in temperate areas. Plants that are stressed by heat are more susceptible to pests and diseases.

While some pests, such as aphids, whiteflies and thrips, attack many types of plants, others prefer only certain plant species. These plants lend their names to the insects that live on them: rape pollen beetles, Colorado potato beetles, European corn borers. These pests can cause huge damage, and may even wipe out a complete crop. Swarms of locusts repeatedly devastate huge areas: most recently in June 2019 on the Italian island of Sardinia, in 2017 in Bolivia, and in 2016 in Russia.

There are various ways to reduce the numbers of insect pests and keep damage to crops to a minimum. Integrated pest management, which is based on recommendations by the Food and Agriculture Organization of the United Nations (FAO) dating back to the 1960s, proposes combining prevention with control. It relies on natural mechanisms, for example by encouraging the natural enemies of the pests. Insecticides should be used only if the infestation has exceeded a threshold level. Even then, the use of chemical applications should be restricted to the minimum necessary amount. Integrated pest management is the guiding principle for crop protection worldwide and was enshrined in the European Union's crop-protection legislation in 2009.

To protect crops without resorting to pesticides, farmers use crop varieties that are adapted to the local climatic and soil conditions, plant them at the appropriate times and in various ways, and control pests by organic means. In line with the integrated pest management approach, they use beneficial insects – the natural enemies of the pests. A typical species of pest has between 10 and 15 natural enemies. These enemies eat the harmful insects, suck out their body juices, or parasitize them by laying their eggs on, or inside, them – which eventually kills the unfortunate host animals. Some of these natural enemies specialize on just one or only a few pest species; others can feed on a wide range of different insects.

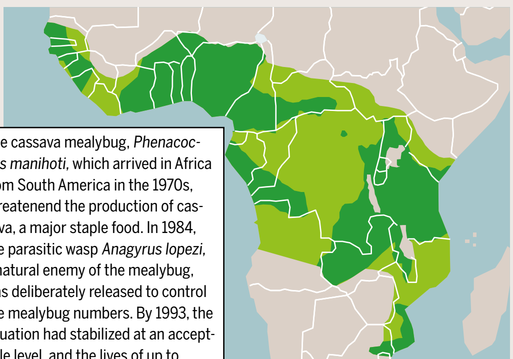
Ladybirds are among the best-known beneficial in-

Swiss entomologist Hans Rudolf Herren received a Right Livelihood Award, an "alternative Nobel Prize", in 2013 for his successful work to control mealybugs in Africa

HUNGER AVERTED

Cassava cultivation areas in Africa threatened by the cassava mealybug, 1981–1993

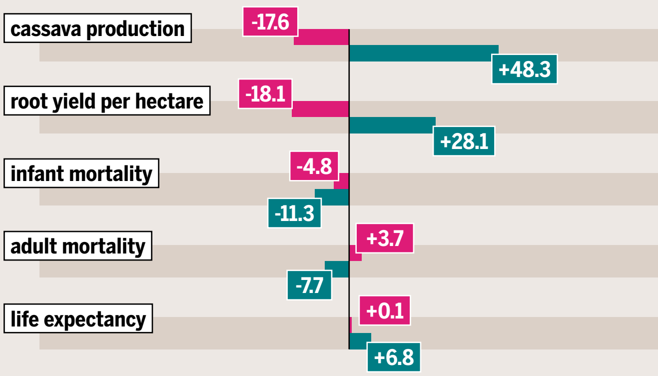
- release areas of parasitoid wasps to control mealybugs
- rapid spread of the wasps in remaining mealybug area

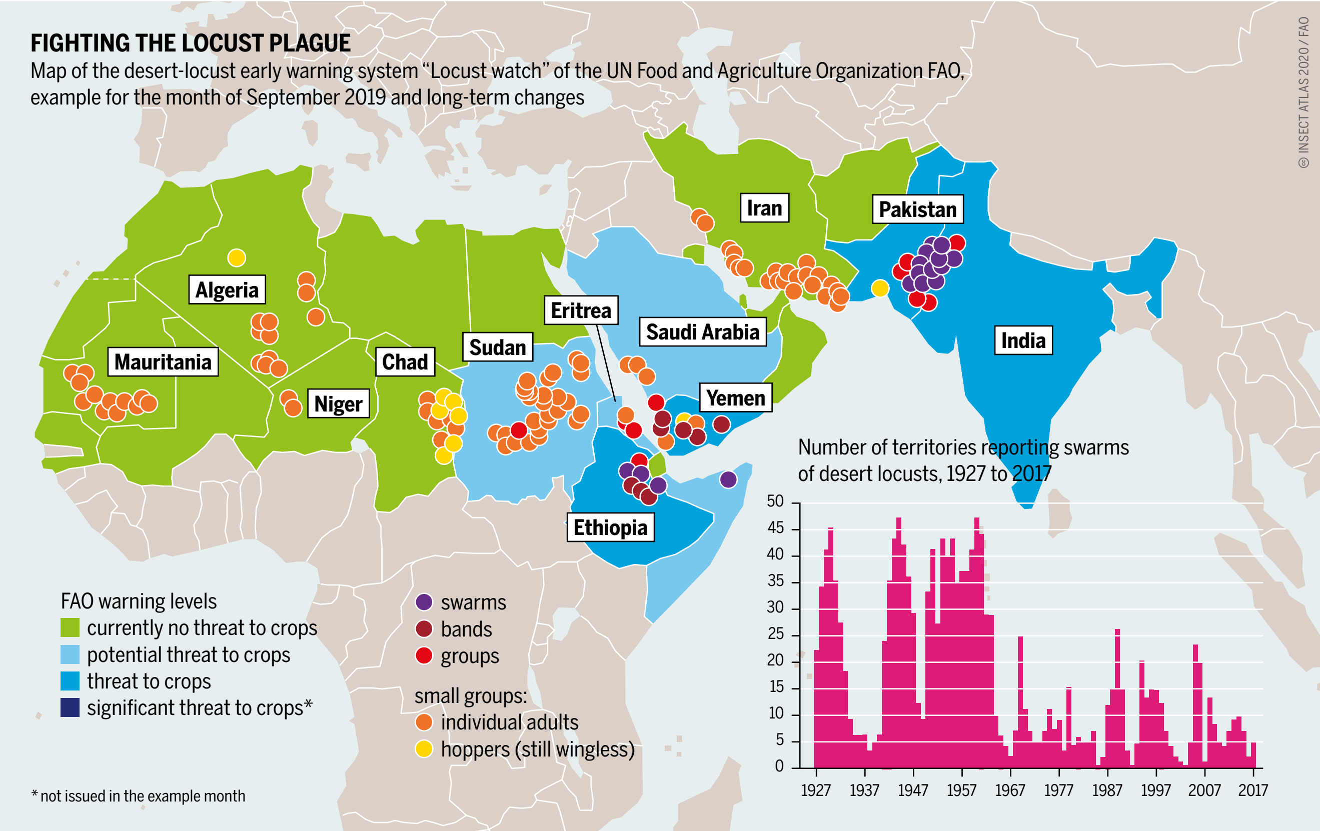


The cassava mealybug, *Phenacoccus manihoti*, which arrived in Africa from South America in the 1970s, threatenend the production of cassava, a major staple food. In 1984, the parasitic wasp *Anagyrus lopezi*, a natural enemy of the mealybug, was deliberately released to control the mealybug numbers. By 1993, the situation had stabilized at an acceptable level, and the lives of up to 20 million people had been saved.

Average effects on cassava production and demographics, 18 affected countries, 1981–1995, in percent

- after arrival of mealybugs
- after release of parasitic wasps





FIGHTING THE LOCUST PLAGUE
Map of the desert-locust early warning system "Locust watch" of the UN Food and Agriculture Organization FAO, example for the month of September 2019 and long-term changes

sects. Both the adults and the larvae are predators: they feed on aphids, leaf beetles, rape pollen beetles, whiteflies, potato beetles, and many other species. A single ladybird can consume around 50 aphids a day, or up to 40,000 in its lifetime. In 1888, the vedalia beetle, Rodolia cardinalis, an Australian ladybird, was introduced in California to control cotton cushion scale insects, a pest that was decimating citrus orchards. The introduction of this ladybird saved citrus cultivation in the United States.

In addition to predatory beetles, various species of bugs and flies eat large amounts of pests. A lacewing larva, for example, can consume up to 500 aphids during its 2- to 3-week lifespan. For this reason, they are often released in greenhouses. Many species of ichneumon wasps are valuable beneficials used in pest control. They parasitize eggs, larvae and adult insects.

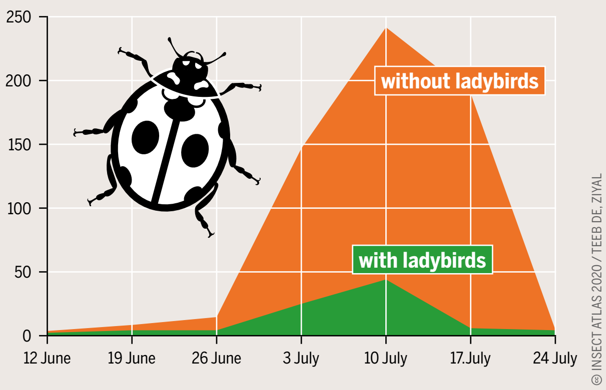
However, releasing beneficial insects in a field of crops is not enough. Field margins, conservation strips, hedges and other near-natural refuges are indispensable starting points for biological pest control. To encourage as wide a range of natural enemies as possible, a mix of newly established and existing landscape elements is necessary. Crop rotations and crop management that take the life cycles of the beneficials into account are also helpful. Part of the area should not be cultivated, and the soil should be worked sparingly, because many types of insects overwinter beneath the surface. To promote beneficial organisms adequately, ecologists recommend the creation and linking of near-natural habitats for at least 20 percent of all landscapes.

Biological control can protect crops and avoid the risks inherent in using agrochemicals – such as the development of resistance

Substances such as insect pheromones and neem oil can help control desert locusts. But insecticides must still be used to manage large swarms

Politicians are responsible for creating economic incentives for more nature-friendly land management, for adopting cross-regional agri-environmental and climate policies, and for prioritizing the availability of the funding. Individuals and communities can also promote beneficial insects and reduce pest populations, literally on their own doorsteps: by maintaining greater diversity in gardens and by providing nesting opportunities for insects, birds and bats.

USING INSECTS TO CONTROL INSECTS
Infestation of wheat with cereal aphids with and without ladybirds (*Coccinella septempunctata*), numbers of aphids per stem



COWPATS AND SHEEP DROPPINGS, NOT GRANULATE AND SLURRY

The number and types of beetles crawling over the dung of grazing animals, and of flies buzzing around it, indicate how intact or damaged an agricultural system is. Biodiversity often suffers from the application of too much artificial fertilizer and manure slurry.

Global crop production has tripled in the last 50 years. In the same period, the consumption of nitrogen fertilizer has grown tenfold. The worldwide use of fertilizers is, alongside practices such as artificial irrigation and pesticide use, a major feature of intensified farming. The introduction of nutrients such as nitrogen has numerous effects on ecosystems and so also on insects.

On grasslands – meadows and pastures, which are usually richer in insects than arable land – fertilization initially always leads to an impoverishment of plant species. The vegetative cover becomes denser, and competition for light squeezes out undergrowth plant types. Plant species that thrive on poor soils disappear because of the surfeit of nutrients. Insects that are adapted to these plants disappear too.

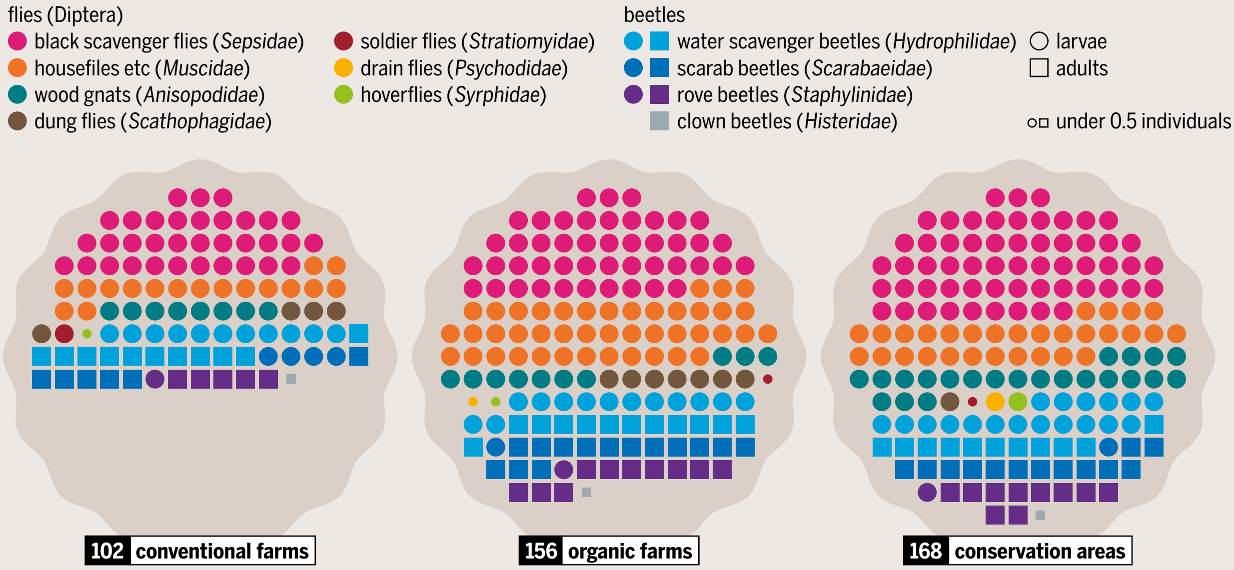
The fertilizer may be organic – such as stable manure, slurry, or fermentation by-products – or synthetic chemicals. Artificial fertilizers remain in the soil for only a short time. Forty percent of mineral nitrogen fertilizer is washed out in the form of nitrates, and a total of around 55 percent is released into the atmosphere as nitrogen, nitrous oxide or ammonia. Organic fertilizers, on the other hand, stay in the soil for longer and are an important source of food for insects that inhabit dung.

Nitrogen is an important resource for insects. They need nutrients for their growth and take nitrogen up through their food. As the nitrogen content of plant tissues and thus in the insects' food source increases, the insects become more successful at reproduction. But not all insects benefit. Specialists species that rely on plants in nutrient-poor locations are harmed by too much nitrogen. For example, some butterfly caterpillars die much more frequently if they grow on plants fertilized with nitrogen, than if they live on natural, unfertilized host plants. Experiments lasting over a period of more than 100 years at Rothamsted Research, an agricultural institute near London, found that fertilizer applications alone reduced the number of meadow plant species in grassland from thirty to just five. The number of plant-eating cicadas sank at the same time.

In pastures under conventional management, 40 percent fewer insects colonize cowpats than in protected grasslands

BREAKING UP ISN'T HARD TO DO

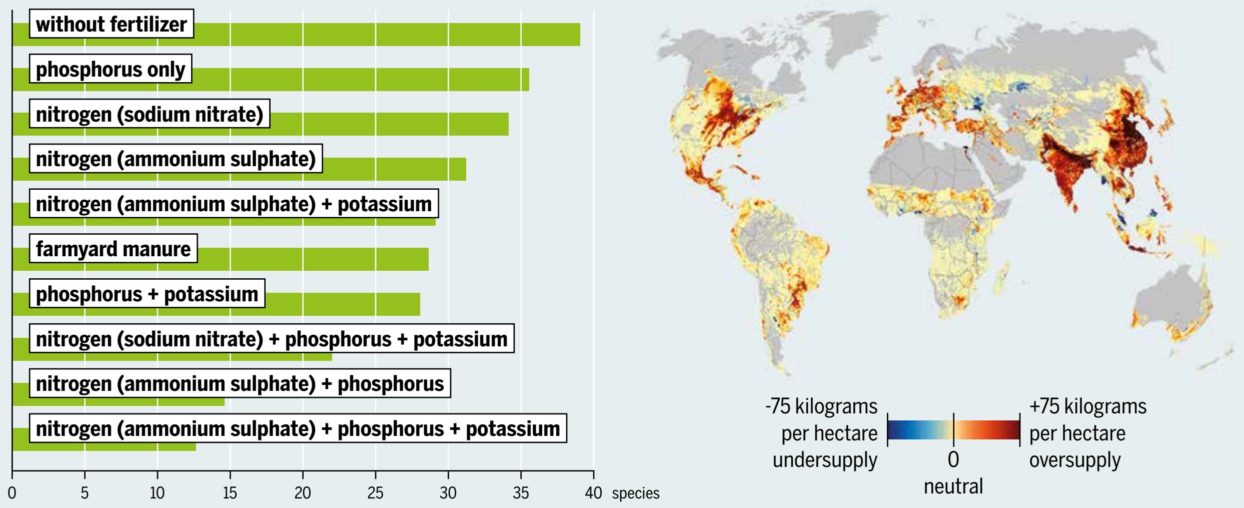
Insects in cowpats on pastures in three farming systems in the Netherlands, average numbers of individuals, rounded*



*12 cowpats, 10 days old, from similar cows on 8 conventional and 6 organic farms and 6 nature conservation areas with similar soils, all within 200 square kilometres

HIGHER YIELDS BUT LESS DIVERSITY

Global nitrogen balance and impoverishment of plant species through fertilization



An analysis of various experiments in Europe, North America and Asia shows that nitrogen fertilization can reduce the diversity of both plants and insects. The habitat specialists are often the first to disappear. They gain shelter, find suitable nourishment, and reproduce only in vegetation that is of little use to humans. On the other hand, heavy fertilizer applications can also lead to increases in the numbers and diversity of certain types of insect. In cropland this may take the form of more pest and disease attacks, which in turn leads to the use of even more pesticides. A combination of fertilizer and pesticide applications and frequent management practices such as ploughing may significantly reduce the diversity of insects in a field.

The effects of fertilizer on insects depends on the type, the application method and therefore also on the management system. Organic fertilizer such as stable manure is itself food for insects – something that cannot be said of artificial fertilizers. In extensive pastureland that is otherwise left to itself, the only fertilizer applied is the dung from the livestock that grazed there. While dung – and especially cowpats – host many types of insects, from dung beetles to flies, the pastureland itself is not automatically rich in insects. For this to happen, the vegetation cover must itself be species-rich, and not more than one cow should be grazed on each hectare.

If intensive fertilization results in nitrate or phosphate getting into surface water, these nutrients may pollute important insect habitats in the surrounding area. In a landscape with streams and standing water, the diversity of insects may decrease by up to 80 percent. Those that remain are an indicator of poor water quality: sugarfly and hoverfly larvae, along with microbial mats and sludge worms.

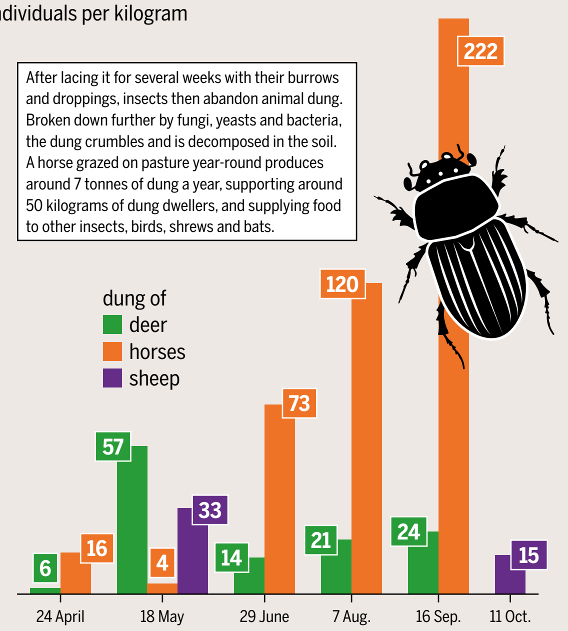
Beetles crawling around in manure show how nature-friendly grazing is. Interference, such as medication for digestive problems in livestock, immediately reduces their numbers

Overfertilization and lower plant species diversity lower the soil quality – in turn reducing the species richness of insects

The diversity of insects in agricultural landscapes is always especially high where many small fields that are used in different ways border each other. Heavily fertilized maize fields could be located next to less-intensively used areas. To promote diversity, though, the key factor is moderate levels of organic fertilizer with a generally extensive type of land use. ●

A MEAL OF MANURE

Dung beetles, including the scarab *Aphodius fimetarius*, in animal dung, spring to autumn, near Augsburg, Germany, individuals per kilogram



INSECTS AS FOOD

SNACKING ON SILKWORMS, LUNCHING ON LOCUSTS

Adding insects to our menus could help overcome the world's food-supply problems. But the industrial production of insects is controversial: would it be useful or dangerous?

Mealworm-protein bars, insectburgers and noodles made from insect flour: flip through lifestyle magazines and you might easily think that entomophagy – the consumption of insects – has arrived in Europe. But it is rather the mixture of newsworthiness, the exotic, and the "yuck factor" that make the consumption of insects such a popular media topic. In Europe, insects are not something the vast majority of people expect to see on their plates.

Things are different in much of the rest of the world. In over 130 countries and for an estimated 2 billion people, beetles, maggots and crickets are a traditional part of the everyday diet. Insects deliver valuable vitamins and minerals, along with lots of protein. Because a wide range of insects are available at different seasons, such a diet is always varied.

Companies that want to popularize insect-based foods in the West put forward convincing arguments: ecological, animal-protection, and above all, the high protein content of such foods. The number of these firms has risen sharply in recent years. The European Union's Novel Foods Regulation of 2015 created the conditions that permit the use of individual insect species as food from the start of 2018. In doing so, it follows the lead of the Food and Agriculture Organization of the United Nations (FAO), which for the past ten years has promoted the idea of using insects as a major food source so as to feed the world's growing human population. For the time being, only four insect species are permitted in the EU: mealworms (*Tenebrio molitor*), lesser mealworms (*Alphitobius diaperinus*), house crickets (*Acheta domesticus*) and migratory locusts (*Locusta migratoria*). Further applications were made in 2019, for instance for the larvae of the black soldier fly (*Hermetia illucens*).

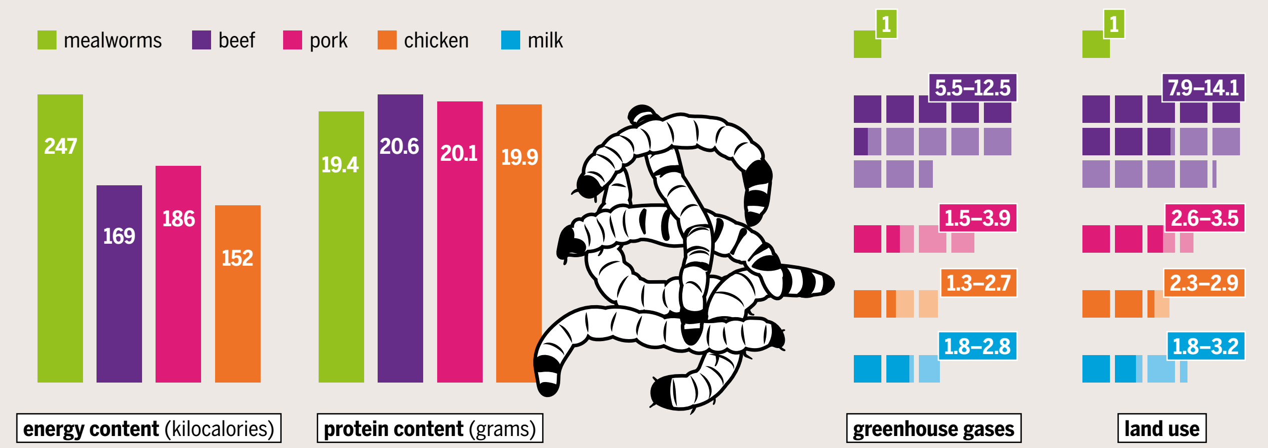
From an evolutionary point of view, insects are one of humanity's oldest sources of protein. A large number of insect species are potentially very valuable foods, though their protein content and the amount of vitamins, unsaturated fatty acids (omega 3 and 6) and minerals they contain varies considerably according to the species, feeding and stage in the life cycle (egg, larva, pupa or adult).

In western industrialized countries it is mainly small start-ups that are trying to establish themselves on the market with the first, relatively expensive, insect-based products. These firms hope to cut their costs and boost their sales through more efficient breeding methods and industrial-style production techniques. The authors of a study by Barclays, a British bank, predict that the "insect protein market" in Europe and North America might be worth as much as 8 billion US dollars by 2030, making it attractive

Unknown to consumers, most mealworms that are raised for human consumption in Europe are made into flour

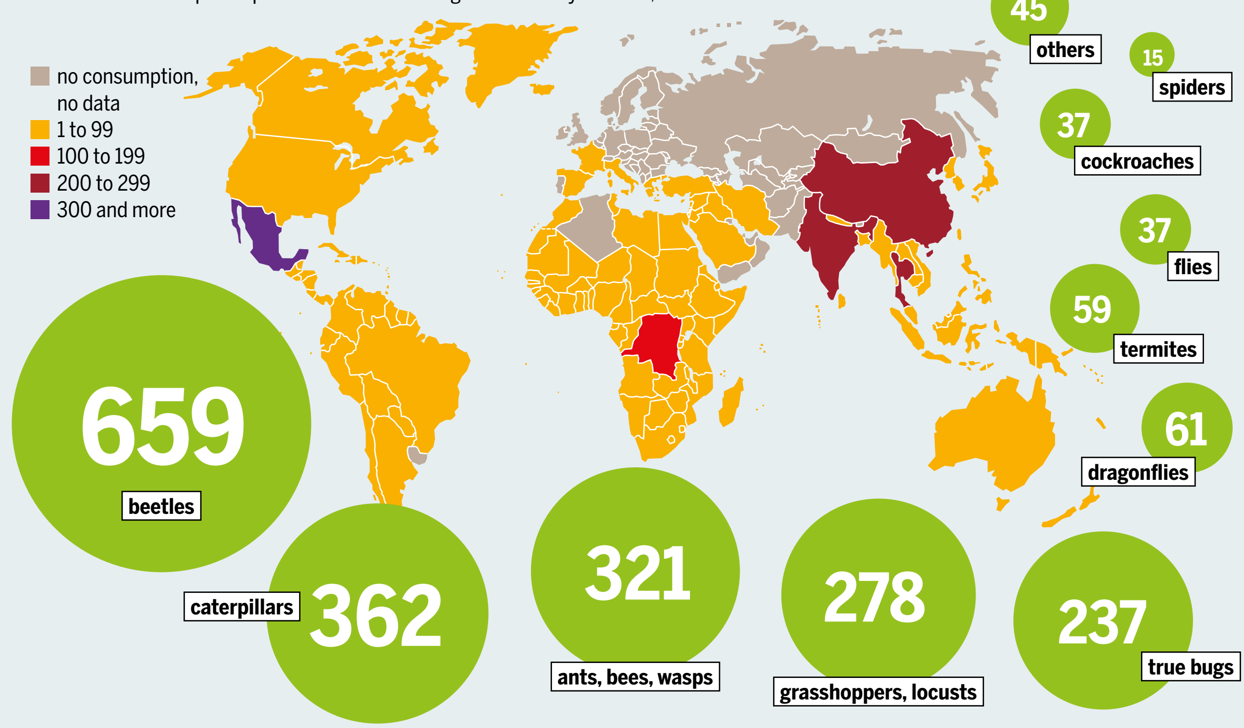
FOOD FOR THOUGHT

Larvae of the mealworm beetle (*Tenebrio molitor*) compared to other animal-based foods, nutrients per 100 grams, and environmental comparison as a multiple of the impact of mealworms, comparative value: protein



GRILLED, BOILED OR STEAMED

Number of insect and spider species recorded as being consumed by humans, 2017



Eating insects is commonplace throughout the world. But in a few places, especially in Europe, it is taboo

for large food manufacturers.

Unlike the situation in Asia, Africa and South and Central America, entomophagy in Europe and North America is rarely seen from a culinary point of view. The target consumers in Europe are mainly people who want to avoid eating meat or consuming other animal products for ecological or ethical reasons. In contrast to the slaughter of cattle or pigs, cold-blooded insects are chilled so they fall into a natural torpor and die without experiencing pain or stress.

At the same time, most species of insects can be raised en masse in factories. Breeding insects requires less space, feed, water and energy than traditional livestock-keeping – at least in theory. In practice, there is a shortage of empirical data, even in countries where insects are a regular part of the menu. There, most of the insects consumed are caught from the wild. Insects are indeed bred in China, Southeast Asia and southern Africa, but the proportion of farm insects accounts for only two percent.

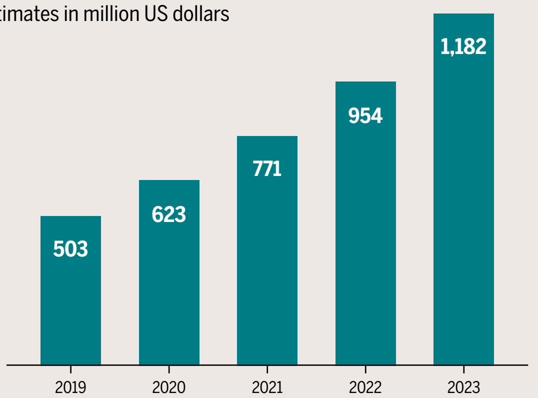
Most insect farms in Asia are run by small-scale farmers. Their experience is often not applicable to European conditions. They often do not raise their mini-livestock in enclosed facilities, but rely instead on the local climatic conditions and on ecosystems such as mangroves. That is especially true for many beetles and larvae that are of greater culinary interest than the species currently approved for consumption in Europe. Examples are the deep-fried water beetles regarded as a delicacy in northern Thailand, and the eggs of waterbugs, sold in Central and South America as "Mexican caviar".

The demand for edible insects is rising, and there is a danger of overstretching natural populations, causing a collapse in numbers, as has happened with overfishing in the oceans. It is also questionable whether the global hunger for insects can be satisfied by industrialized farming. And experts warn that raising insects could repeat the same mistakes as with pigs, chickens and cattle, which have led to the loss of genetic diversity and the emergence of unexpected diseases that can destroy entire stocks. ●

Market researchers expect the turnover of edible insects to double in value in just five years

BIG MONEY FROM SMALL CREATURES

Forecast market value of edible insects worldwide, estimates in million US dollars



ROOTING FOR GRUBS

In economic terms, livestock feed made from insects is still a rarity. If it can be used to fatten chickens and pigs, the market will take off. The environmental sustainability is a different question.

Their high protein and fat content make insects a major food source for many animal species. Chickens scratching around in the ground for worms and maggots are a characteristic symbol of traditional farming. Even though modern management systems in the industrial world seldom permit it, it is in the nature of poultry and pigs to scrabble around in search of insects.

In rural parts of Africa and Asia, though, animals are often still kept in such a way that they look for their own food. And farmers also feed their chickens with the termites and grasshoppers that they have harvested from the wild. They also set out baskets filled with materials that attract termites. A few weeks later, when the insects have colonized the baskets, the farmer can collect them to use as feed.

In modern industrial animal husbandry, livestock are fed with mixtures that contain protein in the form of fishmeal and soybeans. One-quarter of the global fish catch is processed to make fishmeal and oil to be fed to livestock – although most of the fish are actually suitable for human consumption. That is hard to justify: large parts of the world's oceans are drastically overfished, and the diets of more than one-third of the world's population depend on fish. The production of soya, much of which is imported in the EU from South America and the United States, also has far-reaching negative ecological and social consequences.

Interest in insects as a potentially sustainable alternative source of protein for industrial animal husbandry has been growing in both science and business. In Africa, raising insects tends to be rural and small-scale, so makes ecological and economic sense. In Asia and Europe, on the other hand, various initiatives are raising insects on an industrial scale. It is nevertheless questionable whether insects will be able to make a substantial contribution to animal-feed production. The economic profitability and ecological advisability of doing so have not been resolved either. And feeding insects to livestock for ecological reasons would only marginally improve the serious ecological damage caused by industrial animal husbandry.

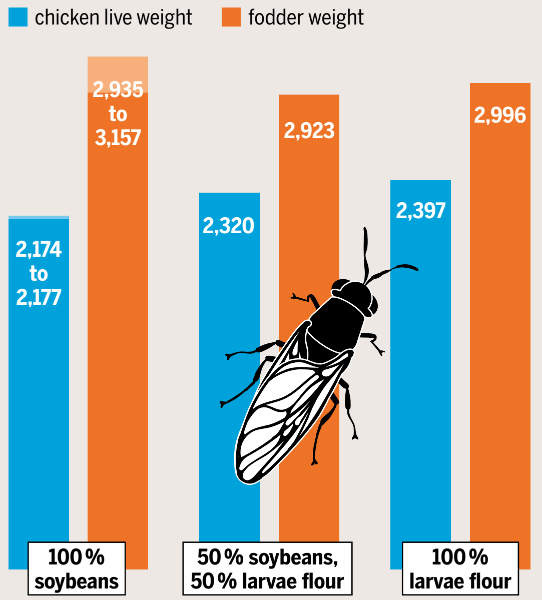
At present, using insects as feed in industrial livestock production is only partly profitable. One reason is that insects are considered to be livestock in the European Union, and may therefore only be fed to pets or to farmed fish. This is because insect meal comes under the same regulations as meat-and-bone meal, which was banned for use as livestock feed after it emerged that feeding infected meal to cattle led to the fatal bovine spongiform encephalopathy, or mad cow disease. Several hundred people died of variant Creutzfeldt–Jakob disease after consuming contaminated beef. Some insect lobbyists now demand that feeding insects to poultry and pigs be permitted because these animals are omnivores, and insects are a natural component of their diets.

The economic and ecological benefits of using insects as livestock feed also depend on which insect species are used, and how they are fed and raised. If they are raised on materials that are otherwise difficult or impossible to use – such as agricultural waste – this could have a positive effect on sustainability and productivity. But because the European Union regards insects as livestock, they may not be fed with food waste, because this may contain animal ingredients. In any case, not nearly enough food waste is available. However, the use of insects might bring additional benefits if they significantly reduce the volume of various types of organic waste, cut the health hazards due to bacteria and viruses in waste, or upgrade food waste to valuable materials that are suitable for use as feed.

Insect species that reproduce easily and whose larvae live naturally in organic materials, in waste and in animal and human excrement are suitable for breeding. An example is the black soldier fly. Its larvae can convert organic waste efficiently into its own body tissues. The larvae con-

BETTER THAN BEANS

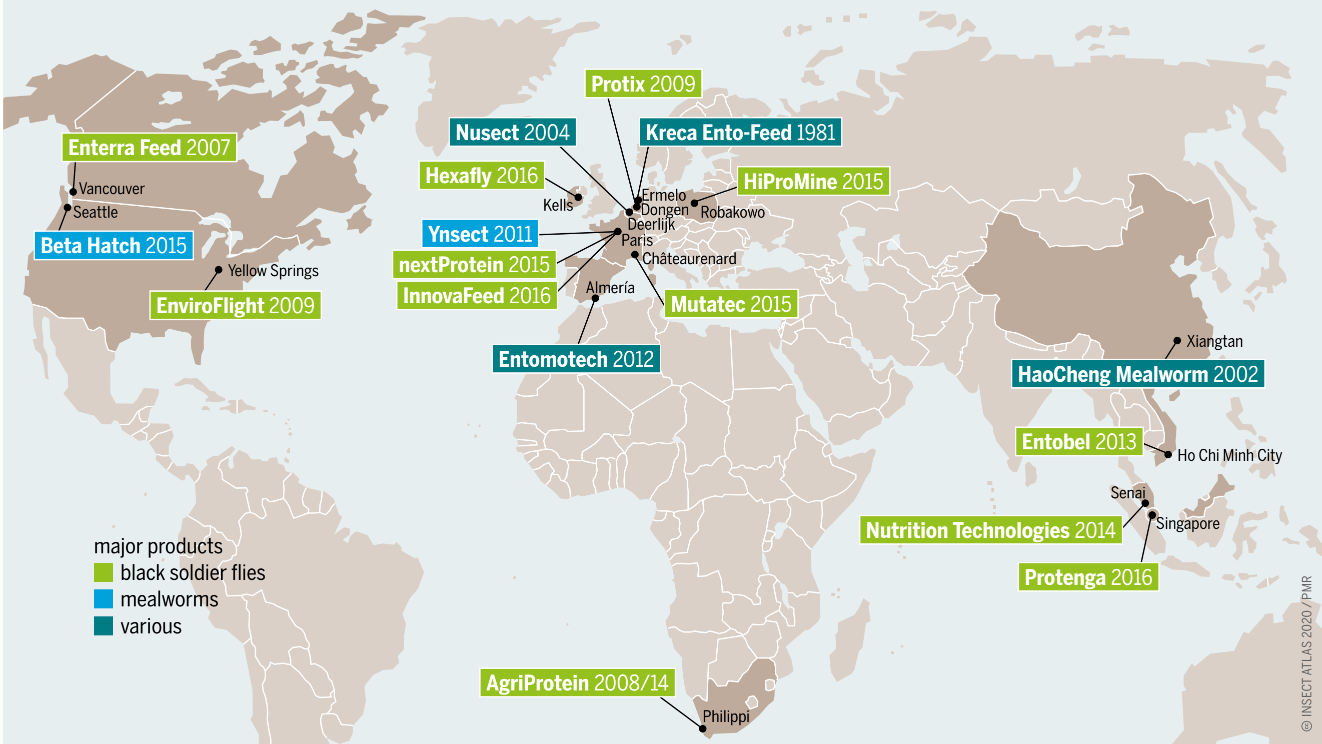
Soybean meal extract and ground larvae of black soldier flies (*Hermetia illucens*) in comparison: weight and fodder consumption of a broiler chicken over 34 days, in grams



The growers who make flour from maggots praise their product as being environmentally friendly. But using it as feed does not make battery chickens "ecologically produced"

THE LONG-LIVED AND THE NEWLY HATCHED

Major producers of livestock feed from insects, company headquarters and year founded, by major products, selected, 2019



Companies around the world are tinkering with their production processes to make fodder insects cheaper to produce than soybeans or fishmeal

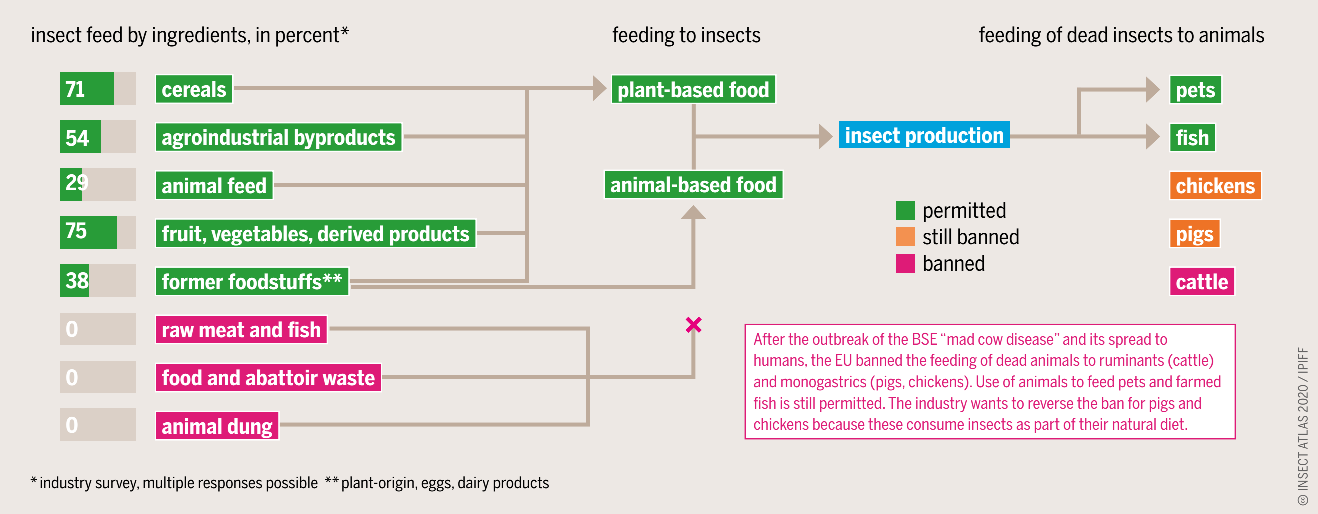
tain protein that is very high quality in terms of nutritional physiology and that could be used to replace the fish meal used in fish farming, as well as the soya used in poultry and pig-raising.

But there is still a lack of research, experience and debate. For example, breeds must be evaluated in terms of their sustainability. The potential use of residual products such as the insects' excreta must also be explored. The ethical aspects of breeding must also be evaluated, as well as the risks involved if insects from breeding facilities escape into the wider environment. Only if these and other questions, such as the suitability of insects as a feed substitute and potential threats to the ecosystem, find positive answers will it be possible to say that insects are a sustainable source of animal feed. ●

After the authorities' sloppy handling of mad cow disease, the risks of using dead insects as animal feed are being examined especially intensively

FEED FOR INSECTS, INSECTS AS FEED

How waste can turn into meat



BEEKEEPING

HONEY FOR HUMANS, POLLEN FOR PLANTS

Honeybees produce honey, beeswax and royal jelly, earn money for beekeepers, and pollinate a wide range of crops. But many types of wild bees are endangered – and we know little about many species.

For thousands of years, humans have savoured the sweetness of honey and valued it as a healthy food. Of about 20,000 bee species, just seven are significantly relevant for honey production. By far the most important is the western or European honeybee, Apis mellifera. In the wild, these bees nest in tree hollows.

Humans offer them alternative residences in the form of a hive specially tailored to their needs. The insects readily take to such quarters, especially as beekeepers provide extra protection from the elements and from natural enemies. In return, the beekeepers benefit from the insects' labour. Removable frames make it easy to remove the wax combs that contain the honey without destroying the entire hive. But despite the care and attention lavished upon them, bees are still wild animals: they can be considered semi-domesticated at best.

Honey is an important economic product: 1.6 million tonnes are produced worldwide each year, of which 300,000 are traded internationally – tendency rising. The European Union is the biggest consumer, accounting for 200,000 tonnes of imports a year.

The world's biggest honey producer is China, with an annual harvest of 500,000 tonnes. The European Union comes second. The 600,000 beekeepers in the EU maintain around 17 million hives and produce more than 230,000 tonnes of honey a year. Turkey comes next, with over 100,000 tonnes a year. Mexico, Russia, the United States, Argentina and Ukraine are also significant producers.

Honey is not the only economically important natural product that bees make. They build their nests and honeycombs out of wax, which has a wide variety of uses, from batik printing in Southeast Asia to candles for the Catholic Church. Bees also produce propolis, a resin that they use to seal gaps in the hive; it is said to have medicinal properties. The same is true of the pollen that bees gather from flowers and the royal jelly, a nutrient juice they make to feed the queen. Although their medicinal benefits have not been scientifically proven, these products are still very popular and are sold in health-food shops.

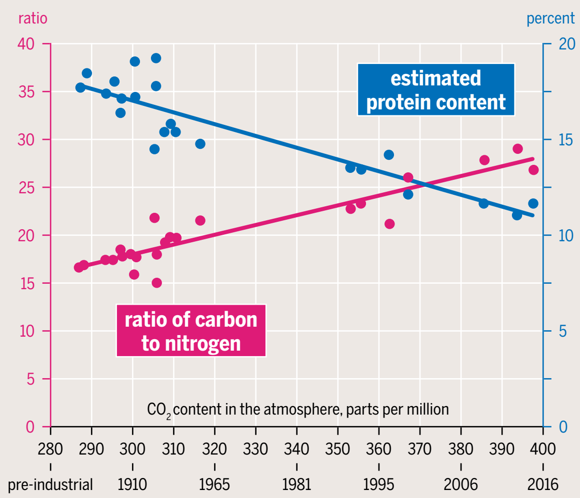
The real economic value of beekeeping is in fact a side-effect of honey production. It is only thanks to the pollination done by bees that many crops can be grown. The list is long: almonds, apples, asparagus, broccoli, carrots, cauliflower, cherries, cucumbers, melons, nuts, onions, peaches, pumpkins and strawberries, to name just a few. In many types of cereals and in grapes, beets and olives, pollination by bees results in a significant increase in yields. In the EU, 84 percent of crop species and thus 76 percent of food production depends on bees. That corresponds to an economic value of 14.2 billion euros a year.

Because hives are easy to transport and bee colonies are easy to relocate, migratory beekeeping has become common in some areas. That allows the bees to do their job where they are currently needed and where the climate is favourable. Migratory beekeepers in the United States cover particularly long distances. In the winter, they load their hives onto big lorries and drive from the northern states or the Midwest to California, where they set up their hives in orange groves that are coming into blossom.

In the developing world too, bees have a positive influ-

WARMER BUT WEAKER

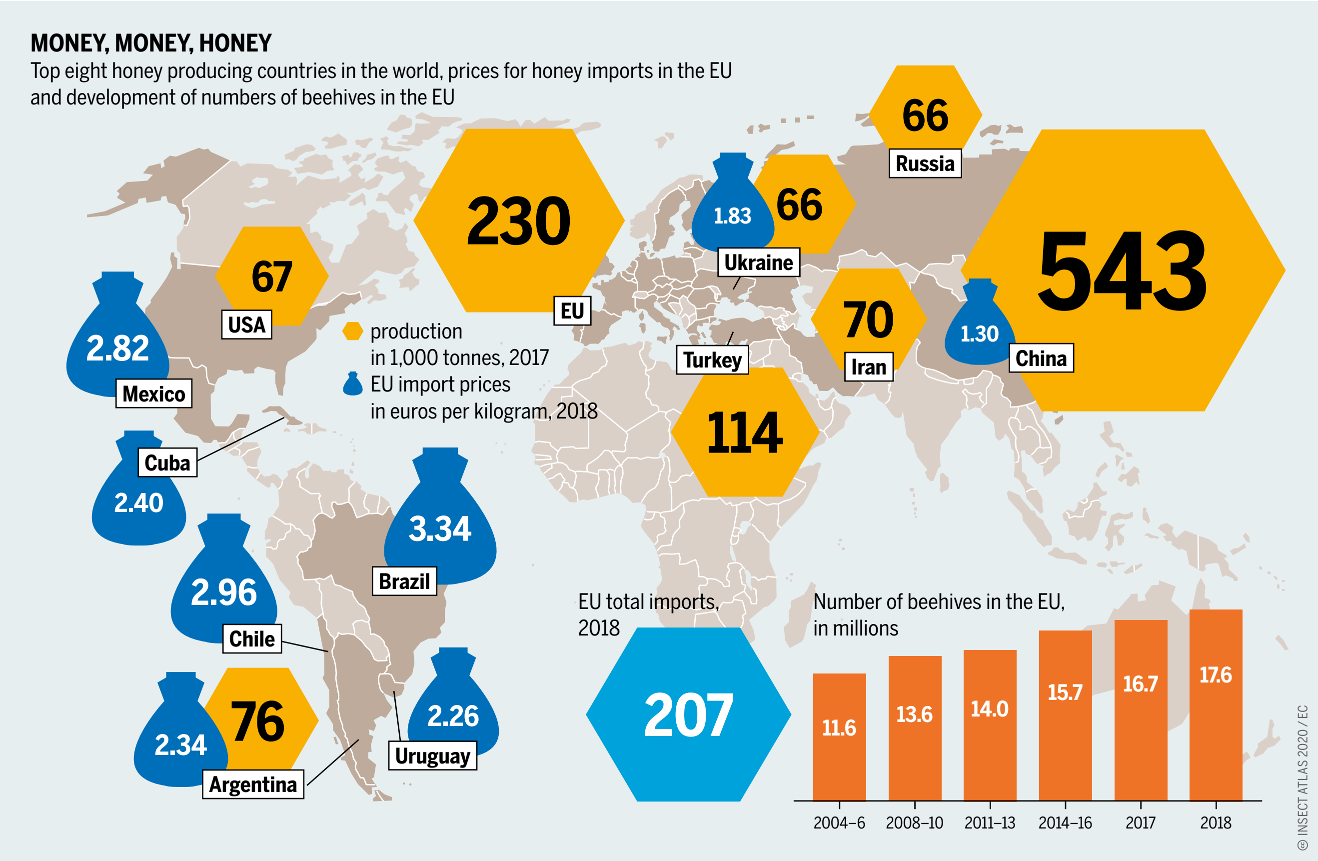
Protein content and carbon: nitrogen ratio in pollen of the Canada goldenrod as a fodder plant of North American honeybees



The pollen of the autumn-flowering Canada goldenrod is a vital source of food that enables bees to survive through the winter. An analysis of goldenrod pollen collected between 1842 und 2014 shows that as CO_2 levels in the atmosphere have risen, so too has the level of carbon compared to nitrogen in the pollen. The protein content of the pollen has fallen accordingly. The loss of one-third of the original quantity of protein can fatally weaken the bees.

Findings for bumblebees *(Bombus spp.)* are similar

Poorly fed bees are more affected by environmental stress. They are more susceptible to diseases and parasites, and they break down pesticides more slowly



A comparison shows the price advantage of honey from China – and hence the widespread mistrust about honey production there

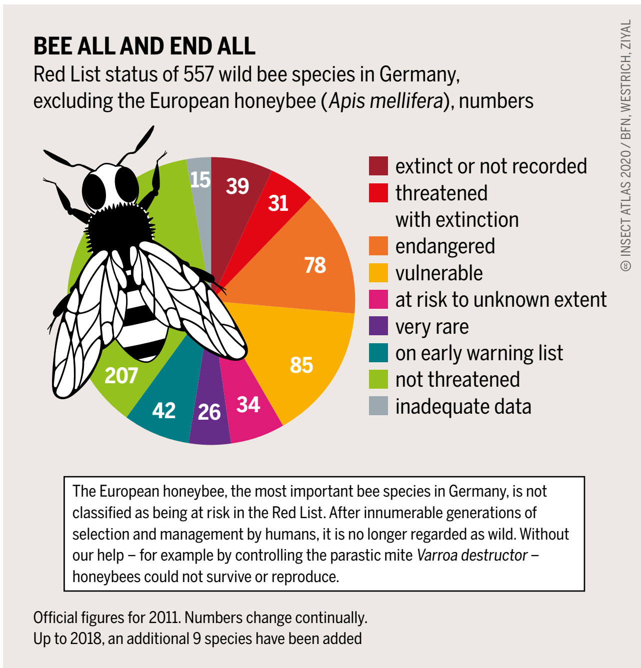
ence. Along with other pollinators, they provide for significantly higher yields in smallholder farms. A field may produce up to one-quarter more yield after these industrious insects have done their work. In this way, bees make a major contribution to global food security, as over two billion people are directly dependent on the output of smallholdings.

Beekeeping is not only extremely useful for local ecosystems; it can provide a significant source of income, especially for rural populations in developing countries. It is an attractive option because it requires relatively little investment and few technical inputs. And since it takes up very little space, honey production a good source of income for women, who are much less likely than men to own land. Beekeeping is also less dependent on the weather than many other branches of agriculture.

Beekeeping is systematically promoted by the Food and Agriculture Organization of the United Nations and by non-government organizations such as Bees for Development. In countries where beekeeping is not yet widespread, interested beginners can obtain a starter kit of hives, protective clothing and beekeeping equipment, along with the necessary expertise. This approach has helped establish or extend beekeeping in many parts of Africa, Asia and Latin America, thus supporting the local economy there.

One example is Somalia, where smallholders, on the whole, traditionally rely on grazing livestock. But the honey produced by a full-time beekeeper with 150 hives can bring in the same income as a herd of 530 goats. A Somali saying is descriptive: someone who is passionately devoted to something and knows a lot about it was "born with a bee.

The 2011 Red List of endangered species classified around half of all Germany's bee species as being in some way at risk



BEES IN SOUTHEAST ASIA

CLIMBING TREES TO HARVEST GOLD

In Europe, we are accustomed to bees that nest in hives, making it easy to harvest the honey. In Southeast Asia, the bee species are different: honey hunters must climb trees to cut down the combs of wild bee species. Even these bees are threatened by modern farming methods.

Among the nine honeybee species known worldwide, only one is native to Europe and Africa. The other eight species are native to Asia, and all are present in Southeast Asia. Asian native honeybee species can be divided into three groups based on their morphology, and the structure and location of their nests. Giant honeybees build a massive single comb suspended beneath a branch or cliff overhang. Medium-sized honeybees build parallel combs inside a cavity. Dwarf honeybees build a single comb around a twig.

Asian honeybees have the unique characteristic of moving their nest in response to changes such as the flowering seasons. These migrations may cover just a few kilometres, or hundreds. Some bee species migrate to higher altitudes in the rainy season and to lower altitudes in the dry season, or avoid harsh winter weather by migrating downhill. Colonies of the giant honeybees Apis dorsata travel up to a distance of 200 km during their seasonal migrations.

Agricultural yields in Southeast Asia can be maximized in terms of both quantity and quality by abundant and diverse populations of pollinators. Having several native honeybee species is an asset for agriculture. The productivity of 70 percent of the 1,330 tropical crops is increased by pollinators (mainly, but not exclusively, bees). The latest data (from 2009) calculates the economic value of insect pollination at around 700 million US dollars for the Philippines and 1.76 billion US dollars for Vietnam. In addition, people with low incomes in the region depend heavily on crops pollinated by animals to supply them with key nutrients. Feral colonies of Southeast Asian native honeybees are particularly beneficial for crops grown on small-scale farms because the bees can find nesting sites and additional food sources on neighbouring land.

Even though none of the eight native honeybee species seems to be threatened with extinction in the short term, studies highlight the decline throughout the whole region. Thai and Vietnamese researchers mentioned the decline of Apis Andreniformis in Thailand and Vietnam, and the species is also rare in Cambodia. In Malaysia, Apis koschevnikovi is decreasing. The Vietnamese population of Apis laboriosa has undergone a dramatic loss since its discovery in 1996, and Apis dorsata has also strongly declined in extended areas of Cambodia, Indonesia, Thailand and Vietnam.

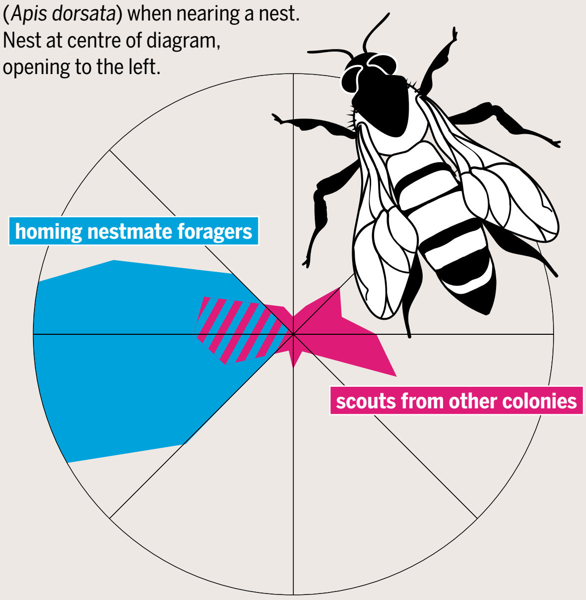
Deforestation and large-scale monoculture constitute the main threats to honeybee populations because they deprive bees of nesting sites and flowers to visit, and may also disturb their natural migration patterns. Southeast Asia is among the world's major deforestation hotspots. Between 1990 and 2010, 33.2 million hectares of forest were lost in the region, a decline of 12 percent. A large part of the land has been converted into oil palm plantations with a very low bee density compared to undisturbed forests.

Pesticides, in particular systemic insecticides, are an additional threat to the bees. Thai bee researchers consider pesticides to be the main factors affecting beekeeping in Thailand. Pesticide treatments in commercial fruit crops that are highly attractive to bees, such as longan, litchi and citrus, or that make ideal nesting sites for dwarf bees, like mangosteen and rambutan, are particularly harmful.

"Honey hunting" is another risk. The collection of wild honey generates income for tens of thousands of honey hunters throughout Southeast Asia, mostly members of the poorest communities. Nearly all the Asian native honey-

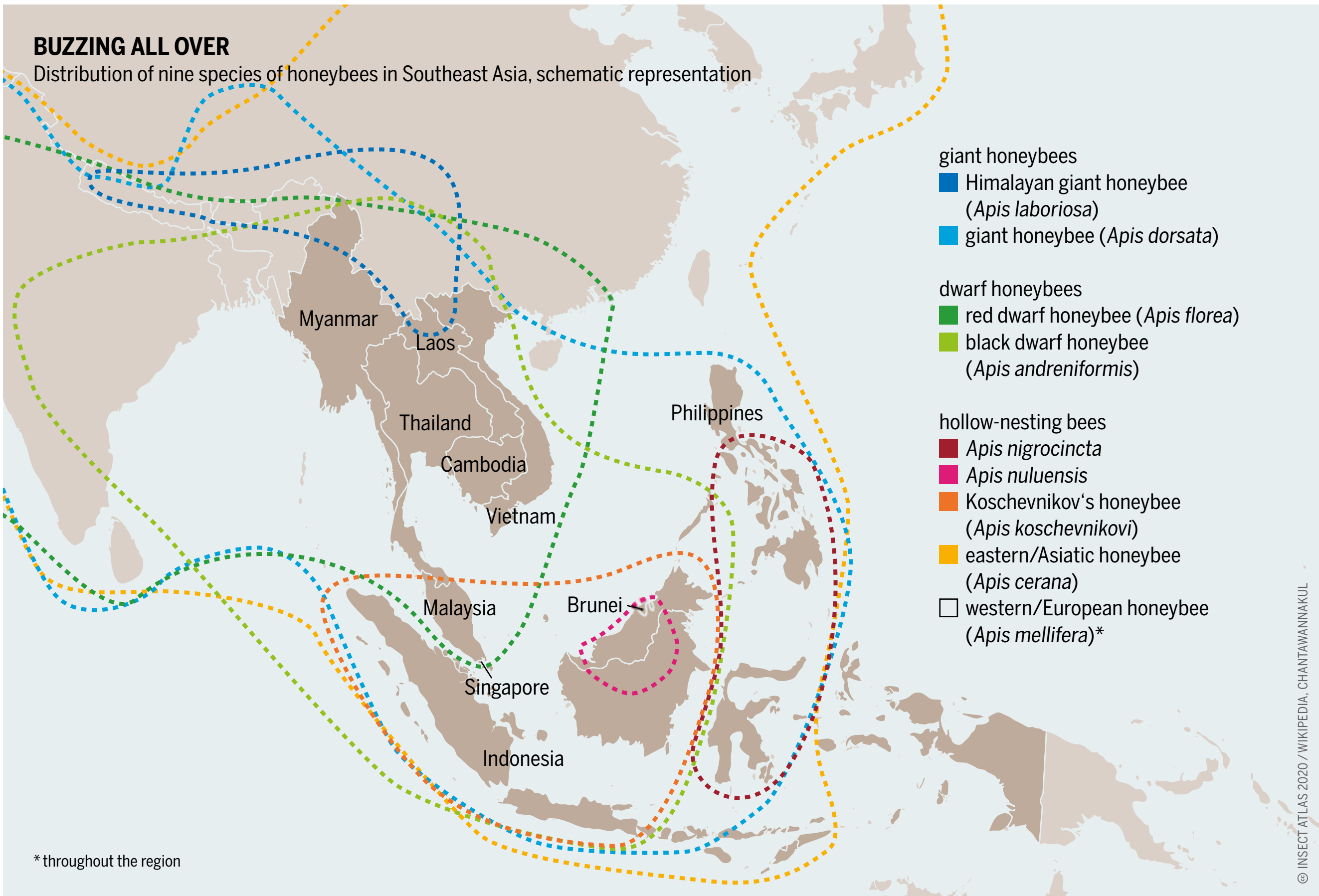
THE FLIGHT OF THE GIANT HONEYBEE

Approach paths of the Southeast Asian giant honeybee (*Apis dorsata*) when nearing a nest. Nest at centre of diagram, opening to the left.



The nests of the Southeast Asian giant honeybee (*Apis dorsata*) are located not in beehives but hang under branches or specially positioned rafters where they are easy for people to reach. The honeycombs are guarded by a protective layer of worker bees. Depending on the temperature, rainfall and location of flowers, the bees may move their nest site one or several times a year. Scout bees go out in search of a new site, and often come close – too close – to other swarms. If a scout lands on another nest, the worker bees there respond quickly – after a reaction time of just 40 milliseconds, several guards arrive and sting the perceived intruder to death. The alarm signals seem to be the erratic flight patterns of the scouts, which do not know the best way into the nest, and that the workers associate with the intruder once it has landed.

Defending their nests against wasps and birds is vital for bees that have free-hanging nests. They use their stings to keep other swarms of their own species away

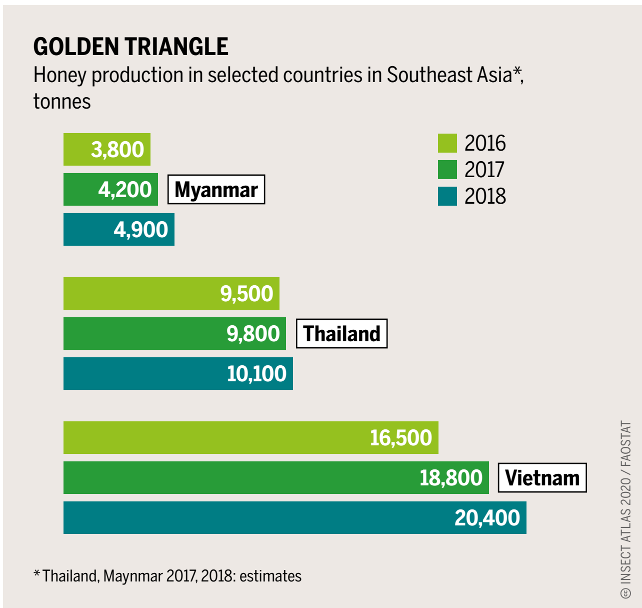


Their nests hang on rocks, branches and twigs, or are hidden in hollow trees and in beehives – all species of honeybees are found in Southeast Asia

bee species are hunted, though at different levels of intensity. The two giant species are the most commonly hunted due to the amount of honey they produce, along with the red dwarf honeybee, Apis florea, whose docile behaviour makes it an easy target. Over-harvesting and destructive honey-hunting practices, in which villagers cut the whole nests or sometimes even use fire and insecticides to reach the honey, also put pressure on wild bee populations.

Colonies can survive the destruction of their nest, provided the queen has not been killed. They rebuild a new nest a little further away, but the loss of their food stock and brood reduces their ability to swarm. Non-destructive honey harvesting methods, in which only part of the honey is harvested while leaving the brood intact, should be encouraged. Populations should be monitored to ensure that the level of harvest is compatible with sustainable management. Rafter beekeeping, a sustainable bee-management method developed by several communities throughout Southeast Asia, could be introduced to communities unfamiliar with the method.

Local initiatives contribute to the protection and restoration of Southeast Asian bee populations. By encouraging small-scale organic farming, the Agroecology Learning Alliance in South East Asia helps restore bee-friendly habitats in rural communities in Cambodia, Laos, Myanmar and Vietnam. The Non-Timber Forest Products Exchange Programme, a network of NGOs, promotes sustainable honey harvesting techniques as part of forest conservation throughout the region. Local initiatives to encourage sustainable beekeeping contribute to the restoration of local cavity-nesting bee populations and encourage hunters to refrain from destructive honey collection. ●



Exports are stimulating honey production in Southeast Asia. The biggest demand comes from Indonesia

GENDER

MICROLIVESTOCK AGAINST POVERTY

In poor countries, women can earn extra money by collecting, processing and selling nutritious insects. But harvesting too many can threaten sustainability.

In 2018, more than 821 million people around the world went hungry, and the diets of many others did not contain enough of the most important nutrients. Women in rural areas in developing countries are especially prone to undernourishment and lack important nutrients because so many of them earn less than men. Male-dominated social norms as well as inequality in marriage and inheritance laws restrict women's access to land, information, capital and credit, making it harder for them to manage their farms and grow enough food.

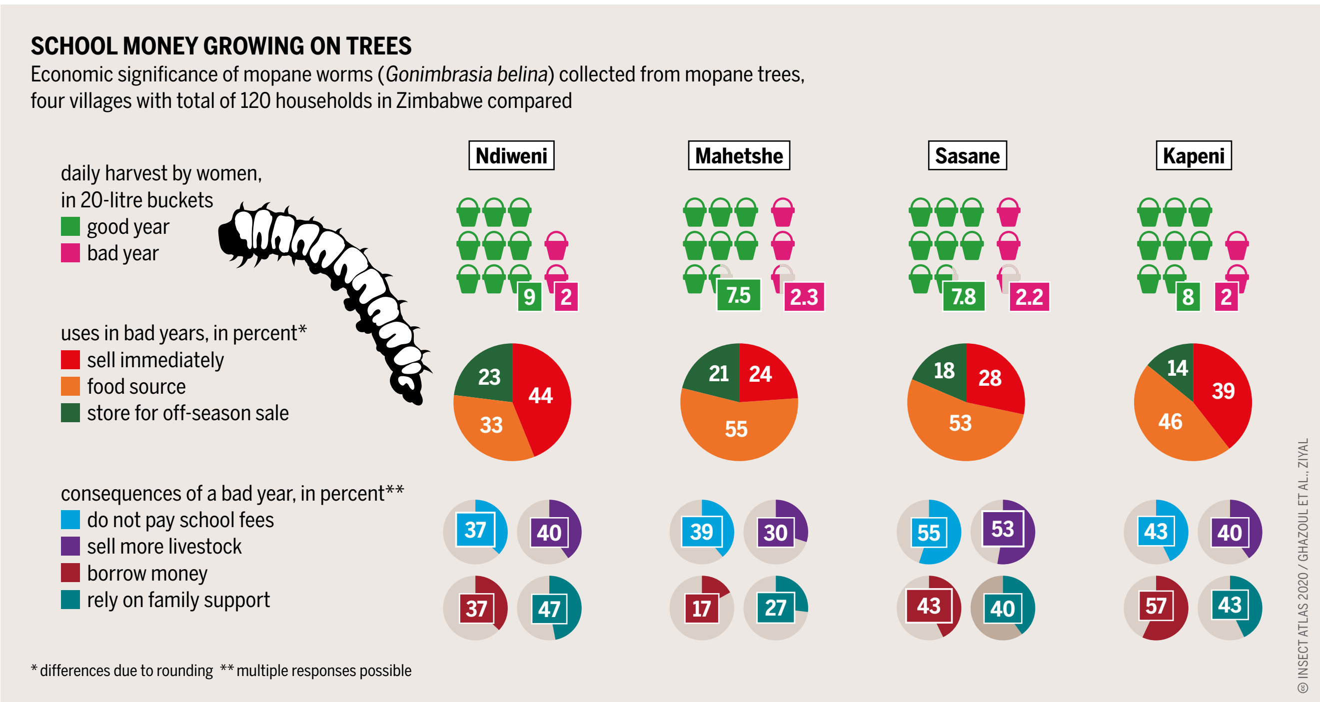
A 2013 report by the Food and Agriculture Organization of the United Nations pointed out that raising and marketing edible insects offers opportunities, especially to poor women, to improve their income and nutritional status. Compared with other more conventional livestock, less land, water, feed and labour are required to produce food from insects – furthermore, they contain similar nutrients to meat and can easily be sold.

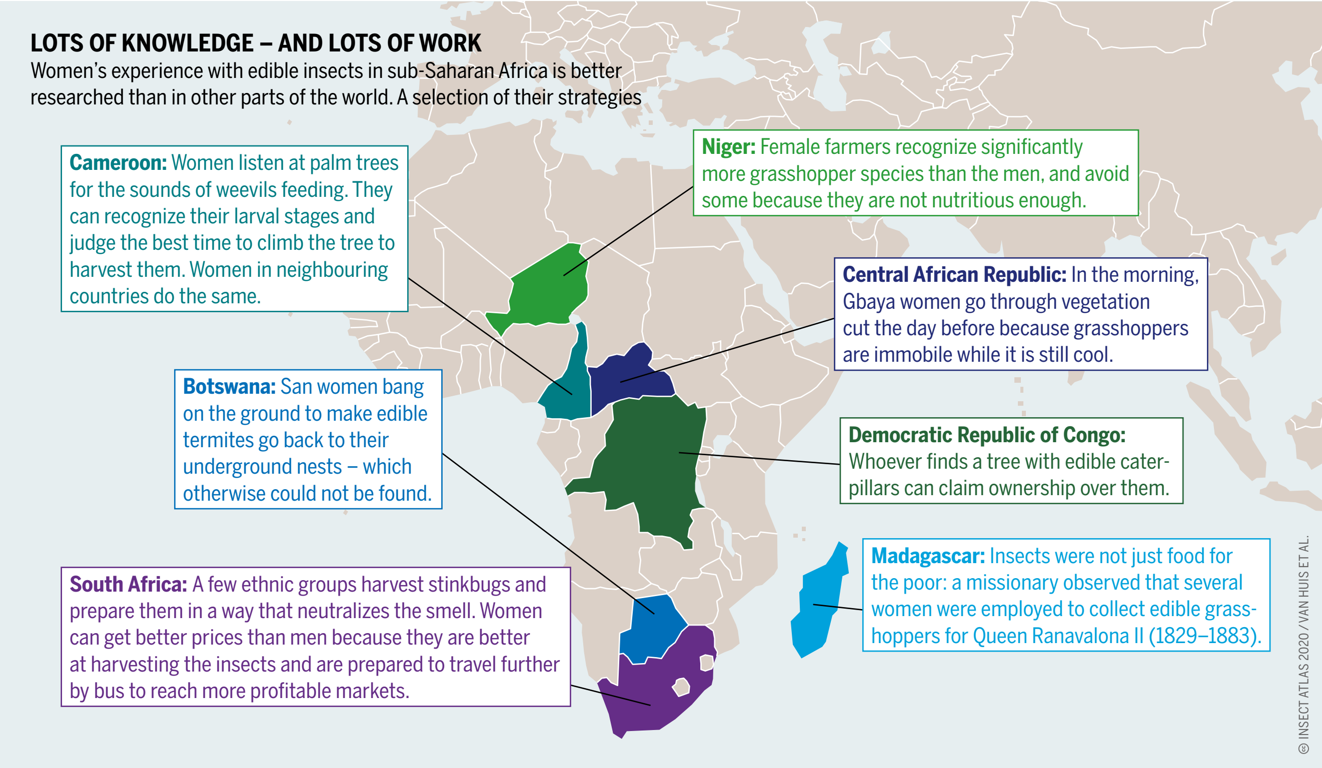
In some traditional, male-dominated cultures, men are served first at meals, thus getting the lion's share of the meat. Women and children eat what remains. Meat is often scarce and expensive. Even in cases where women are pregnant or breastfeeding, and actually need more protein and iron than men, they often get less meat to eat. By supplementing their diet with insects, women can achieve a more balanced supply of nutrients. In parts of the Brazilian state of Amazonas, indigenous women obtain 26 percent of their protein from insects; the figure for men was just 12 percent, according to a 1996 study.

An estimated 2 billion people live in societies where the consumption of insects is widespread. Many of the insects are collected or bred by women. In Cameroon, 94 percent of the "non-wood forest products", a statistical category that also includes insects, are gathered, produced and traded by women. Mopane worms, the large edible caterpillars of an emperor moth species that is widespread across Southern Africa, are considered a delicacy and are almost exclusively collected by women and children. Caterpillar harvesting also involves cleaning them to expel the contents of the gut, and drying them - tasks that are traditionally done by women. Selling the caterpillars in local markets can generate an important source of income for those involved. In South Africa, this may amount to 160 US dollars a month, or 30 percent of the household income. The lucrative long-distance and international trade in mopane worms, however, belongs to men: women generally do not have as much access to suitable means of transport.

Currently, the vast majority of insects that ended up as food are collected from the wild. But this does not guarantee a secure food resource or income, as many species are available only at certain times of year and in highly fluctuat-

In southern Africa, rural women earn a significant part of their income by harvesting mopane worms. A bad harvest can pose big problems for families





ing numbers. In addition, overharvesting may damage the forest and may lead to the collapse of insect populations – eliminating them as a reliable food source in the long-term. Intensive harvesting of mopane caterpillars and felling their host trees for firewood has already contributed to a decline in worm populations.

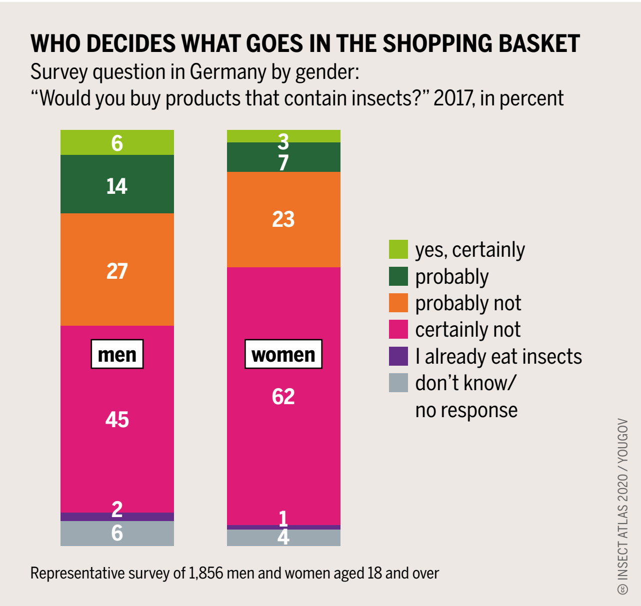
Because the market is growing, breeding insects – also referred to as "minilivestock"– offers a secure alternative to wild-harvesting, providing farmed insects as a source of protein and a reliable income. Many farmers are introducing it as an additional enterprise to diversify their farms. In Thailand, more than 20,000 farmers now earn additional income by rearing crickets. Although the consumption of insects has a long tradition in this country, breeding them did not start until the mid-1990s.

The modest effort and technology required to raise insects makes the process especially suitable for poor women. They benefit from the short life cycle of insects, meaning that an investment quickly produces a return. A new batch of crickets can be sold after just 45 days. The income generated varies according to the supply, demand and marketing possibilities. One insect farmer says she now has an additional 400 euros a month at her disposal. In Papua, Indonesia, a bag of 100 to 120 palm-weevil larvae fetches an average of 2.10 US dollars on the local market, about the same as 20 chicken eggs or 3 kilograms of rice.

A growing number of initiatives have recognized the opportunities presented by minilivestock for women with very low incomes. In Guatemala, three women have set up MealFlour, a project to combat malnutrition in the western highlands. People in this region suffer from chronic protein shortages because meat is far too expensive for most families to afford. MealFlour shows local women how to breed and raise mealworms, how to process them into flour, and how to bake flatbread from the flour. Mealworm farming improves household nutrition. In addition, the women can sell insect flour at the market and boost their incomes – an issue of great importance in Guatemala given it is more prone to malnutrition than anywhere else in Latin America. ●

Apart from the lucrative large-scale production and trade, most of Africa's edible-insect business is managed by women

Edible insects are "women's business" in much of the world. But not in Germany



POLICY

PLENTY OF PROMISES, TOO LITTLE ACTION

The dramatic die-off of insects and its possible effects on nature and humanity are scientifically proven. But policymakers are hesitant to respond. They often shy away from picking a fight with the agricultural industry.

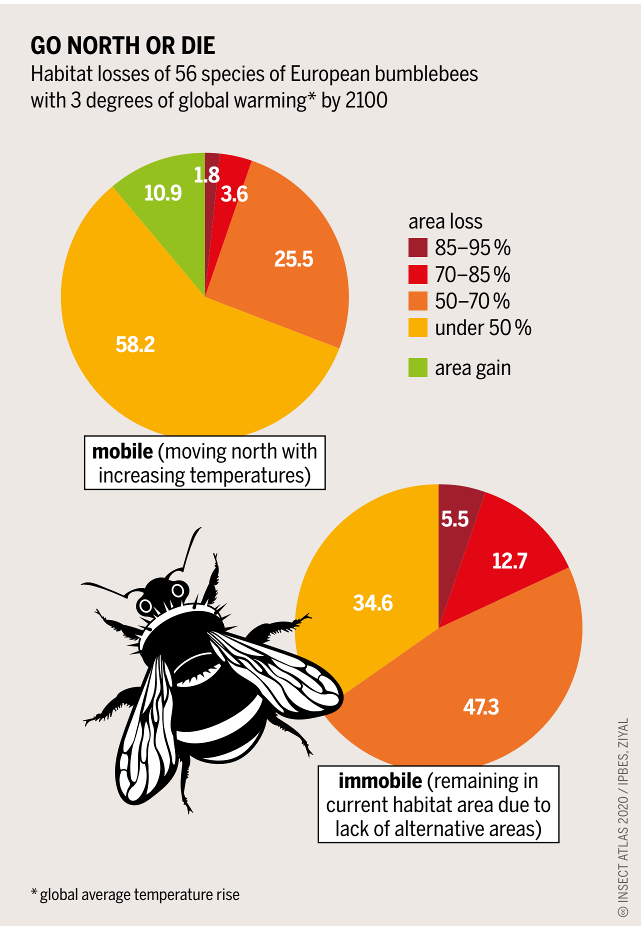
The agenda of the 1992 Earth Summit in Rio de Janeiro covered not only climate protection but also biodiversity. The Convention on Biological Diversity was created to conserve the multiplicity of species around the world. Signed by over 160 countries, it is the most comprehensive international agreement protecting nature and natural resources. But despite some progress, the goal of halting the loss of biological diversity by 2010 was not achieved. Today it is clear that extending the deadline to 2020 has also failed.

The World Biodiversity Council (IPBES) was founded in 2012 to provide scientific advice to policymakers in the field of biological diversity and ecosystem services. Its first report in 2016 analysed the situation of pollinators, pollination and food production. It noted a dramatic decline in the numbers of pollinators in terms of both diversity and the abundance of individual species. In its policy recommendation, IPBES pointed to intensive farming and the associated use of pesticides as being special threats to insects and called for a fundamental transformation across society to halt biodiversity loss.

As a result, a group of countries launched an initiative known as "Promote Pollinators, the Coalition of the Willing on Pollinators". The aim of this group is to put the protection of pollinators onto the international agenda. Members commit themselves to developing a national strategy to protect their own pollinators, and to exchanging information regularly on the experiences they have gained. The objectives are to set up a monitoring system and to plan, establish and expand research, information campaigns and protection measures for insects and their habitats. Although this is hardly a challenging set of requirements, fewer than 30 members have signed up to the coalition.

Launched in June 2018, the European Union's Pollinators Initiative addresses the decline in pollinators. It focuses on improving knowledge and public awareness of the decline, highlighting laws and initiatives that can be used to improve the status of insects. It points to the better implementation of the EU's Birds and Habitats legislation and the Common Agricultural Policy to improve the natural conditions for pollinators. Civil society organizations assess that both of these have so far failed to halt any decline. On the contrary, the Common Agricultural Policy with its support for industrial agriculture is partly responsible for the problem of plummeting insect populations.

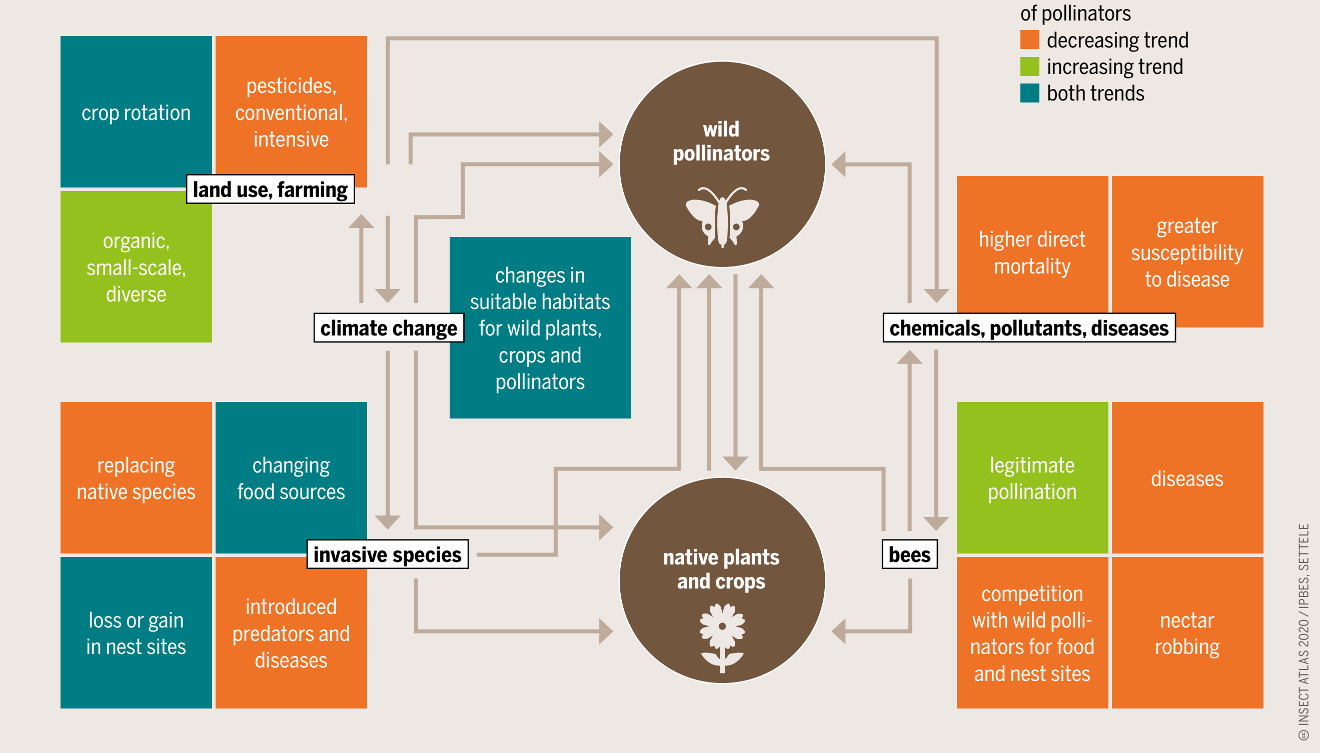
To halt the decline in insect numbers, governments and decision makers need to make fundamental changes in order to improve the natural conditions. The current negotiations on the reforms to the Common Agricultural Policy show how difficult that is in practice. The farm-support system is revised every seven years. Non-government organizations have for years been arguing that the almost 60 billion euros that go into supporting agriculture every year should be tied to the achievement of environmental goals, and should reward farmers for protecting animals, biodiversity and the climate. But the texts coming from the European institutions are inadequate both in terms of protecting insects, the climate and biodiversity. Most of the money is transferred to farmers as a payment per hectare,



European bumblebees are better adapted to cooler regions than butterflies, for example. They are at a special disadvantage when the temperature climbs

ADVICE ON POLLINATOR POLICIES

Individual and combined influences on pollinators and pollination, simplified overview of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2017



The positive and negative trends (according to current understanding) show the consequences of agricultural, environmental and climate policies for biodiversity

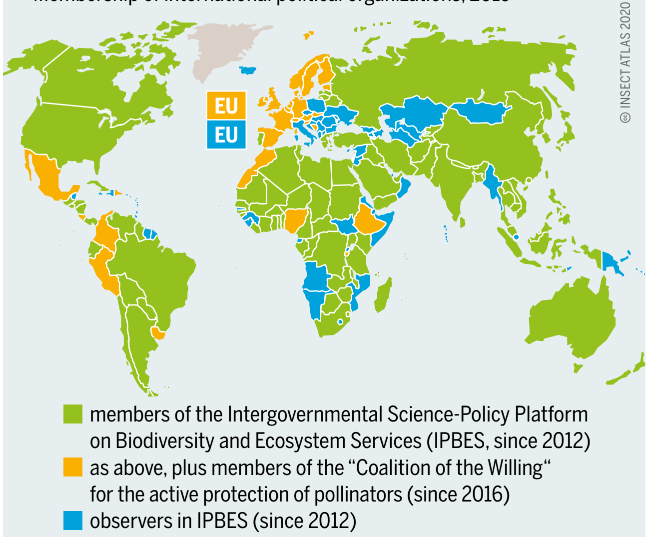
with weak requirements in return for the receipt of public funds.

The EU is still backing the wrong horse: if you have a lot of land, you get a lot of money. This approach does not require concrete measures for protecting species or the climate; nor does it oblige member states to allocate an ambitious proportion of the agricultural funding to promote ecological goals. Environment groups and specialists instead demand that there should be strong, binding conditions for receiving the funds, linked to the fulfilment of environmental services. This might include better management to improve soil quality, setting aside uncultivated areas, or planting hedges to provide habitat for insects and to link biotopes together. EU funds should also be used to support more organic farming throughout the European Union.

The conflict between the need to protect insects and the interests of the agricultural industry are evident in the revisions of the EU's guidelines on bees. In 2008, the application of neonicotinoid insecticides was followed by a dramatic die-off of bees in the Upper Rhine region in Germany. As a result, the European Commission tasked the European Food Safety Authority with revising the evaluation criteria for the authorization of pesticides. This was intended to improve the effects of these chemicals on the environment and especially on pollinators. The resulting bee guidelines contributed to restrictions on the use of three neonicotinoids on field crops in 2013. New evidence assessed in 2018 confirmed these restrictions. In 2019 however, the EU member states agreed on a watered-down version of the bee guidelines, even relaxing the approval standards that had been previously applied. They should instead have tightened them.

ACCELERATOR OR BRAKE?

Membership of international political organizations, 2019



Membership in international organisations is no guarantee that a country is pursuing an appropriate national policy. But it is a step in the right direction

INCENTIVES OR BANS, PRICE TAGS OR RULEBOOKS

Can the value of nature be expressed in terms of money? That is debateable. Attempts to do so aim to convince governments of the need to take action. They have met with little success.

Save Bees and Farmers" is a European civil-society movement that was launched at the end of November 2019. It calls for a step-by-step phasing out of pesticides, the specific promotion of biodiversity in agricultural areas, and support for farmers who want to better protect insects. It happened to coincide with several thousand farmers driving their tractors into Berlin to demonstrate for the exact opposite: they were against stronger environmental protections.

Farming and protecting insects are often not easy to combine. But doing so is worth it in the long term. Globally, the economic value of pollination by insects is estimated at between 235 and 577 billion US dollars per year. In the European Union, around 12 percent of the profits in the agricultural sector depend on it.

Most studies on the economic value of insects focus on the pollination work they do. The reason is simple: if insects did not do this work, marketable crops would not be produced. Looking at the prices and volumes of these products is the easiest way to calculate a potential loss. But the activities of dung beetles for the decomposition of manure and the work done by ladybirds to protect crops, also contribute to the economy. The latter is thought to amount to around 5.4 billion US dollars a year in the United States. The OECD, a club of industrial countries, also makes a business case for protecting biodiversity – along with the insects that biodiversity includes. It calculates the global damage caused by its member states' failure to act between 1997 and 2011 at between 4 and 20 billion US dollars.

Such economic arithmetic on the value of insect services is intended to facilitate rational policy decisions. The calculations rest on the assumption that greater economic losses can be prevented through sensible policies. Civil society, on the other hand, often criticizes the use of such calculations for so-called "ecosystem services".

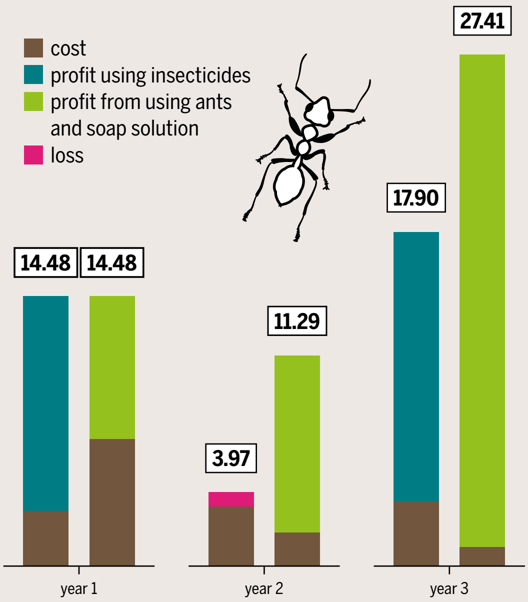
In their opinion, economic calculations reflect a capitalistic approach to nature by facilitating market-based solutions such as the trade in certificates and compensation payments for ecological problems. Some propose including nature in the market because giving it a price tag means it cannot be freely exploited or destroyed. Others criticize exactly this idea. They demand that nature be protected for its own sake. They advocate against using economic yardsticks and in favour of using purely regulatory measures.

The OECD also records how member states protect their biodiversity. Alongside trade in certificates, there are taxes, levies and subsidies. For years, new taxes have been imposed that are important to biodiversity. In the OECD countries, they now amount to around 7.4 billion US dollars a year. Globally, some 80 countries rely on economic instruments to protect biodiversity in general or insects in particular. A prominent and successful example is Denmark's pesticide tax. This led to the halving of pesticide use between 2013 and 2015, and brought in 70 million euros that were used to compensate Danish farmers for shortfalls in production.

Agricultural subsidies in the EU are tied only marginally to biodiversity protection. Although almost 60 billion euros of public money flows into farming in the 28 member

A NASTY NIP BUT A NICE PRICE

Added value per tree from using insecticides or weaver ants (*Oecophylla smaragdina*) to control pests in mango orchards, Australia, in Australian dollars

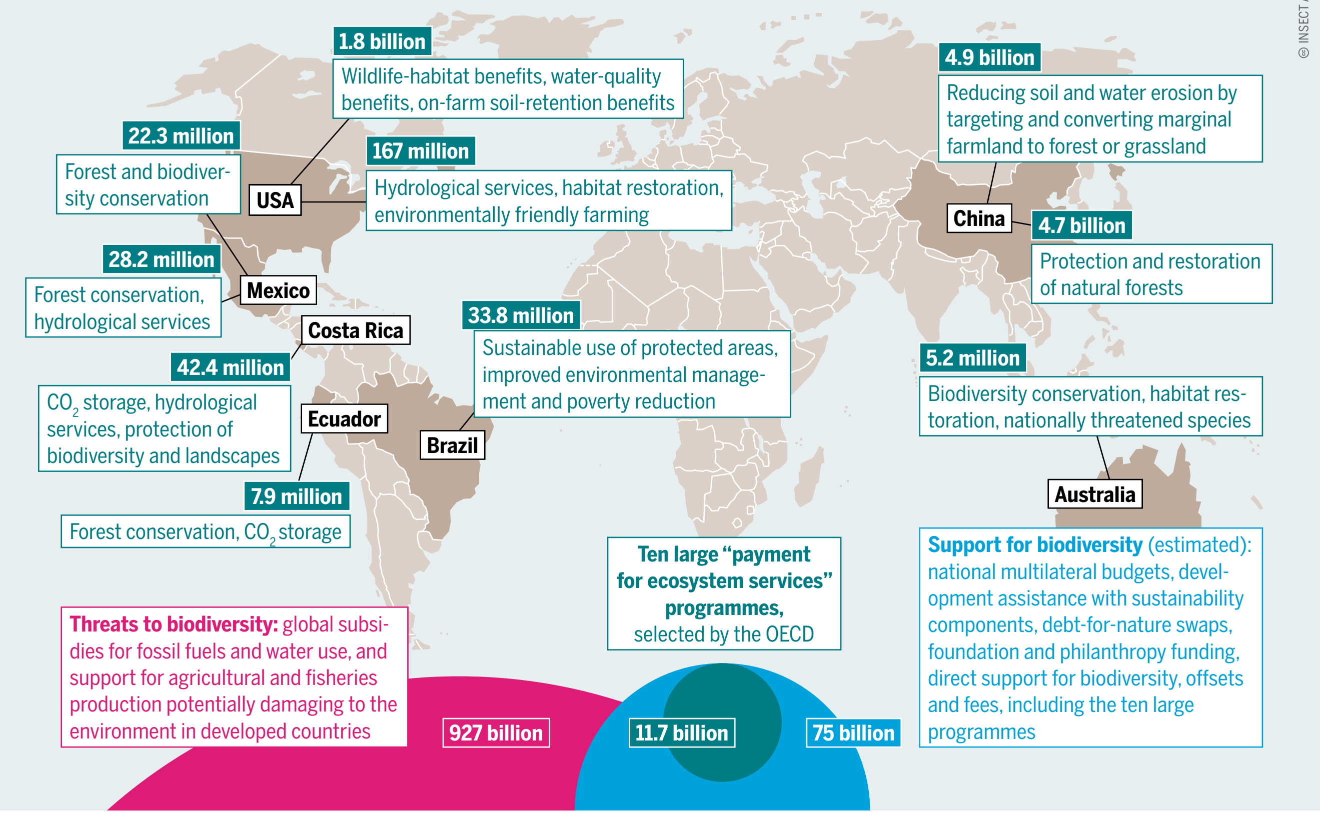


Weaver ants live in fruit trees and mangroves. They defend their habitat against plant pests through bites and by secreting acid. They feed on insects and farm mealybugs for the honeydew they produce. Where they are present, more top-quality large mangoes grow because the ants keep other insects away. A 3-year field study in mango trees in Australia found that despite the cost of establishing them in trees, weaver ants were already more effective than using insecticide after a year. Occasionally (twice a year) it was necessary to use a weak soapy solution to control mealybugs.

To deal with pest attacks, farmers have a choice: they can apply pesticides and so incur more costs, or they can introduce weaver ants for cost-effective biological control

FOR AND AGAINST NATURE

Ten "large" programmes that support biodiversity, compiled by the OECD group of developed countries, and estimated annual financial flows of policy measures that threaten or promote biodiversity, compared, 2012 to 2018, in US dollars



states each year, no one has yet worked out how much of this money is explicitly allocated to insect protection. Since 2015, all recipients of subsidies with more than 15 hectares of arable land are required to manage 5 percent of them as ecological priority areas. But the rules are lax and fail to have much positive impact on insect populations. Since the same year, the proportion of fallow land, e.g. in Germany's arable area, has risen by only 1 percent. This is a long way from the 10 to 20 percent that according to scientific findings would have to be taken out of production to stabilize insect numbers.

Although the number and area of ecological reserves is growing worldwide, insect populations are declining. This shows that because of their extent, agricultural areas must be kept as insect habitats. Protected areas now cover 20 million square kilometres, or 15 percent of the world's land surface. Nevertheless, they still cannot compensate for the large-scale negative effects of agriculture. And intensive farming is also permitted in many areas that are supposedly protected. Conclusion: only a combination of both – incentives with subsidies on one hand, and a rulebook with bans and obligations on the other – are needed to protect insects in farmland.

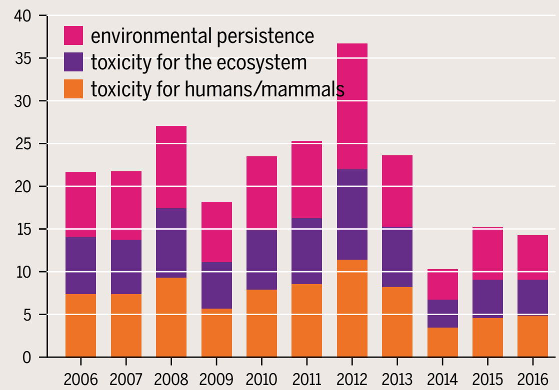
Many conventional farmers, and the associations that represent them, reject the idea of new rules. They propose purely voluntary measures. Environmental groups and organic growers see it differently. On the day that 5,000 tractors rolled through Berlin "against the regulation mania", the organic growers' movement Bioland agreed on stricter rules to protect insects. ●

It is hard to calculate how much money is used to promote biodiversity. But it is clear that vastly more tax money goes to supporting measures that threaten it

The expected introduction of a tax on pesticides in 2014 in Denmark led to stockpiling in 2012. Since 2014, the annual toxic load of pesticides has fallen by a third

TURNED AROUND

"Toxic load" of pesticides sold in Denmark before and after the introduction of a pesticide tax in 2014, in 10,000 points*



*active ingredients of pesticides in tonnes, multiplied by a numerical value measuring 15 parameters reflecting the toxicity of each substance

ORGANIC FARMING

BUZZING AND CHIRPING VS SPRAYS AND SILENCE

Organic farming focuses on maintaining soil fertility and biodiversity. But for an insect-friendly future, the whole farm landscape will have to change.

Compared with conventional agriculture, organic farming has clear advantages for insects and for biodiversity in general. A 2015 study related to the EU Biodiversity Strategy found that organic farms generally have 30 percent higher species richness and 50 percent higher abundance of organisms than conventional farms. A study from Germany summarizing many individual investigations found that 23 percent more insect species that visit flowers were present on organically farmed fields than on those subject to conventional management.

The organic fields had an average of 30 percent more types of wild bees and 18 percent more butterfly species. Organically managed land not only had a greater diversity of insects, it also had more insects in total. On average there are 26 percent more flower-visitors and almost 60 percent more butterflies on organic fields.

Farmland birds are commonly used as indicators of biodiversity and of insects. A 2010 EU wide study showed a higher number of farmland birds on organic farms than on conventional farms. Recent data from Germany indicate that there were 35 percent more such bird species on organically managed land, and they were 24 percent more numerous in terms of population. Overall, there has been a decrease in bird species that feed on small insects and spiders during the breeding season in Germany in recent years. Scientists attribute this to a lack of food in conventionally managed fields and to the widespread use of insecticides.

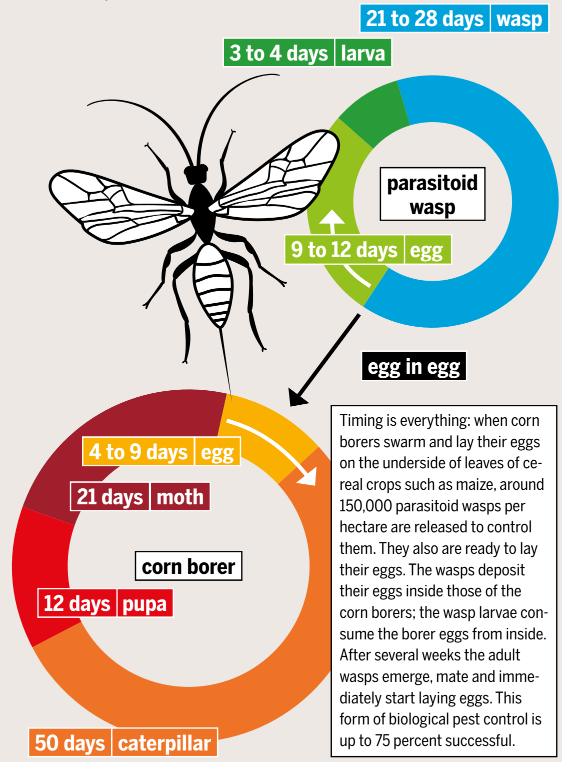
Organic farming has a positive effect on biodiversity and on insects for various reasons. It avoids using synthetic pesticides that conventionally managed farms apply to control weeds and pests. Instead, it removes weeds mechanically, or controls them by rotating and switching crop types each season. Organic farms also do not use artificial nitrogen fertilizer. Instead, they sow clover, lucerne or lupins. These plants fix nitrogen in the soil and therefore make a good green manure. At the same time they provide insects with both food and habitat. The German metastudy found that the number of wild plant species on organically farmed fields averaged 94 percent higher than on conventional fields, and 21 percent more plant species were found in the field margins.

In cereal growing, the effects of organic farming on biodiversity are far-reaching because conventionally grown grain relies on heavy applications of mineral fertilizers and pesticides. Pollinators are very sensitive to pesticides. Because organic farms abstain from using chemicals, local pollinators become more abundant. But since pesticides may drift with the wind, and insects naturally visit conventionally managed farms nearby, the negative effects of pesticides may overshadow the positive ones. This may also be true if hedges, flowering field margins and other ecological niches are missing. Overall, though, organic farming has a bigger positive effect on insect numbers if the surrounding area is monotonous: i.e., if it has few variegated landscape elements and is only covered with a single type of crop.

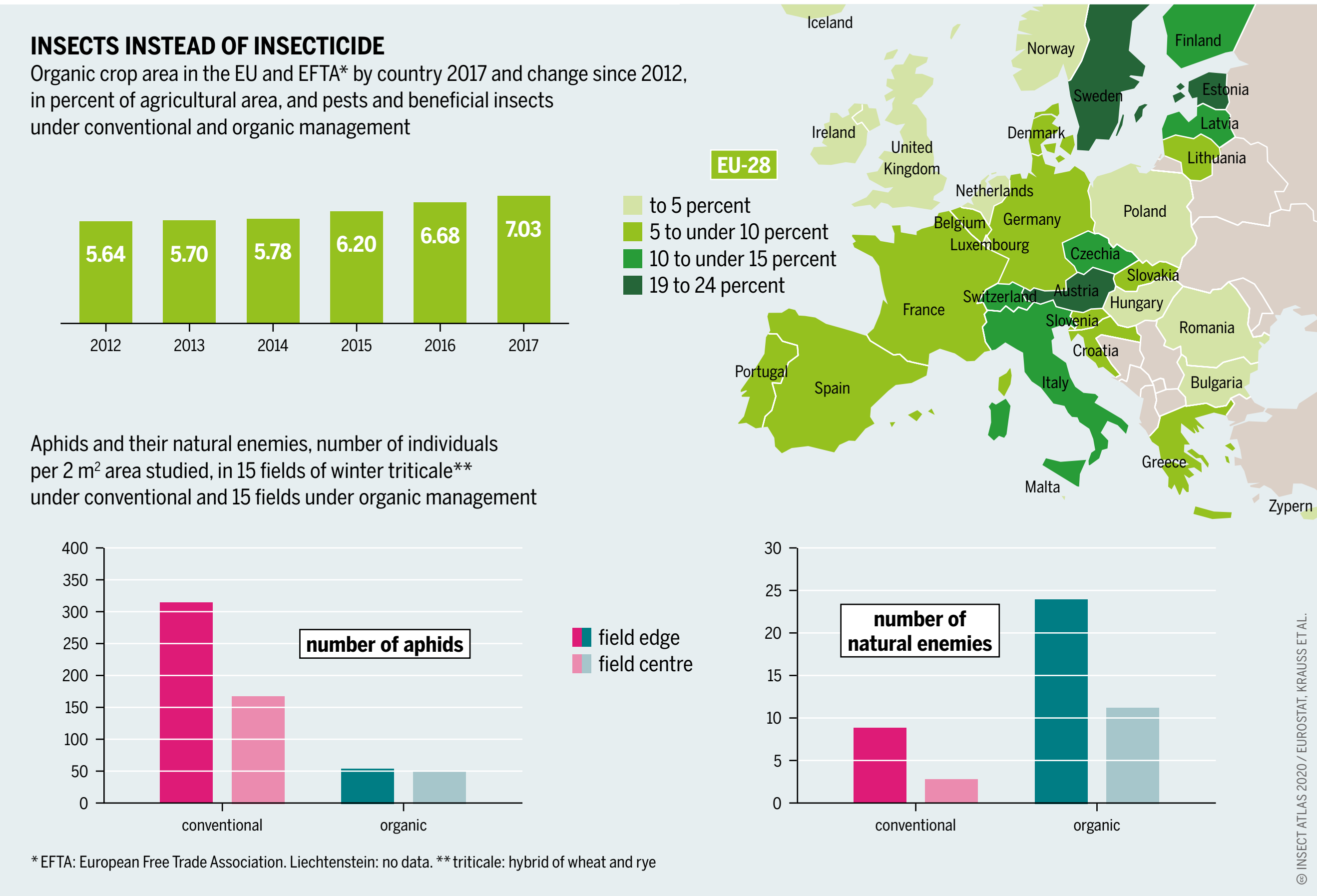
Critics argue that the lower yields of organic farming would make it necessary to expand the area of cultivated land worldwide by converting previously unused land that is high in biodiversity. This would make the net effect of organic farming negative, because uncultivated land

DYING INSIDE

Egg laying by the parasitoid wasp *Trichogramma brassicae* and the European corn borer



Parasitoid wasps are among the best known biological pest controllers. They attack the eggs of about 150 other species

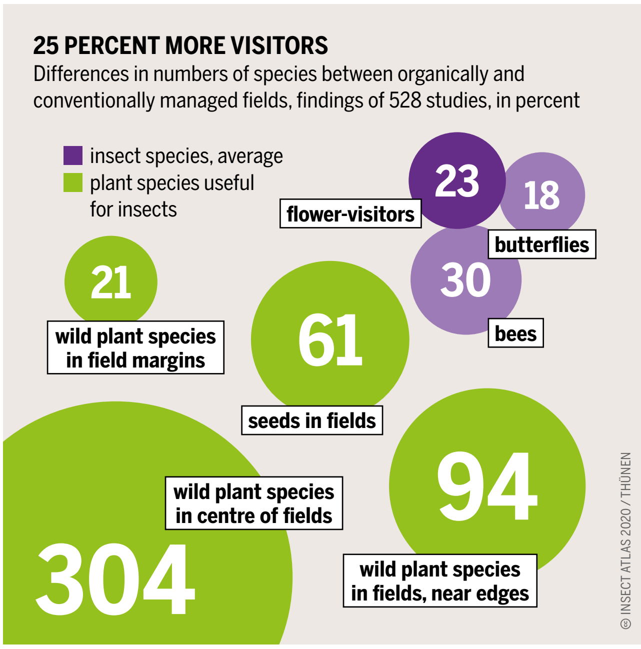


Insecticides did not kill all the aphids – but so many of their natural enemies that ultimately there were more aphids on the sprayed fields than on fields without any insecticide

has greater biodiversity than organically managed fields. Such criticism is justified in that, in temperate latitudes, yields from organic farming are lower than those from conventional farms. Nature would benefit from 100 percent organic farming only if land is saved through lower meat consumption and if food losses are reduced. The production of 327 million tonnes of meat a year, the world's current consumption, takes up almost 80 percent of the global agricultural area. Therefore, lower meat consumption is of central importance to sustainable land management.

Organic farming has so far been a niche business in many developed and emerging countries. Worldwide, it covers only 1.5 percent of the agricultural area; in the European Union the figure is 7 percent – though it is growing quickly. Major differences exist among the EU's members: in Malta, organic farmland covers a minuscule 0.4 percent of the total, while in Austria it accounts for over 23 percent. These figures only include areas that are certified as organic.

But many farms worldwide follow the basic principles of organic farming: maintenance of soil fertility, the cycle of soil–plants–animals and humans, and farms' independence from external inputs such as fodder and synthetic fertilizer. Few of these farms are certified as organic. The broader concept known as "agroecology" is promoted by many civil society organizations around the world, along with international organizations such as the Food and Agriculture Organization of the United Nations. They all support the ecological and social restructuring of the agricultural and food system, including marketing and power structures – thus promoting an insect-friendly future.



Long suspected: now there is proof. An analysis of numerous individual research studies found that organic farms were more biodiverse than conventional ones

MAIL-ORDER POLLINATORS

As farmers and the agricultural industry search for alternatives to pesticides, the raising of insects for sale is becoming more common – pollinators such as bumblebees, and pest-controllers such as ladybirds.

Insects are not just bred and sold for consumption by livestock or humans. They are also marketed for the work they do – for the ever more specific roles they play in agriculture. Two of the most important jobs are controlling pests and pollinating crops. In the biological control of pests, viruses, bacteria and fungi are also deployed alongside insects. The "beneficial" insects can be ordered from a mail-order supplier and are delivered in a packet. Bumblebees are most widely employed as pollinators, though bees and flies also have a slice of the market.

In 2016, biological pest control was used on around 30 million hectares of agricultural land worldwide – out of a total of 4.86 billion. Europe is the biggest market for invertebrate pest-control officers, while North America leads the way in using bacteria and viruses. Latin America and Asia trail along behind, but the market there is growing quickly.

Official employment statistics for insects, for example from the Food and Agriculture Organization of the United Nations or from industry associations, are not available. The sales volumes of individual companies are still too small to compile comprehensive data. A study in 2016 estimated that 500 commercial firms were operating in this field worldwide. Most of them had fewer than 10 human employees. Some very large agricultural firms in Latin America breed their own insects to control pests. Industry experts estimate that the world market leader, Koppert Biological Systems from the Netherlands, has an annual revenue of 120 to 150 million euros. The Biobest group in Belgium turns over about 100 million euros, while the French InVivo Group comes in at 50 million euros. The market for beneficials is dominated by medium-sized and small firms. In general, they supply both pollinators and insects for pest control.

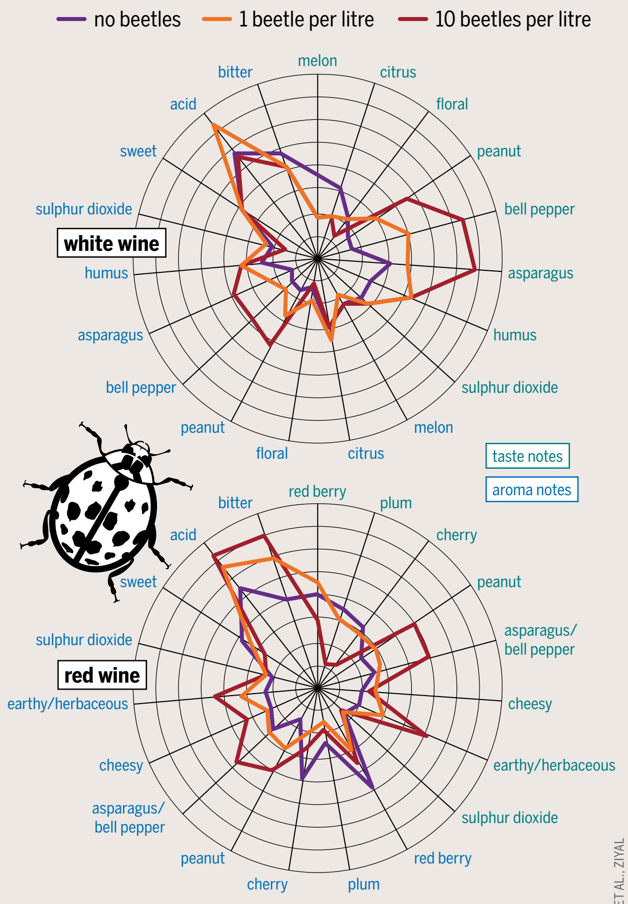
The firms breed the insects and then send them to customers. There is no targeted breeding to obtain insects with particular characteristics, so "breeding" in fact means "multiplication". Some 350 species are actively used in pest control. The bumblebee genus Bombus is the most common species used for the pollination of soft fruits and fruit vegetables (such as tomatoes). For this purpose, bumblebee colonies are raised in special nest boxes that can be sent to where they are needed.

If adult insects are shipped – as is the case with parasitoid wasps – no more than two or three days can elapse between the collection and packaging, and the release. This does not permit long-distance or intercontinental transport of the insects. Large, globally oriented suppliers therefore maintain breeding stations at multiple locations to serve the various regional markets. In addition, suppliers have started shipping beneficial insects in the pupal stage. With sturdy protective packaging, the insects can withstand transport that lasts up to a week. Pupae can also be put into artificial hibernation; suitably cooled, they can be stored for up to half a year.

In fruit plantations, bees of the genus Osmia are put to work; in seed cultures, flies of the genus Lucilia is the main source of personnel. In North America, millions of beehives

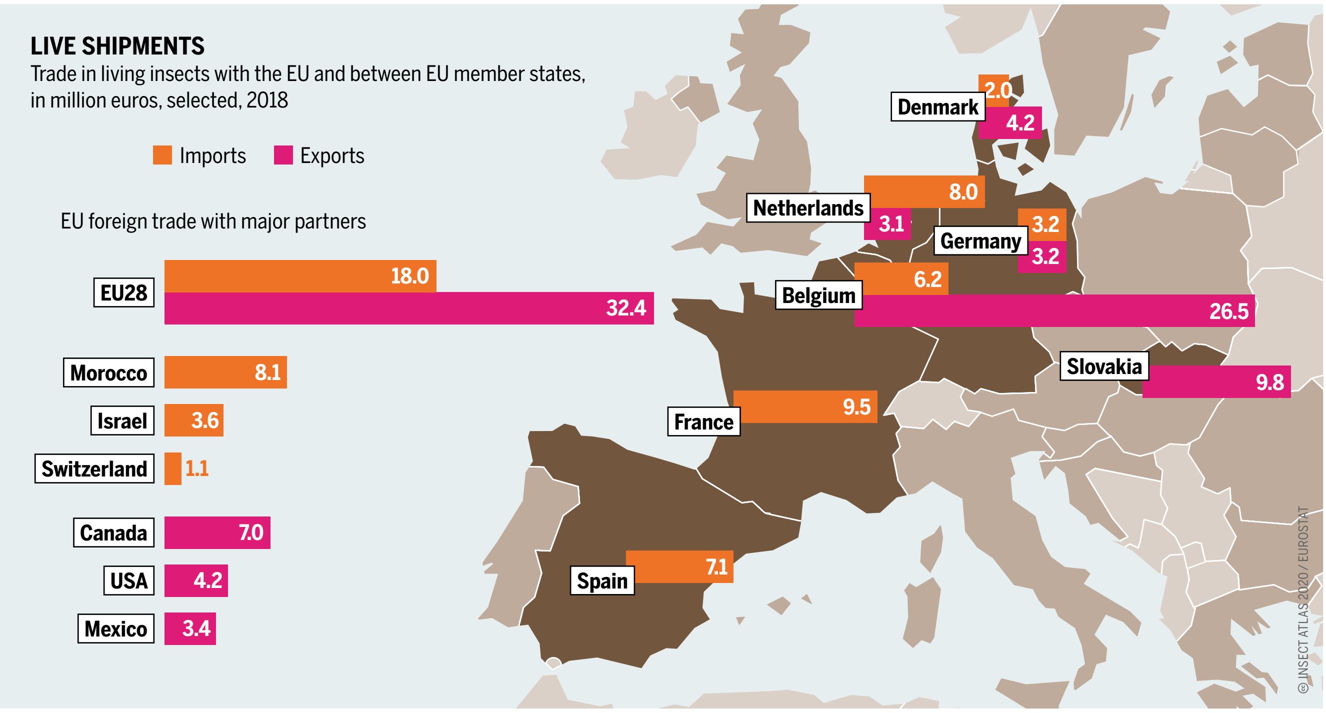
WHEN BEETLES GET INTO BOTTLES

Effects on wine of the harlequin ladybird *Harmonia axyridis*, traded internationally as a beneficial but also causes damage to grapevines, responsible for changes in taste and aroma



The harlequin ladybird, native to eastern Asia, has been imported to North America and Europe as a beneficial because it consumes five times more aphids than do local ladybird species. But if it has consumed all the aphids, it starts eating other ladybird species. It can infest damaged grapes and if threatened releases a bitter defensive substance. A single beetle in a grape can damage a litre of wine. In the USA, scientific tastings have investigated the effect of adding either one or ten beetles to a litre of white and red wine. The acceptable limit is about 1.7 beetles per kilogram of Riesling grapes.

If grapes are harvested by hand, it is possible to separate out those that are damaged by Harmonia axyridis. This is not possible with mechanical harvesting



Belgium is the hub of the insect trade: imports and exports from the whole EU pass through its ports

criss-cross the continent. Around two million beehives with 31 billion bees are needed to pollinate California's 90 million almond trees during the January blossom period. After they have done their work there, the bees and their hives travel to the Pacific Northwest, where they service cherry, plum and apple orchards. They then move to pumpkin fields in Texas and citrus plantations in Florida. In Europe, bumblebees make it possible for tomato growers to obtain yield increases of 50 to 100 percent.

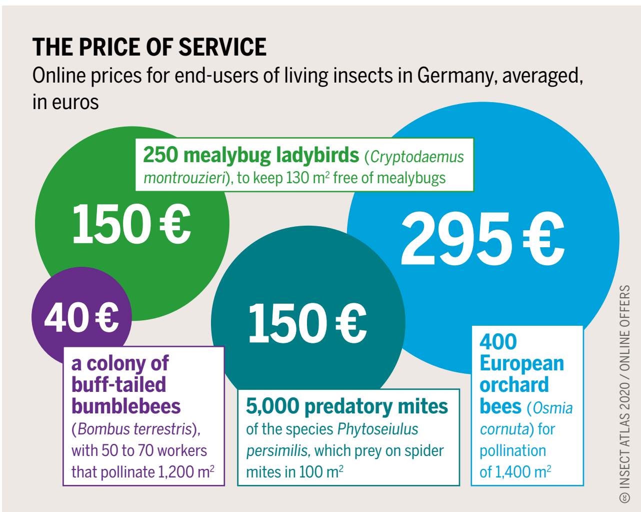
Using beneficials for both pollination and pest control has many advantages. Yields go up, and toxic residues from chemical pesticides that may harm health, the soil and water are eliminated. A disadvantage from the trade in beneficials may arise because the species are introduced into new areas. They may threaten the local insect populations if they are released in the wild or escape from greenhouses.

That was the situation for the harlequin or Asian ladybird, Harmonia axyridis, which has been used since the 1980s to combat pests because it reproduces faster than its European cousins, and eats five times as many aphids. It has spread across North America and Europe and is crowding out the local species. Controversy rages over whether invasive pests that have moved from one region to another should be controlled using natural enemies from their original homes.

The brown marmorated stink bug, Halyomorpha halys, has also spread from East Asia throughout North America and Europe. The use of its natural enemy in Asia, the samurai wasp Trissolcus japonicus, has been successful in controlling the stink bug especially in Switzerland and Italy, where it had caused major damage. However, its effect on the local fauna is still unclear.

Growers can buy armies of pollinators and predators to fertilize and protect crops grown in greenhouses and polytunnels. The mercenaries arrive in a delivery van

Alien species are subject to different regulations in each country. In the United States, a permit is needed to import such insects, transport them over state lines, or release them. In Switzerland, the authorities issue permits for releasing beneficials. A 2009 directive of the European Union on the sustainable use of pesticides approves the use of biological control methods. But the use of beneficials is regulated differently in each of the member states. France, for example, is working on a far-reaching regulation with the goal of preventing the release of alien insects into the wild. It anticipates that farmers or breeders must use a gene test to prove that the beneficials they release are indeed native to the region. And in Austria, beneficials may be released only with a permit from the federal Authority for Food Safety. ●



OUT OF THE LAB AND INTO THE FIELD

Resistance results in higher yields. This principle is being used to confer crops with the ability to tolerate herbicides and pests. Now, insects too are coming into the crosshairs of genetic engineering.

Between 1996 and 2018, the proportion of the area cultivated worldwide with genetically modified crops rose from 3.6 to 12.8 percent. Today, 90 percent of the 192 million hectares are located in just five countries: the United States, Brazil, Argentina, Canada and India. The vast majority consists of just three crops: soybeans (50 percent), maize (30 percent) and cotton (13 percent). This has huge implications for insect habitats, because of both the production methods and the novel characteristics of the crops themselves.

The genetically modified plants are grown as monocultures on intensive, large-scale farms. Insects are left without a diverse range of fodder plants. There are few hedges, field margins or uncultivated areas. On top of that, most genetically modified crops are "herbicide-resistant", i.e. they can be sprayed during their growth phase without being negatively affected. Other vegetation in the field is susceptible to the poison; it dies off. That leaves insects with few other flowering plants as a source of food. Both industrial farming and the use of agrochemicals restrict insect habitats or eliminate them altogether.

"Insect resistance" is a second important feature of genetically modified crops. GM maize or cotton plants produce a toxin that kills of the most important pests of these crops. The effects on other insects that do not damage the crops are scientifically controversial and have not been sufficiently examined, as is the extent of damage to and losses, both for pollinators and soil insects.

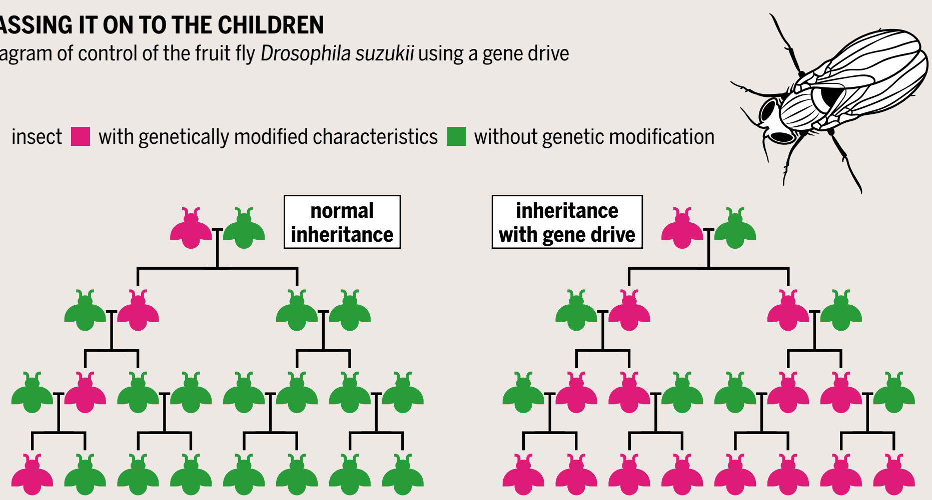
But the evidence shows that the toxins produced by maize plants to combat European corn borers can also severely harm the caterpillars of butterfly species. Especially problematic is the fact that the plants produce the toxin throughout their entire growth cycle, from the roots to the leaves, flowers and pollen, thus harming insects for months on end. According to the broad scientific consensus, herbicide resistance has a negative effect on biodiversity and on insects.

Research into so-called "new" genetic engineering methods has been going on for around 15 years. These are closely linked to digitalization and make the modification of genes in the genome easier, cheaper and more targeted than the "old" approaches could. Genetic material from other species can now be introduced, and individual genes can be switched off, duplicated or reordered. Civil society organizations that are critical of these techniques fear that the genetically modified varieties will be approved before their effects on the environment and on insects have be properly studied and understood. They also see a danger that characteristics such as herbicide resistance, which are so harmful to insects, can be incorporated into other crops more easily and cheaply. The major seed companies are already securing the most important patents for themselves,

Gene drives offer hope for controlling pests, but also have unknown risks. The United Nations is discussing a moratorium on using them

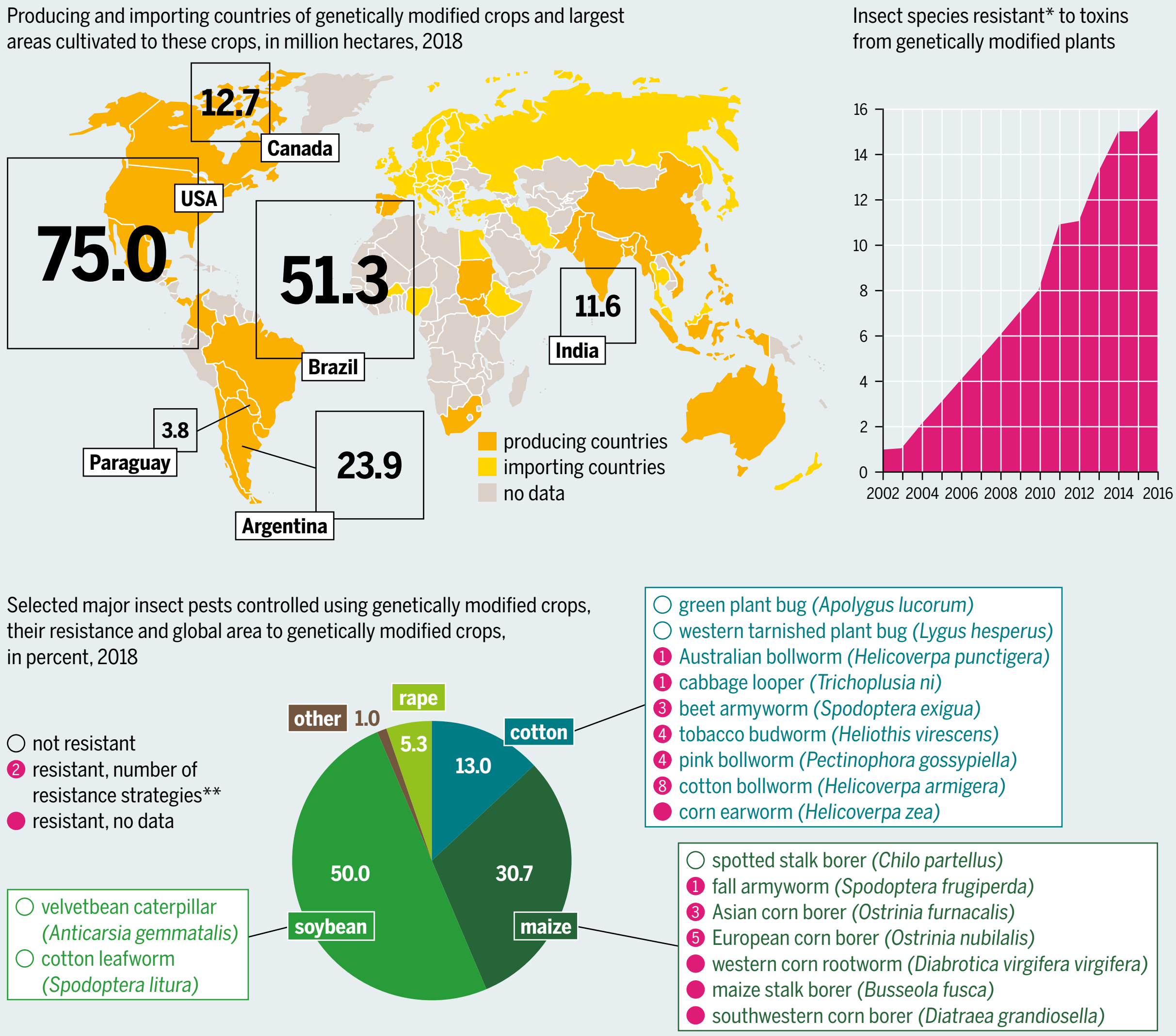
PASSING IT ON TO THE CHILDREN

Diagram of control of the fruit fly *Drosophila suzukii* using a gene drive



Fruit flies, which survive from 3 to 9 weeks per generation, can cause immense damage for fruit growers, even destroying an entire harvest. Fruit they attack become mushy and rot quickly. A new genetic technique known as a "gene drive" was adapted for fruit growers in California. In normal Mendelian inheritance, a fly with a genetic modification to cause sterility can pass to only half its descendants. With a gene drive, the sterility is passed on to all its descendants, and can spread quickly throughout the whole population. However, insects can develop resistance even to gene drives, in that the genetic information conferring sterility is not transmitted to all new chromosomes.

PROMISES UNFULFILLED
Genetically modified crops and resistant insects



* more than half the individuals in a population
** e.g., mutation, downregulation of receptors, deactivation of genes

both on plants and on techniques.

New approaches to genetic engineering are also targeting insects themselves. One method that has been tested in the laboratory but not yet in the field is the gene drive. This can fix desirable or undesirable traits in the genome in such a way as to ensure that they are passed on to all the offspring, and thus eventually spread throughout the entire population. Because of their short reproduction cycles, insects are particularly well suited to this technique. The best-known example of gene drives is the attempt to control malaria by eradicating the mosquito species that transmits the disease. The first genetically modified mosquitoes have already been released.

The eradication of crop pests such as the spotted wing drosophila (a fruit fly that infests cherries) and the olive fruit fly (a pest that feeds on olives) is also being researched, though not yet in the field. Many researchers are critical of gene drives because releasing modified organisms may be very risky and have global effects on the ecosystem. As soon as the characteristics are transferred from the target organism to related species or populations outside the target zone, there is the risk of their spreading globally, with unknown consequences for the ecosystem.

Pest resistance against genetically modified crops is growing faster than new ways can be found to combat it

Another area of research focuses on using insects as a type of drone in agriculture. Insects are inoculated with genetically modified viruses, which they transfer to crop plants when they visit the flowers. The viruses then trigger a desirable genetic mutation during the crop's growth phase. The idea is to achieve such changes in the short term so the plant population can better respond to its environment or to pathogens. Putting new genetically modified crops into the environment that are capable of erasing other species, is a cause of growing concern amongst politicians and the civil society. ●

TECHNOLOGY WON'T SAVE US

If insect diversity were to disappear, a vital part of the system that supports us would be lost. Nature would change, and our diet would have to change with it. Pollinator robots would not be able to compensate for the absence of insects.

In early 2019, *The Guardian,* a British newspaper, anxiously wrote that the world's insects might disappear within a century if their populations continue to shrink at current rates. But even though scientific studies confirm the decline of insects, they will not disappear altogether. On the other hand, habitats, diversity and numbers are changing dramatically. If insects cease to perform many of the services they currently provide to nature and to humans, what would the world look like?

Most plants are reliant on insects because their flowers are not self-pollinating, and their pollen is not carried by the wind. Without insects, global nutrition would be less varied. Insects transfer pollen from one flower to another, and ensure the exchange of genetic material between plants of the same species. This enables the plants to produce seed and fruit, and over generations to adapt to a changing environment.

If pollen is transferred between fewer flowers, plants that rely on pollination by insects develop fewer seeds and fruit. Harvests of maize, rice and wheat, the most important staple crops, are not at risk because their pollination does not depend on insects. But yields of many fruits and vegetables would suffer. These crops are an important source of vitamins and nutrients. Production of cherries could fall by 40 percent, and of almonds by 90 percent. Some types of vegetables, such as cucumbers and pumpkins, might almost disappear. Around 6 percent of the total volume of cultivated plants would be lost, according to some estimates. Producers in Germany alone would lose around 1.3 billion euros a year.

A development of this kind would further exacerbate the problem of ensuring an adequate and balanced diet for humanity worldwide. Cross-pollination (by insects or the wind) stimulates many plants to produce greater quantities of certain vitamins and minerals. Without pollination by insects, the composition of nutrients in foods would change. This is especially worrying in developing countries, where people cannot simply take food supplements to obtain the missing nutrients as in industrialized countries.

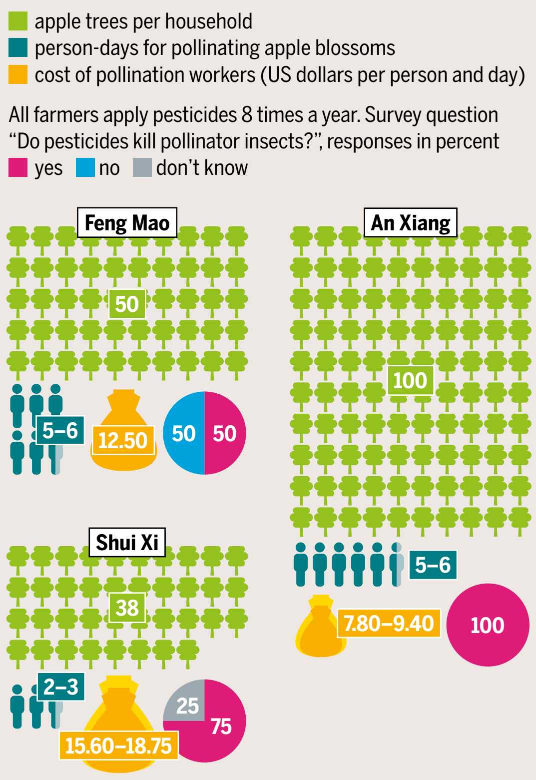
To counteract this situation, plantings could be pollinated by hand, and robot bees could be used in polytunnels. Certain crops, such as apples, pumpkins, cherries and kiwis, are already being pollinated by hand in over 20 countries, including China, Korea, Pakistan and Japan, as well as Argentina, Chile, New Zealand and Italy.

Some varieties of apples, pears and pumpkins set fruit without having to be pollinated by insects. This characteristic could be expanded through breeding and used widely to maintain harvests. An unpollinated pear blossom that develops into a fruit has no seeds – a phenomenon called parthenocarpy. This commonly occurs through the mechanical stimulation of the carpel (the female reproductive part of the flower). This and similar processes have disadvantages: a seedless apple contains less calcium and rots more quickly than one with seeds. In strawberries too, pollination by insects has a decisive influence on hormonal processes in the developing fruit – resulting in a better-tasting and longer-lasting fruit.

Greenhouses or polytunnels eliminate the wind, so to-

WORKERS, NOT BEES

Pesticide applications and pollination of apple trees by hand in three villages in a mountainous area of Sichuan, China

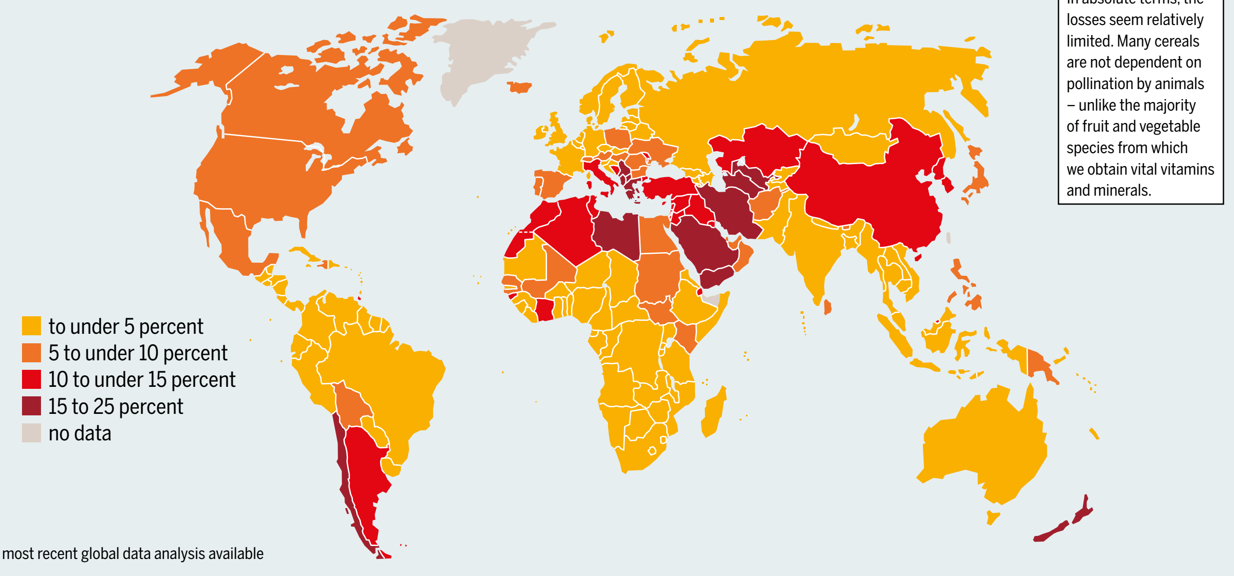


The relationships between pollination and yields and the dangers that pesticides pose for pollinators are still unknown to some rural people in Asia. In China's traditional apple-growing region, hand pollination and the application of insecticides have been promoted and practised since the 1960s. By 1980, the bees had died out. Because of out-migration and labour shortages, it has become necessary to employ migrant workers from afar to pollinate the crop. The reintroduction of bee colonies for pollination has failed because pesticide continues to be applied.

A vicious circle of pesticide applications and hand pollination hinders sustainable fruit production

NO INSECTS, NO FOOD

Dependence of agricultural production on pollination by animals, 2012*



* most recent global data analysis available

matoes grown in them have to be "buzz pollinated". Because they are effective pollinators, bees are often introduced into these structures. The bees vibrate their wings at a particular frequency, causing the tomato flowers to release their pollen. Humans can use an electric toothbrush to imitate this effect. In an insect-free world, one where bumblebees have also fallen by the wayside, robot bees might be able to take over the buzz pollination. That is not yet possible, but engineers are already working on technical solutions.

The ecology of pollination differs markedly from one plant species to another, and building suitable robot bees for all of them will not be possible. Wild plants take on a wide range of forms and occur in stands of different mixed-species. Robots would have to learn to recognize each species and adapt their pollination mechanism to each one.

Technology is still a long way from replacing the complexity of ecological systems with artificial intelligence. Many flowering species in meadows rely on insect pollination; without their six-legged friends, there would simply be no more species-rich flowering meadows. Meadows and pastures would consist only of self-pollinating and wind-pollinated grasses.

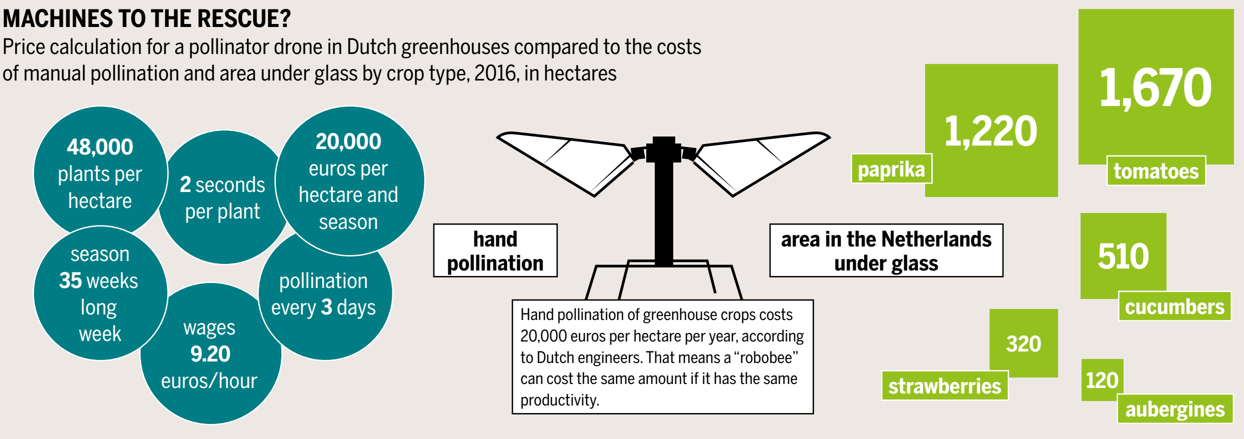
Grazing would also be much more difficult. Along with earthworms and microorganisms, insect larvae help prevent erosion by stabilizing the soil. Without them, cattle would slip and slide around in wet weather. Insects are also indispensable in decomposing manure. Without specialist dung beetles, the ground would be littered with ageing cowpats. This ecological problem has already occurred once before: at the start of the 19th century, when cattle were introduced to Australia, there were no native dung beetles. It was only after they were imported that the problem was solved. ●

It is the high-value bush, tree and field crops that are most dependent on pollination by insects

Maintaining and strengthening current ecosystems would cost just a fraction of the investment needed to develop and deploy millions of pollination robots

MACHINES TO THE RESCUE?

Price calculation for a pollinator drone in Dutch greenhouses compared to the costs of manual pollination and area under glass by crop type, 2016, in hectares



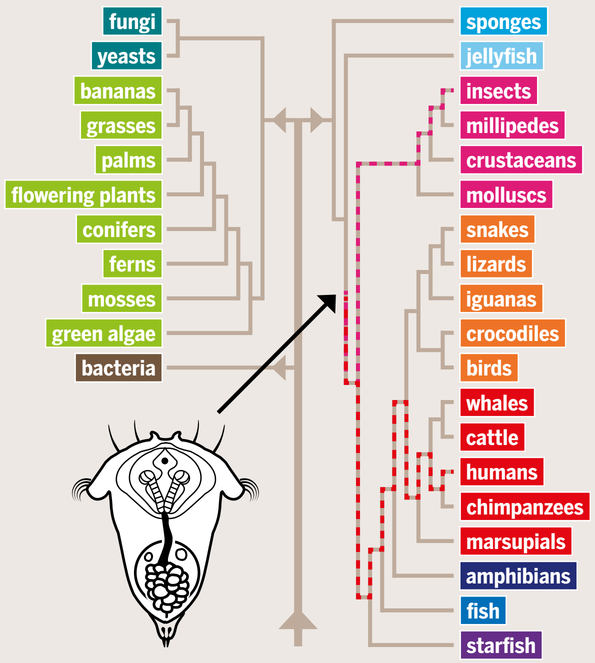
AN ANCIENT COMMUNITY OF FATE

The relationship between humans and insects has long been a difficult one. The history of farming is in part the history of pest management. It is only relatively recently that we have come to appreciate the value of insects as pollinators.

Underestimated. This describes the attitudes of humans towards insects. We underestimate the numbers of insect species and of individuals. We fail to appreciate their diversity of types, lifestyles and habitats. We underrate their significance for the economy and medicine. And we don't particularly like them, at least in most of the developed world. When Gregor Samsa, the protagonist in Franz Kafka's novella awakens after a restless dream metamorphosed into a cockroach, he does not regard the transformation as an upgrade.

COMMON ANCESTORS

Schematic representation of evolution, selected branches with common names, and *Bilateria* as the most recent link between insects and humans



The biggest commonality between humans and insects: both are bilaterally symmetrical along the length of their body. They have left and right sides that are mirror images of each other, and front and back ends. Some 800 million years ago these Bilateria broke away from other animals. About 680 million years ago, the Protostomia, the predecessors of insects, developed, along with the Deuterostomes, from which vertebrates and eventually humans emerged. About 370 million years ago, the insects were the first creatures that could fly. Three to four million years ago, humans arrived with their own innovative form of locomotion: they could walk on two legs.

Early humans regarded insects as one source of food among many. For hunters and gatherers, they were an important source of protein. Aborigines in Australia still revere cicadas, honeypot ants and wichetty grubs as totemic animals. In many parts of the world, the enormous reproductive ability of insects has left traces in creation myths in which they play a central role. The formidable building abilities and the well-organized societies of many species certainly contributed to this respect.

Bees have always played a special role for humanity. In the early cultures of India and Africa, they served as totems of tribes who were said to have the ability to handle stinging insects well. Cave paintings dating back 8,000 years depict how people collected honey from bees. Long before the discovery of sugar beet, sugarcane or saccharin, honey was the only major source of sweetness. Because wild honey is hard to get, humans probably began raising bees somewhere between 5,000 and 7,000 years ago. This intimate relationship is reflected in Egyptian hieroglyphics, in stylized beehives, on mediaeval heraldry, and in computer-animated cartoons.

The ancient Egyptians' reverence for the sacred scarab is initially somewhat harder to understand. The scarab is a species of beetle that lives on the dung of larger animals. Despite this unappetizing predilection, the scarab was embalmed with the greatest reverence. Its artistic image decorated the tombs of pharaohs. But in fact, the large number of dung beetle species are an essential part of the ecosystem. Without them, the ground would be buried under a deep layer of undecomposed dung, especially after humans began keeping cattle, buffaloes, horses and goats in large numbers.

As humans made their great cultural leap from nomadic to sedentary life, they did so hand in hand with insects – or rather, hand in tarsus – the last segment of an arthropod's leg. It was only the pollination services provided by dozens of insect species that made it possible for us to practise agriculture. And in return, through our fields, food stores, houses and of course the massive increase in our own numbers, we have provided a richly decked table at which many insect species can dine.

That is why the history of agriculture is also the history of pest management. Ancient authors such as Pliny and Virgil addressed the subject. Swarms of locusts were such a natural catastrophe that they were regarded as a punishment from the gods. In the 20th century, outbreaks of potato beetles were portrayed in propaganda as biological weapons deployed by the enemy. For thousands of years, humans have been relatively powerless in the struggle for food against our small but efficient competitors. We resort-

What did the first bilaterally symmetrical animals look like? We can only guess by looking at much more recent species. The reconstructions change with almost every new discovery

TEN BIBLICAL PLAGUES – MOSTLY THE WORK OF INSECTS

Scientific theories about an ancient report

Exodus, the second book in the Old Testament, describes how the God of Israel punished the pharaoh because he did not permit the Israelites to depart from slavery. After ten plagues, the pharaoh gave way. The events may be based on a volcanic eruption in the second millenium BCE. Historical research on Exodus is a scientific field in its own right.

Water turns into blood: Toxic bacteria colour the water red, or pumice dust after an eruption settles on the water or comes as sediment down the Nile to Lower Egypt.

Frogs teem into the land: Amphibians flee the toxic Nile water and die.

Gnats plague humans and animals: Because the amphibians have died, the gnats have few natural enemies. Their population explodes.

Biting flies fill the houses: Flies lay eggs in the dead frogs and multiply.

Pestilence kills all horses, camels, cattle and sheep: The huge numbers of insects bite animals, causing open wounds, infections and deaths.

Boils on people and animals: Humans also die from ulcers caused by insect bites and stings.

Hail kills humans and animals: Volcanic eruptions, but violent thunderstorms with hail also possible.

Locusts cover the land: Such plagues can happen at any time. The locust migration may have been triggered by volcanic ash.

Darkness lasted three days: Perhaps caused by volcanic ash or a massive swarm of locusts darkening the skies.

Death of all first-born children of humans and animals: The first-born sons and animals are given the first, and largest, meals. Because of the scarcity of food, they eat more of the usual cereals, but these are contaminated with ergot, a toxic fungus that proliferates on grain that is not adequately sun-dried.

- directly caused by insects
- indirectly/possibly caused by insects
- volcanic, amphibian, fungal causes

Biblical plagues are today often explained as being the result of unstable ecological conditions. With their short lifecycles and rapid generational turnover, insects can adapt quickly

ed to prayers, or to curious defensive measures such as nailing toads to barn doors.

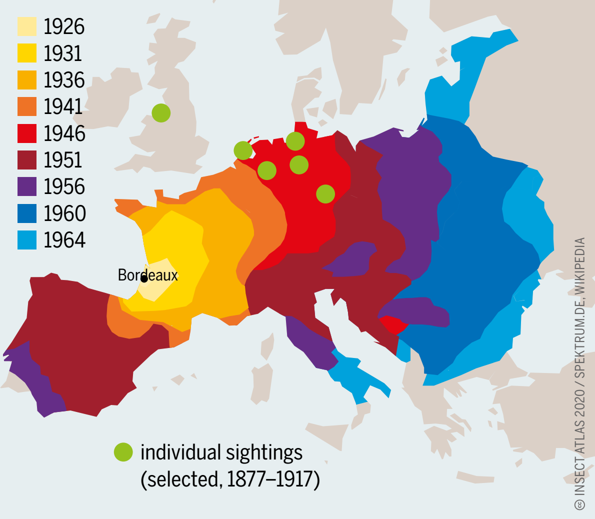
Insects did not just chomp their way through fields and grain stores. They also added to the damage they caused by transmitting plant diseases. Cicadas and aphids that suck plant juices are responsible for transmitting 90 percent of the viruses that cause plant diseases. Phylloxera, a minuscule insect just one-and-a-half millimetres long, arrived from North America in the 19th century and quickly devastated one-third of France's wine-growing regions. It was controlled only when resistant rootstocks from North America were also introduced.

In the 20th century, chemicals such as DDT brought resounding success, but not without harming other animals such as birds and mammals, and damaging entire biotopes. Rachel Carson described these correlations in her book, Silent Spring, published in 1962. It is considered the birth of the modern environmental movement. Nonetheless, agroindustry spent huge sums to agitate against the scientific findings contained in this book – an interesting parallel to the current debate on climate change.

Insects have affected humanity in profound ways, and vice versa. This community of fate will continue into the future. By destroying habitats and through climate change, we humans are now in a position to drive many insect species to extinction. The consequences for mankind are serious, both because of the ecological imbalances this would cause, and through the loss of as-yet unknown biological substances and insect characteristics that future generations might be able to use. But the adaptability and resilience of many insects are enormous: they can withstand high doses of radiation and develop tolerance to just about any type of poison. It is likely that when our long, shared success story reaches its final chapter, it will be the insects that evolve into the future – not us.

UNWELCOME ARRIVAL

Spread of the Colorado potato beetle from the port of Bordeaux



The Colorado potato beetle was the most significant threat to Europe's food supply in the 20th century. It has since reached Kamchatka, in the Russian Far East

AUTHORS AND SOURCES FOR DATA AND GRAPHICS

All online links were last checked in April 2020. See page 2 for the websites where you can download a clickable PDF of this atlas. Lengthy links have been shortened using the bitly web-address conversion service. Numerous scientific sources are not available for free online. Many of the bitly links for scientific papers point to websites that give a DOI (Digital Object Identifier), a global address for online articles in scientific journals. Enter http://doi.org/ followed by the DOI to check for the availability of the article online or through libraries.

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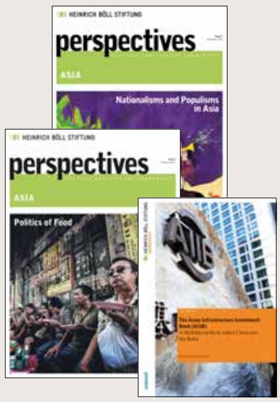

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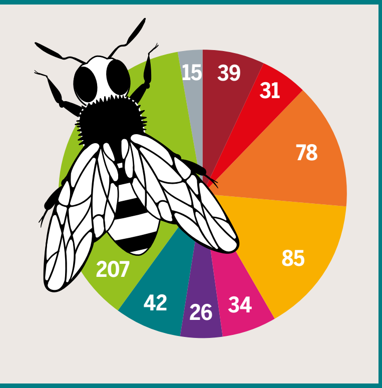

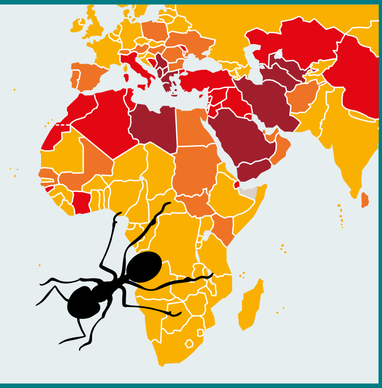

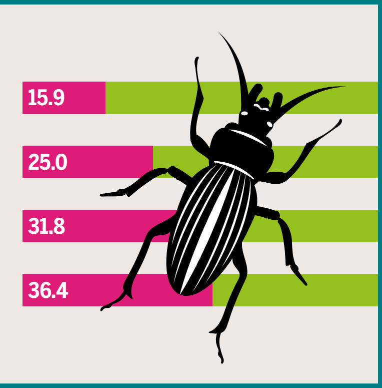

Many species perform important services in agriculture. A bumblebee, for example, may pollinate up to 3,800 flowers in a single day.
from: SIX FEET ON THE GROUND, page 10

Insects are disappearing mainly from cultivated land and intensively used pastureland. The scientific consensus is that agriculture has a negative influence on insects.
from: A CRISIS WITHOUT NUMBERS, page 14

Brazil is one of the most insect-rich countries in the world, but soybean production there is affecting its biodiversity.
from: FROM FOREST TO PASTURE, FROM PASTURE TO FEEDLOT, page 24

The loss and fragmentation of habitats mean it is not possible for many species simply to move north as conditions alter.
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