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Understanding insect decline: data and drivers



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OVERVIEW

This POSTbrief provides further information on the data limitations for understanding insect declines and emerging methods to address these limitations. Further detail is also given on the evidence for drivers of insect declines, such as disease or artificial light at night, which are summarised in POSTnote 619. The POSTbrief also highlights areas where evidence is established or where there are gaps in knowledge, such as insect abundance data.

BACKGROUND

Over recent years, studies from across the globe have indicated a decline in insect abundance, diversity, distribution and biomass.¹⁻⁴ However, the trends for global insect declines are uncertain and may be over- or underestimated. For example, a well-reported 2019 global review has been recently criticised as its results were skewed by excluding studies that reported stable or increasing insect populations.⁵⁻⁹

Fully understanding the data on the drivers of insect decline is complex as there is limited evidence on how drivers influence each other, and which drivers are having the greatest impact. Also, some of the largest declines may have occurred prior to research being carried out, further complicating the data. Particular drivers, such as climate change, may also benefit some insects but be detrimental to others. Much of the data for the effects of drivers is based on research in controlled laboratory environments and focuses on individual organisms, or is undertaken over short time periods (1-2 years) that are not relevant for long-term population-level processes.¹⁰ Because of this, it is challenging to apply the findings of this research to assess the impacts of drivers on complex insect communities and ecosystems under natural environmental conditions that can't be controlled for. This complexity has so far limited the evidence on the impact of declining populations on ecological processes.

Having standardised, systematic and long-term data sources is key to understanding insect decline and toward identifying the drivers behind the trends.¹¹ Relevant and reliable data are needed to measure the effectiveness of interventions, such as those supported by agri-environment schemes.

Glossary

Abundance: the number of individuals of a species.¹²

Arachnids: animals that usually have a segmented body divided into two regions of which the front bears four pairs of legs but no antennae. These comprise chiefly terrestrial invertebrates, including the spiders, scorpions, mites, and ticks.¹³

Bioinformatics: conceptualises biology in terms of macromolecules (in the sense of physical-chemistry) and then applying “informatics” techniques (derived from disciplines such as applied maths, computer science, and statistics) to understand and organise the information associated with these molecules on a large-scale.¹⁴

Biological record: a record of a species in a particular place at a particular time by a named person.¹⁵

Biomass: the amount of living matter measured in grams.¹⁶

Distribution: where a species occurs at a given time and the geographical area.¹⁵

Ecological community: a group of species that occur in the same geographical area at a given time. There are often relationships between each species (such as predation or pollination).¹⁷

Ecological function: the biological processes that control the fluxes of energy, nutrients and organic matter, which underpin the goods and services that humans receive.¹⁸

Ecosystem services: the outputs of ecological processes that provide benefits to humans (e.g. crop and timber production or well-being benefits, [POSTnote 281](#)).¹⁸ In the Millennium Ecosystem Assessment, ecosystem services were divided into supporting, regulating, provisioning and cultural categories. However, a recent Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) assessments have replaced this classification, with “nature’s contributions to people” – all the positive contributions, losses or detriments, that people obtain from nature to capture both beneficial and harmful effects of nature on people’s quality of life.¹⁹ This encompasses services that fit into more than one of the four categories such as food, which can be both a provisioning service and a cultural service, as well as novel approaches to understanding people-nature relationships, such as relational values.^{20,21}

Electromagnetic radiation: is a flow of energy in the form of electric and magnetic waves, including radio waves, infrared, visible light, ultraviolet, X-rays, and gamma rays.²²

Entomology: “a branch of zoology that deals with insects.”²³ An entomologist is someone that studies insects.

Environmental impact assessment: Environmental Impact Assessment (EIA) is the procedure (usually governed by the [Town and Country Planning \(Environmental Impact Assessment\) Regulations 2017](#) depending on the type of development) for evaluating the likely environmental impacts of a proposed project or development, taking into account inter-related socio-economic, cultural and human-health impacts, both beneficial and adverse.²⁴ The environmental statement produced for the EIA must be prepared by competent experts and include at least the information reasonably required to assess the likely significant environmental effects of the development.

Fungicide: is a chemical agent that destroys fungi or inhibits their growth but may also impact on the gut microbial fauna of invertebrates.²⁵



Two black beetles, image Krzysztof Niewolny

Genetically modified: refers to a group of applied techniques of genetics and biotechnology used to cut up and join together genetic material, particularly DNA, from one or more species of organism and to introduce the result into an organism in order to change one or more of its characteristics (see [POSTnote 360](#)).²⁶

Insects: are invertebrates but only include organisms with a well-defined head, thorax and abdomen, only three pairs of legs, and often one or two pairs of wings.²⁷

Invertebrates: are animals that lack a spinal column, such as molluscs, spiders and insects.²⁸

Microbiome: is a community of microorganisms (such as bacteria, fungi and viruses) that inhabit a particular environment, such as soil or the human body ([POSTnote 574](#) and [601](#)).²⁹

Monoculture: is the cultivation or growth of a single crop or organism especially on agricultural or forest land.³⁰

Parasitoid: an insect, usually a wasp species, which completes its larval development within the body of another insect eventually killing it and is free-living as an adult.³¹

Priority species: are species identified under legislation or policy that require particular action or protection. For example, as part of the UK Biodiversity Action Plan (a response to an international legally-binding treaty the Convention on Biological Diversity) a set species were identified as being the most threatened and requiring priority in conservation action.³²

Species richness: is the number of different species for a given area and time.

Taxonomy: is the scientific discipline of describing, delimiting and naming organisms, both living and fossil^{33,34}

LIMITATIONS OF INSECT DECLINE DATA

To understand insect decline, different types of data are required for a wide range of insects using standardised sampling ([POSTnote 379](#)).^{11,35,36,37,38} Globally, data on insects are limited because of the large number of species, with species continuing to be discovered and described.^{11,36,39,40} For example, there are an estimated average of 5.5 million insect species globally, with about 1 million of these already discovered and described.⁴¹ Even the most comprehensive review of global invertebrates highlights large gaps in the data, with the conservation status of less than 1% of all described invertebrates being known.³⁹

The UK has more long-term monitoring data than most countries because of its history of amateur collections and long-term recording schemes, citizen science engagement ([POSTnote 476](#)) and strong research community.^{15,36,40} For example, the Natural History Museum London has the oldest entomological collection with over 34 million insects and arachnids, and the Rothamsted Insect Survey has an estimated 100 million insects stored in their archive since 1973.⁴² There are also an estimated 70,000 people submitting monitoring data to the Biological Records Centre amounting to an estimated £20.5 million per annum of volunteered time.^{15,43} Methods developed by researchers in the UK are being employed internationally, further indicating the strength of the UK's activity. However, UK-centric data are limited by gaps in what is measured and how. The ways in which these issues can be addressed is described below.³⁶ If resources remain limited it may be possible to focus on monitoring species that can act as an indicator for similar species, which provide a key and readily measurable ecosystem service and do so in habitats that are under threat from pressures, such as land-use change.³⁷ One such example would be bumblebees for other bees.

Methods

Surveys that use a standardised method across sites and measure at systematic intervals exist for only a limited group of species and habitats (see Rothamsted Insect Survey and the UK Pollinator Monitoring Scheme).^{11,44,45} UK data could be improved by standardising across monitoring schemes.¹¹ This would aid in comparisons across time, habitats and insect groups. A large quantity of unstandardised data is also collected (see volunteer-based data collection below).

Time of data collection

There are very little data available before the 1970s. This creates an arbitrary baseline for long-term comparison.¹¹ The data prior to 1970s have large gaps that limit any analysis and conclusions. Insect populations also often vary greatly from year to year.^{11,46,37} Measuring at regular intervals gives more accurate trends over time rather than selecting distinct time periods to compare.^{38,47,48,38} For example, a recent study looking at moth biomass trends in the UK found an incorrect trend one-quarter of the time when using only the first and last year in the analysis (compared with using all years in the analysis).⁴⁷ However, care should be taken to adjust the sampling period to account for any climate change related shifts in phenology, as measuring at the same time each year may miss changes in activity and record lower numbers as the sampling took place later in the season compared to previous years.³⁸

Natural history collections in museums can help to fill in the gaps across time as they can show where species have existed in the past, but fewer specimens are available after the 1970s.^{11,42,49} Wider use of systematic long-term recording would prevent gaps in data and provide a stronger evidence base for historical comparison, addressing the ‘shifting-baselines’ phenomenon where successive generations accept their current levels of insects as ‘normal’.^{50,51}

Location

Data collection can be skewed towards particular habitats (such as nature reserves that are popular with volunteers).⁵² The trends from these systems are not transferable to other systems such as urban areas or can give incorrect trends.⁵³ Some monitoring schemes aim to address this bias through randomising sites for data collection.⁵⁴ For example, to address the skew towards nature reserves in the main UK Butterfly Monitoring Scheme, the Wider Countryside Butterfly Survey uses randomised sites to encourage collection from urban areas.^{54,55}

What is measured

More data are collected on pollinators and popular species like butterflies than other functional groups (decomposers, beetles; natural pest control, wasps; wildlife nutrition, flies).^{36,40,56,57} This makes it difficult to assess overall insect decline and its impacts on other ecosystem services. Monitoring schemes often only record the adult stage of insects, which means that key evidence to inform interventions is missing.⁵⁸ The UK Butterfly Monitoring Scheme includes egg and larval counts, but only for specialist species.⁵⁹ Standardised schemes are effective at monitoring commons species but

some species are hardly recorded as they are rare species, or are harder to detect or identify (for instance, many species of fly, or soil fauna, such as springtails). Based on trends reported in other more widely monitored groups, it is highly likely that gaps in monitoring local extinctions or declines have occurred for many under-recorded insect groups. Rare species (of conservation concern) require targeted monitoring in places they are known to persist, with sampling in a standardised manner.^{60, 37}

Type of data collected

The type of data can affect the conclusions made about insect declines.¹¹ For example, species richness tells us the number of species present. However, abundance may be more strongly linked with ecosystem service provision than richness.^{1,61-66} Without knowing the abundance, changes in communities can be masked.⁶⁷ For example, having a diverse pollinator community can act as insurance against pressures such as disease that could disproportionately impact one species. Biomass data is also tied to ecosystem service provision and ecosystem function.^{1,18} However, there are only a few biomass studies in the UK.^{47,68} Data on the distribution of a species can improve understanding of how common a species is and the impact of drivers, such as climate change, on the species range.⁶⁹ Community composition data and species richness can be used to explore the ability of the community to resist or recover from environmental changes and maintain function for the provision of services.^{18,61} However, little community data are available. The variety of data can make it difficult to compare across insect groups, locations and time. New statistical methods can help analyse non-standardised data.⁷⁰

Volunteer-based data collection

The reliance on volunteers means that there is irregular sampling across time and geographic area.^{35,71,72} There is a concern that highly skilled volunteers with experience in the taxonomy required for identification are decreasing (see Box 1).^{73,74} This limits the efficiency of monitoring and research. For example, the Rothamsted Insect Survey aphid early warning system⁷⁵ is constrained by the limited number of people with identification skills, and the moth survey data are limited by the number of volunteers.



An orange ladybird, image Gido

Box 1. The importance of taxonomy in assessing insect decline

Taxonomy is the scientific discipline of describing, delimiting and naming organisms, both living and fossil.³³ These skills are required for monitoring and to identify what insects are present at any given time and location. These data help to create baselines for comparisons across time. Some of the highly specialised skills can take years to master and are held by a limited number of experts. For example, in the UK “there are 210 members of the recording scheme devoted to the study of the 510 species of ants, bees and wasps but scarcely more than half a dozen who contribute information on the occurrence of the 6000 species of parasitic Hymenoptera”.^{34,76,77} A review of an 84-year series of entomological papers published by a UK journal prior to 2001 found that “professional taxonomy appears to have undergone a long and continuing decline since its peak in the 1950s and 1960s”.⁷⁶

These skills are important for a variety of policy areas including (see [HL Paper 162](#)):

- **Conservation targets (UK and international)**
- **Protection against invasive species**
- **Responding to climate change**
- **Understanding ecosystem services**
- **Policing the global trade of endangered species**
- **Promoting public engagement with the natural environment**

The House of Lords Science and Technology Committee has held three separate inquiries into taxonomy science (1992, 2001–02 and 2007–08). The latest inquiry (2007–08) concluded that “the state of systematics and taxonomy in the UK, both in terms of the professional taxonomic community and volunteers, is unsatisfactory” (see [HL Paper 162](#)). The report highlighted a widespread concern about the state of the discipline and the decreasing supply with increasing demand. A review from 2010 directly identified 727 taxonomists across 25 UK organisations, ranging from natural history museums, government agencies and private companies. Universities were under-sampled in this review, however, the review found that retiring university-based taxonomists were not replaced, leading to a marked decline since the mid-1990s. In 2017 the Biotechnology and Biological Sciences Research Council (BBSRC) stated that “taxonomy skills continue to be a concern, with a lack of future supply of individuals; intervention is needed at the school and undergraduate levels”.⁷⁸ In the UK there is one undergraduate degree, four postgraduate taught degrees and two postgraduate research degrees with ‘entomology’ or ‘insect’ in their course titles.⁷⁹

Concerns were further supported by the ageing demographic of taxonomists (see [HL Paper 162](#)).⁷⁸ A review conducted by the Natural Environment Research Council in 2010 found that 57% of the taxonomists working in natural history museums and botanical gardens in the UK were 40–50 years old, whereas 64% of commercial taxonomists were 20–30 years old.³⁴ There is more variability in age across voluntary organisations.³⁴ Emerging methods can help to fill the skills gap (see Emerging methods).

To continue collecting data, long-term investment into building skills and capacity is required to maintain volunteers, support amateurs and incentivise professional development.^{73,74,80–84} Learned societies such as the Royal Entomological Society,⁸⁵ the British Ecological Society,⁸⁶ the Royal

Society of Biology,⁸⁷ and wildlife charities,⁸⁸ can play a role in supporting skills development and enabling public engagement with citizen science. Activities such as holding a 'BioBlitz' are useful public engagement tools and generate some usable biological records data but not at the same quality as long-term monitoring (Box 2).⁸⁹ Apps such as iRecord enable individual recorders to collect data and identify species.⁸²

Box 2. Public engagement through BioBlitz

A BioBlitz is "a collaborative race against the clock to discover as many species of plants, animals and fungi as possible, within a set location, over a defined time period – usually 24 hours".⁹⁰ Experienced scientists work together with members of the public, volunteers and school groups to catalogue biodiversity in their local area.⁹¹ The most recent report on BioBlitz activities in the UK estimated a total of 24,948 people had taken part in 2013 (2,250 of those were people with little or no prior knowledge of nature conservation).⁹¹

Data from environmental consultants

Current approaches do not encourage environmental consultants to have or develop taxonomic skills beyond those required for priority species. Professional development of taxonomic skills can be supported by taking an approach that recognises the key role of insects in ecosystems. This would move away from the priority or single-species approach to require assessments for functions and relationships, encouraging a broader understanding of taxonomy and ecology. This could be applied to Environmental Impact Assessments. However, new identification methods such as DNA analysis help address a decreased pool of taxonomy skills (see Boxes 1 and emerging methods section).^{40,47,55,92–95} Also, methods in development such as bioacoustics^{96–98}, BioDAR^{99,100} and camera traps¹⁰¹ can monitor insects remotely across large areas with reduced labour (see Emerging methods section).¹⁰²

Accessing and sharing data

Useful data sources exist but remain fragmented (held privately by researchers or companies such as agricultural or environmental consultancies).¹¹ Collaborative



Museum collection of butterflies assorted by colour, image drz

working across stakeholders would allow for resources to be pooled and enable more comprehensive studies across species, locations and time. The understanding of insect decline could be accelerated and expanded by greater knowledge exchange across these groups. A requirement to submit data to a centralised data storage and sharing facility would aid this exchange. For example, the National Biodiversity Network Gateway stores data for 45,530 species from 147 partners and enables data to be shared via the internet.⁶⁹ The data remains the intellectual property of the data provider and access to some records is restricted (see [POSTnote 490](#)). Extra care should be taken when sharing data on rare species¹⁰³ or data collected by volunteers.¹⁰⁴

A study of 104 regional coordinators and 510 recorders taking part in the UK's recording schemes found cautious support for open access of the data they collect.¹⁰⁴ Recorders are wary about sharing the location of rare or popular species due to the risk of being captured for private collections. Recorders were also cautious about the commercial use of data.¹⁰⁴ Current funding models for accessing and sharing data may require a small fee for specific biological data from Local Environmental Records Centres that are, in part, funded by Local Planning Authorities. The full release of species data could undermine the funding model for some Local Environmental Records Centres and monitoring schemes.¹⁰⁵ To gain access to records, requests would be sent to all relevant recording organisations. This process facilitates a relationship between record-holders and those seeking access to the data, which can help address any misinterpretation of the records and allow for additional ecological information that may not be held in the database to be shared (see [POSTnote 490](#)). However, research grants are often spent on an independent taxonomist rather than funding or integrating the resources of voluntary organisations into projects.

Other useful UK data sources are available to explore long-term trends for UK insects such as museum collections (physical and digital)^{42,49} and long-term environmental data collected by the Ecological Continuity Trust, an NGO,¹⁰⁶ and the Environmental Change Network, a Centre for Ecology and Hydrology research program.¹⁰⁷ The Environment Agency also collects freshwater insect data as part of its water quality monitoring programme.¹⁰⁸



This is in fact an arachnid, not an insect, image Vidar Nordli-Mathisen

Emerging methods

There are new methods that can help to address the decreased availability of taxonomic skills and experts.¹¹ However, it is important that new approaches develop alongside classical methods (see [HL Paper 162](#)). These methods can use automated technology to identify species. This could lead to greater engagement with data collection as the methods can be cheaper but also require fewer specialised skills at entry.

Artificial Intelligence supported identification methods

Artificial intelligence could help with monitoring insects by automating parts of the identification process. By combining artificial intelligence and image recognition software species identification can be sped up; for example, butterfly species can be identified with 98% accuracy by using automated software.¹⁰⁹ Another example is ‘smart insect cameras’ used in the Netherlands to help automate recording and identifying insects by creating a network of cameras in rural and urban habitats.¹¹⁰ “The cameras are made smart with image processing, consisting of image enhancement, insect detection and species identification being performed, using deep learning-based algorithms.”¹¹⁰ Sampling across sites was standardised by installing the same size of lit-up screens for insects to land on and by taking pictures every 10 seconds.¹¹⁰ The software can then enhance the image and count the insects (with the software recognising and not counting the same individual twice).¹¹⁰ However, some of the automated methods require high computing power that is not usually readily available.¹¹¹ This automated process can be built into phone applications to allow for automated identification in the field (see the [Pl@ntNet app](#)¹¹² as an example). This could increase the accuracy of identification and data collection in citizen science projects.

Molecular techniques

New identification methods such as DNA analysis help address a decreased pool of taxonomic skills (see Box 1) by automating part of the identification process.^{42,49,58,92–95} DNA barcodes (a part of DNA) can be compared with large online data sets to help identify species rapidly and reliably.^{58,92,93} These methods are commonplace for insect identification and are not dependant on the state of the specimen (for example, when identifying multiple life stages or using an incomplete sample).⁵⁸ The presence of species in a habitat can be identified from non-invasive methods that use DNA traces collected from the environment, this is called e-DNA.^{58,113} For example, a study in Zurich found that using e-DNA sampling of freshwaters had medium to very high consistency with the results from the standard method of kick-sampling (placing a net in the direction of flow, with open net mouth facing upstream) and could detect the presence of macroinvertebrates (including larvae of mayflies).¹¹⁴ However, the e-DNA method offers a non-destructive method compared to the standard practice of kick-sampling.¹¹⁴

Using DNA barcodes can be time-consuming, as individual specimens are identified. However, metabarcoding (next-generation sequencing) can identify multiple specimens simultaneously by using DNA or environmental DNA (e-DNA from soil or water).¹¹⁵ For example, a common method involves a malaise trap which are large tent-like screens that insects fly into and are then directed into one large collection bottle. Usually, the bottle would be emptied, and specimens would be sorted and identified individually. However, when using metabarcoding the contents of the bottle can be processed together and matched automatically against a database (as long as the species are all in the database) to identify what species were present in the whole bottle sample. For some data collection methods such as malaise trapping may not require any sorting of specimens before analysis, speeding up the process further.⁵⁸ This could accelerate the identification of species and, if done regularly, help monitor the community composition of sites. To secure the future of long-term data, monitoring schemes could collect and store specimens ready for future DNA analysis as the cost of this analysis continues to decrease. However, these techniques don't reflect the abundance of species present and cannot provide data about population dynamics.

Passive recording

New data collection methods such as bioacoustics⁹⁶⁻⁹⁸, BioDAR^{99,100} and camera traps¹⁰¹ can help to record insect populations passively across larger areas with reduced labour and costs and with the potential to send back live data to inform early warning systems.¹⁰² These data are likely to have fewer gaps across time as systematic recording intervals can be set. These methods could be standardised across recording schemes, species, times and location. There are ethical considerations for passive recording techniques if recorders are in areas where there might be 'human bycatch' (recording sound clips or images of people without consent).¹¹⁶ The passive recording techniques can also substitute changes across space where data are not available across time (for example, comparing changes in biomass of insects in agricultural habitats compared with urban areas). However, it is unlikely that these methods can identify species.

Bioacoustic monitoring involves recording sounds and identifying species or individuals by their acoustic signature (similar to a voice).⁹⁷ This can be used for insects, and even predict the pollinating potential of individual bees.⁹⁸ Advances in this technology can reduce costs while increasing the quality and quantity of data.¹⁰² This technology can also be applied over larger geographic scales or used for citizen science projects. For example, a study in the New Forest generated crowdsourced data using smartphone microphones and software embedded in a smartphone app that could identify the mating call of the New Forest cicada (the only species native to the UK) in real-time and above background noise.¹¹² This greatly increased the sampling across time and space in the search to rediscover the cicada in the New Forest. There were over 1000 users of the app with 6000 records

of insect activity.¹¹⁷ Although the cicada was not rediscovered in the New Forest, the app was proven to be accurate at identifying the same species in real-time field conditions in Slovenia and is used to regularly detect the presence of the cicada.¹¹⁷

BioDAR is developing a method to use weather radar to identify and monitor insect biomass.^{99,118,119,100} Weather radar scans happen as regularly as every 5 minutes and can pick up insect data (particularly swarms, such as flying ants appearing as raindrops on the weather satellites).¹²⁰ This could be rolled out across the UK weather network to record insect abundance, biomass and diversity, and their relationships with drivers of loss (such as habitat availability and connectivity). There is potential to integrate with the UK Biodiversity Indicators datasets. This method is particularly good at recording insects that fly more often in good weather (butterflies, hoverflies and aphids). However, it cannot be used to explore insect decline before the early 2000s.

Camera traps are standard practice for monitoring vertebrates but are beginning to be adapted to help monitor insects.^{101,121} Particular methods of sampling insects can lead to some groups being over-represented (particularly those that sample via pheromones or light attraction).¹⁰¹ However, camera traps aren't biased to particular insects and have the potential to sample insects of a range of sizes and with different behaviours. Some methods for sampling flying insects are focused on identifying the number of different species but not the change of abundance over time.¹⁰¹ The distribution of insect abundance over space and time is often poorly described and usually limited to swarming events (which can be unpredictable).¹⁰¹ However, camera traps can be set up in a standardized and non-invasive manner across a landscape to take pictures at the same regular time intervals to record insects.¹⁰¹ This method can be used to identify insect species when close to the camera or quantify insects at a distance.^{101,122} For example, one study in Queensland, Australia found that using time-lapse cameras (with 1 – 15 min intervals) 'recorded around twice as many insect taxa per day and a third more individuals per day compared to a traditional lethal method of using pitfall traps.¹²² The camera method also captured insects (such as ants, web spinners and cockroaches) that are susceptible to being under sampled as they frequently escape pitfall traps.¹²² Camera traps can be used to record activity, abundance and swarms across seasons, nights, habitats and environmental conditions.¹⁰¹ One study from North-eastern Poland used cameras to explore the change in the number of nocturnal insects over time (over a night and across the change in seasons) as well as changes across space (within and between habitats).¹⁰¹ The camera could identify insects (wing-length 10-20 mm) up to 10 m away and insects in more than 200 m³ of air.¹⁰¹ Smaller insects (wing length of 4-5 mm) could be detected up to 4 m away.¹⁰¹ The method was able to determine peaks in insect abundance in May-June for open, forest and lake habitats and in at the beginning of May for wetlands.¹⁰¹ Across each night insect abundance peaked just after sunset.¹⁰¹ However, this method produces a large quantity of data that requires manual image analysis but automating this process could accelerate analysis.

DRIVERS OF INSECT DECLINE

There are a variety of drivers behind insect decline, and their impacts differ across habitat, species and time. While research is growing, there is still much that is not understood about why drivers appear to affect different groups of insects in different ways (especially as the impacts may have already occurred prior to research being conducted).^{11,68,123,124,38} For example, both bees and hoverflies show a similar level of decline but the greatest decline for hoverflies occurred between 1987–2000, and from 2007 onwards for bees.¹²⁵ Evidence for some known key drivers is summarised below. High-quality, long-term data on drivers are limited (such as land-use change or light pollution). However, the availability of high-quality meteorological data available to understand changing weather as a driver for population trends contrasts this. Drivers may also interact with each other and increase the impact on insect populations. Drawing conclusions about interactions between key drivers is challenging when insect species differ in their life histories (from egg to larvae to adult), such as the timing and length of larval stages and maturation into adults.¹²⁶ However, the effects of these pressures differ between species; for example, exposure to pesticides can make bees more susceptible to parasites.¹²⁷ Habitat loss could also amplify the impacts of pesticides on bees.¹²⁸ Climate change is likely to interact with multiple stressors, such as increased invasive species and reduced habitat availability.^{129–131}

Habitat loss, fragmentation and degradation

Habitat loss and degradation caused by land-use change can reduce the resources for insects across their life stages (nesting sites, foraging sites, shelter from weather and predators).^{132–134} Hostile environments, such as roads, often run through fragmented semi-natural habitats and make it more difficult for species to move ([POSTnote 300](#)).¹³⁵ Land-use change can remove semi-natural and natural habitats such as hay meadows, heath and wetlands. This simplifies the landscape by reducing the range



Reproducing dragonflies, image Clément Falize

of habitats, in turn affecting plant-insect and community interactions. For example, there have been large declines in the nectar resources across Great Britain between the 1930s and 1990s (with just four plants species providing 50% of national nectar reserves in 2007, which supplies a less varied diet of pollen).¹³³ There is potential for these changes to make ecological communities less diverse (made up of a few dominant species compared with a range of species).^{132,136–138} Some habitats are experiencing loss faster than others. Specialist species with specific habitat needs are more vulnerable to the impacts of land-use change.^{132,139} For example, the decrease in brownfield sites is disproportionately impacting species only found in that habitat.¹⁴⁰ Water abstraction and drainage can also reduce habitat availability for insects across life stages that are in freshwaters, such as dragonflies.¹³⁴

Land-use intensification

Large-scale agriculture is often accompanied by high chemical inputs (fertilisers and pesticides), ploughing, grazing and mowing, which can impact insects through habitat loss, degradation and fragmentation.^{3,132,141,142} Although crop monocultures can provide resources such as oilseed rape flowers for pollinators,¹³² they can lead to decreased insect abundance, changes in community composition,¹³⁵ and affect ecosystem service provision.^{60,143–145} For example, large scale crop monocultures can simplify the landscape by reducing flowering plants¹⁴⁶ and nesting sites,¹⁴² although there is evidence that some crops (e.g. oilseed rape) may provide important foraging resources for bees early in the year.^{147,148} Monoculture floral resources are short-lived whereas wildflowers offer resources throughout insect lifecycles.^{133,142,149} Densities of bumblebees, solitary bees, managed honeybees and hoverflies were lower with more monoculture habitats (oilseed rape, sunflower and orange orchards).¹⁴³ Significant winter losses of managed honey bees were associated with monoculture in fruit orchards, oilseed rape, maize, heather and autumn forage crops.¹³⁷ This can impact pollinator and insect communities by reducing abundance or diversity.¹³⁵ This can affect service provision such as yield of pollinator-dependant crops or the success of wild plants.^{142,143}

Urbanisation

Urbanisation is a type of land-use change that can impact the connectivity of habitats through the construction of roads and infrastructure.¹²⁷ For example, moth biomass decreased in urban areas but did not decrease in arable farmland between the 1960s and 2000s.⁴⁷ The same pattern was found for moth abundance, it decreased in urban habitats but not in agricultural habitats (1969–2016).⁴⁶ There is a significant gap in the evidence on the impacts of urbanisation on insects other than pollinators and the

movement of urban insects between habitats. However, urban areas (including gardens or brownfield sites such as Canvey Wick) can support high and unique insect biodiversity.^{137,139,150–157} Some urban habitats have similar levels of pollinators compared with nature reserves,¹³⁸ similar levels of flies compared to non-urban areas,¹⁵⁰ and support higher reproduction and survival in bumblebee colonies compared with agricultural areas.¹⁵² Gardens were also found to support bumblebee nests and survival.^{153–155} However, urban pollinator communities are often dominated by generalist species.¹³⁸ Air pollution and artificial light pollution can impact on insects but evidence on the scale of effects is limited.^{158–163} For example, diesel pollution overpowers natural chemical scents from flowering plants, reducing the ability of honey bees to forage for nectar.¹⁶³ One study found that within one minute of exposure to diesel pollution (at environmentally relevant levels) leads to a reduction in the abundances of four of the chemicals associated with oilseed rape flowers, with two of the components being undetectable by bees.¹⁶³

Artificial light

Although data are limited, artificial light at night is thought to be increasing,¹⁶⁴ which can have lethal and sub-lethal impacts on insects by decreasing fitness through changes in movement, feeding, predation, communication and reproductive behaviour.^{160–162,165–160} Existing evidence focuses on individual organisms, but emerging studies have explored the impacts at a community level.^{170,171} The cascading impacts of artificial light on insects have also been exhibited at the ecosystem level.¹⁷² For example, a decrease in parasitoid wasps was connected with fewer aphids under artificial light at night.¹⁷³ Habitats that are naturally dark at night are fragmented by lighting along roads and limit connectivity for nocturnal insects across environments.¹⁷⁴

Electromagnetic radiation

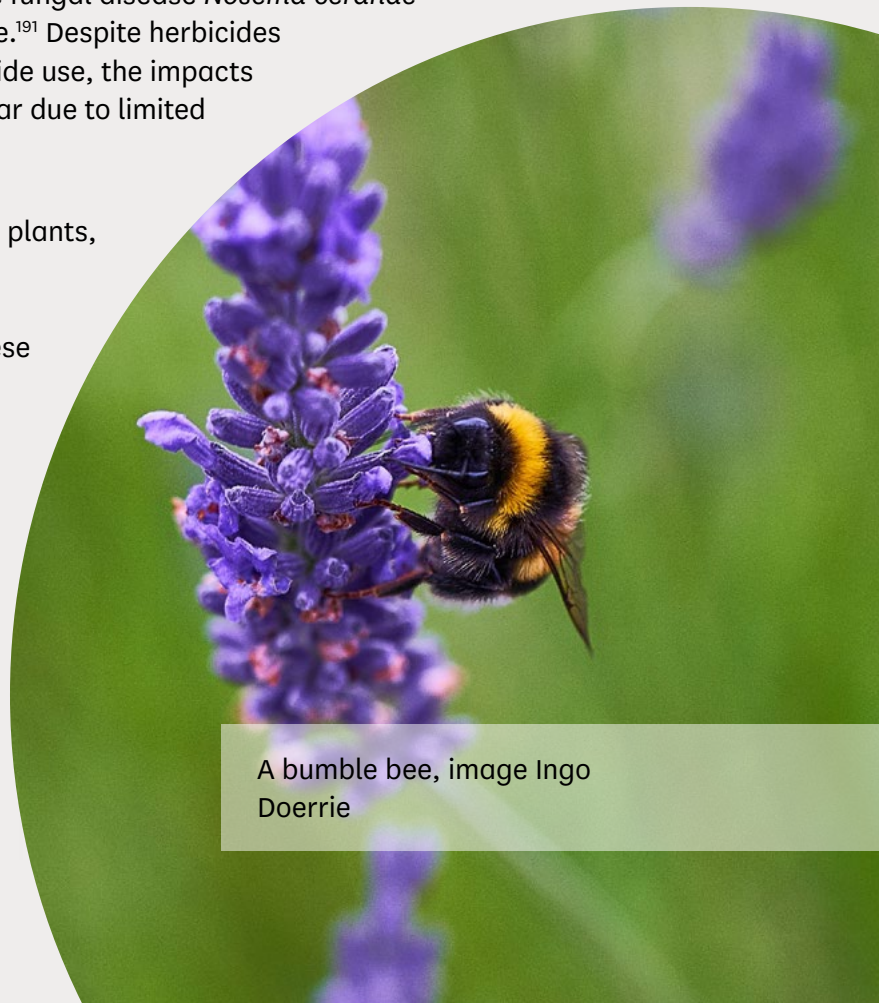
Technologies such as 4G, 5G and power lines emit radiofrequency electromagnetic radiation. There is potential to interfere with insect communication, foraging, navigation, orientation and reproduction.^{159,175–177} Insects (such as bees, flies, locusts and plant-hoppers) may use electromagnetic fields to navigate (similar to how birds use their ‘magnetic compass’ to help them migrate).^{176,178} For example, bumblebees use information from surrounding electric fields to make foraging decisions by using their antennae and special hairs.¹⁷⁶ The real-world effects are unknown due to scarce data and a lack of high quality, field-realistic studies.¹⁵⁹ Current evidence has focused on the impacts of electromagnetic radiation on fruit flies, beetles and ants, but is skewed towards pollinators, particularly commercially managed pollinators such as honey bees.¹⁵⁹ For

example, one-laboratory-based study found a link between radiofrequency electromagnetic radiation (equivalent to that emitted from powerlines) and a decline in worker bee learning and memory.¹⁵⁰ Most studies are laboratory-based.¹⁵⁹ It is therefore difficult to translate these findings into a natural habitat setting and assess the impacts at an ecosystem level.¹⁵⁹ A few such field studies exist, but they show inconsistent effects of electromagnetic radiation on the abundance and diversity of pollinators.^{159,179}

Pesticides, fertilizers and veterinary medicines

Chemicals are used in rural and urban environments that can have negative impacts on non-target wildlife,¹⁸⁰ including insects.^{132,141,148,181-199} For example, neonicotinoids can have a lethal effect on bees (Box 3). These chemicals can have indirect negative impacts on non-target wildlife,¹⁸⁰ including insects.^{141,148,181-185,187-192} Insects are often exposed to a mixture of chemicals,¹⁷⁴ this can increase toxicity and stress,^{183,184,200} but the impacts of this combined exposure remain unclear.¹²⁴ For example, one study of wild pollinators found that 71% (of individuals with detectable levels of agrochemicals) were exposed to more than one chemical substance.¹⁸⁵ Another study found that bumblebee exposure to a combination of two pesticides (neonicotinoid and pyrethroid) decreased colony success.¹⁷⁵ The toxicity of neonicotinoids also increases with co-exposure to pesticides.^{187,201} Fungicide exposure is common in wild bumblebees but little is known about its impact.¹⁸² Fungicides can kill gut cells and increase levels of the fungal disease *Nosema ceranae*¹⁸² and impact the honey bee microbiome.¹⁹¹ Despite herbicides constituting 40% of worldwide pesticide use, the impacts of these chemicals on insects is unclear due to limited research.²⁰²

Chemicals can accumulate in soil and plants, affecting ecosystems.²⁰⁰ For example, bovine health treatments (injections/oral treatments) build up in dung. These chemicals can greatly decrease the density of beetles and flies (adults²⁰³ and larvae²⁰⁰). When more than one chemical was present in dung, a reduction of 86% was seen in the abundance of larvae. This was linked to the decline of the red-billed croucher that feeds on insects in dung.¹⁹² Accumulated chemicals in plant and soil matter can also be washed by runoff into water systems, leading to exposure and



A bumble bee, image Ingo Doerrie

Box 3. Neonicotinoid pesticides

In 2018, an EU-wide ban was applied due to poisoning and sublethal effects on pollinators¹⁴³ (which can translate to reduced reproduction or colony level failures)²⁰⁵ but evidence for other insects is limited (Commons Briefing Papers SN06656).^{206–208} Exposure to neonicotinoids reduced foraging efficiency, colony reproduction and overwintering success in honey and wild bees, and increased declines in solitary bee populations.^{148,188,201,209} Bees also prefer consuming neonicotinoid-treated food, making it difficult to control their exposure as they were not deterred by taste.^{210,211}

The impacts of neonicotinoids on insects is context-specific. One study found that the impacts of neonicotinoids could be amplified with the presence of other stressors such as reduced foraging resources (amount or lower nutritional value) or pathogens and disease.¹⁸⁸ It also found that some positive effects of neonicotinoids on effects on colony size can occur in the absence of other stressors.¹⁸⁸ There are few long-term, field-based studies that explore the sublethal impacts at an individual and colony level.¹⁹⁸

Neonicotinoids can also negatively impact aquatic systems.^{180,184,212,213} A report found that 88% of 23 UK freshwater sites were contaminated with neonicotinoids, some probably coming from flea treatments applied to pets and then passed into the water system.¹⁸⁴ The reduction of aquatic insects can impact higher levels of the food chain such as fish,⁶² bats²¹⁴ and birds.¹⁸⁰ One study in the Netherlands found that just 20 nanograms of neonicotinoid per litre of water led to a 30% fall in bird numbers over 10 years.¹⁸⁰

Risk of exposure remains, with persistent detectable levels (20% of 109 honey samples²¹⁵) and increased toxicity across environments.^{185,216} After the ban the risk for rural bumblebees declined while the risk for bumblebees in peri-urban areas remained the same.¹⁸⁵ This highlights the widespread use of neonicotinoids across systems (agriculture and urban areas). For example, neonicotinoid residue was found in wild plants and pollen.^{217,218} In some cases the exposure to neonicotinoids in wild plants was higher and more prolonged compared with treated crop fields.²¹⁸ New insecticides (such as sulfoximines) have emerged in response to the neonicotinoid ban, but as yet there is limited evidence on the impacts of these on insects and ecosystems.^{132,202,219–221}

impacts for freshwater insects (Box 3).^{200,203,204} However, there is limited evidence on the impacts of pesticides, herbicides and fungicides on insects other than pollinators, as the majority of evidence has explored impacts of neonicotinoid pesticides on a limited range of pollinators (Box 3).¹⁸¹

Climate change

Climate change can affect individual insect species both positively and negatively.^{56,131,141,222–232, 233} For example, due to a warming climate, aphids had an earlier and longer flight season and were able to reproduce more compared to previous years, becoming more abundant.^{224,234} Another study of 66 bumblebee species across North America and Europe found that the increase in the number of unusually hot days was driving declines in colonization, distribution and species richness, and higher local extinction rates (1901–1974 vs 2000–2014).²³² Species richness was more likely to decline in regions experiencing warming, particularly if a species was present in the warmest parts of their range.²³² The larger and more widespread declines described in this study, particularly in Europe, are due to potential underestimates of richness in previous studies; as the best-sampled regions in Europe began cooler and have experienced less warming compared to other parts of the continent.²³²

Changes in weather and temperature can alter the timings of insect life-cycles that can negatively impact fitness or prevent emergence altogether.^{70,155,234–240} Of 130 butterfly and moth species, 39 had increasing abundance but early emergence led to neutral or negative impacts for 91 species.²⁴¹ Changes in climate can lead to changes in species ranges; for example, some species have moved northwards and upwards in the UK, while others have contracted.^{56,129,225,232} The changes in communities can lead to temporary increases in the number of species through the rise of novel ecosystems.²⁴²

Evidence on the links between climate change and insect extinctions, population dynamics and ecological interactions is limited making it difficult to predict impacts through modelling. However, one modelling study of butterflies in the UK predicted extinctions of widespread but drought-sensitive species.²³⁰ Climate change is also likely to interact with other stressors; including invasive species, land-use change, and habitat degradation, fragmentation and loss (or expansion); but is also considered to be an important driver on its own.^{226,232}

Invasive species

Invasive non-native species (POSTnotes [303](#), [394](#), [439](#)) can create opportunities (such as increased pollen availability) or risks (such as changes to species interactions or increased predation).²⁴³ The impact of the invasive species depends on its abundance and the role it plays in the system, but the perturbation of communities can lead to temporary increases in the number of species through the rise of novel ecosystems.²⁴² For example, some invasive plants are readily taken up by native pollinators.²⁴³ Invasive plants could act as a hub for insects,^{244,245}

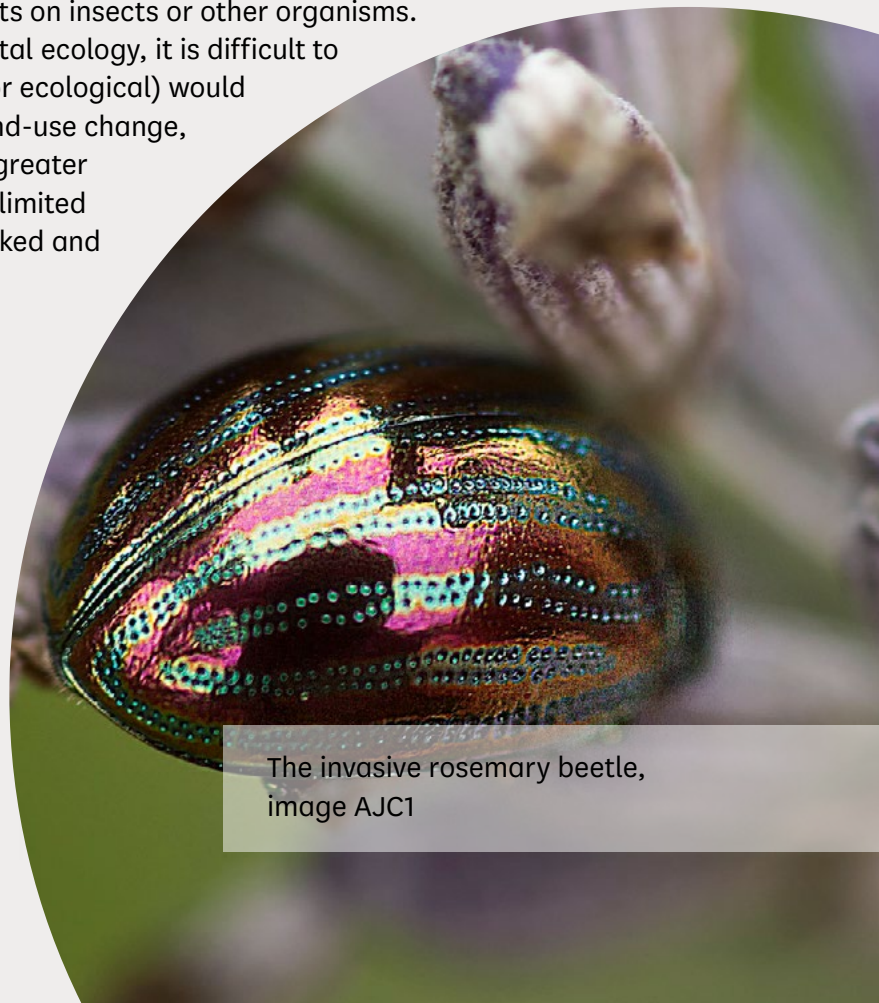
but subsequent management and removal of these plants could trigger secondary extinction cascades due to reliance on the invasive plant.²⁴³ Invasive plants can provide food resources but could alter the availability, timing and nutritional value that could cause deficits in essential nutrients for native pollinators,²⁴³ and some can even be toxic.²⁴⁶ There is very limited evidence on the impacts of invasive plants on UK insects. However, one study found no impacts of invasive plants on pollinator abundance or functional diversity.¹³²

Invasive insect predators tend to have strong top-down pressure on insects.^{143,247,248} For example, the Asian hornet hunts honey bees and wild pollinators.¹³² The presence of other stressors, such as disease, can make bees more vulnerable to predation. The harlequin ladybird has been linked to declines in native ladybirds by eating native ladybird eggs and out-competing them for food.^{247,248} One study found declines in seven of eight UK ladybirds after the arrival of the harlequin ladybird, with the two-spot ladybird declining by 44% in 5 years.²⁴⁷ The impact of the harlequin ladybird on native ladybirds differed across habitats (impact was seen in lime tree sites but not in pine or nettle sites).²⁴⁸

Little is known about the impacts of other invasive insects on native insects but climate change is likely to lead to the expansion of the range of previously non-native species, creating novel communities. The UK Plant Health Risk Register²⁴⁹ is a comprehensive resource to assess the potential for pest invasion and its impacts. However, it focuses on insect pest species that are likely to cause an economic impact on plants and doesn't include those with potential ecological impacts on insects or other organisms. Without understanding the fundamental ecology, it is difficult to predict what the impacts (economic or ecological) would be. Other drivers of insect decline (land-use change, habitat loss, pathogens) may have a greater impact on insect declines,²⁴⁴ but with limited knowledge, the risks could be overlooked and understudied.²⁴³

Pests and diseases of insects

Current evidence is biased towards pollinators, particularly honey bees.¹⁸¹ Infections such as the deformed wing virus (DWV), associated with infestations of the *Varroa* mite, and chronic bee paralysis virus (CBPV) can contribute to declining honey bee



The invasive rosemary beetle, image AJC1

numbers.^{132,250} However, the data on their contribution to recent declines remain unclear.²⁵¹ The management of disease risk is reliant on good bee-keeping practice.^{132,252} For example, a recent European-wide study found a winter colony loss of 25% (2012–13) was explained by bee-keeper practices increasing *Varroa* mite infestations.²⁵² There is limited knowledge of how these diseases impact ecosystem services¹²⁴ or wild insects.^{132,181,253}

Managed bees (honey bees^{253,254} and bumblebees²⁵⁵) share pathogens with wild pollinators, with potential for negative impacts (see bumblebees, solitary bees or hoverflies, but the direction of infection remains unclear.^{253,255–257} Imported commercial bumblebees could also act as a source of parasites and pathogens for wild pollinators, but only limited evidence exists on these risks.^{132,255}

Genetically modified and edited crops

Existing genetically modified crops have the potential to impact insects through changes in management practices, such as insect-resistant and herbicide-resistant crops.^{132,143} Currently there are no such agricultural genetically modified organisms (GMOs) grown commercially in the UK and there is very limited evidence base exploring the impacts of GMOs on insects.^{132,143,258}

Insect-resistant crops are aimed at herbivorous larvae of butterflies, moths or beetles. There is little evidence on the impacts this has on insect communities, although resistance has evolved in some insect pest species targeted.^{143,149,259} For example, a toxin produced by the soil bacteria *Bacillus thuringiensis* has been used to kill pests in organic farms and has been incorporated by genetic modification into crops.²⁶⁰ When the toxin is ingested by insects it destroys its gut and kills it.²⁶⁰ However, insects are becoming more resistant to the toxin as changes in the way their gut process it is making them less susceptible.²⁶⁰ A review of evidence from 77 studies across five continents (Africa, Asia, Australia, Europe and North America) found increased resistance to this toxin in the field (2005: 1 of 13 major pest species vs. 2013: 5 of 13 pest major species were resistant).²⁶¹ However, the authors note that most pest populations remained susceptible to the toxin but that there was reduced efficiency.²⁶¹ Although there is potential for Bt crops to have negative effects on pollinators, a meta-analysis of the current evidence didn't find any direct negative effects of these crops in pollinators.²⁶² If insect-resistant crops lead to reduced use of insecticides then some pollinators could theoretically benefit from reduced exposure^{143,149} However, the introduction of insect-resistant crops could have also affected the relationships between insects, ecological function and higher levels of the food chain.^{132,143,149}

Genetically modified herbicide-tolerant crops require regular application of herbicides to reduce weeds.¹³² This is likely to reduce the supply and diversity of pollen and nectar.¹³² There is little evidence globally for the long-term impacts of herbicide-tolerant crops on insect communities and service provision.¹⁴³ There is also a lack of evidence on the impacts of the genetically edited crops being developed ([POSTnote 548](#)), but one study has shown that changing the fatty acid profile of oilseed rape for human nutrition and reducing environmental impacts of aquaculture may have negative effects on insect physiology (such as wing deformities) and survival as these compounds accumulate in the food chain.^{263–265}

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