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Insects in the age of extinction

It is undeniable that we are now in the sixth great extinction. Traditionally, concern has been focused on birds, mammals, and other charismatic taxa. However, in recent years, entomologists have noted that insects too are declining. Because insects are critical to almost all key terrestrial ecosystem processes, this has sparked major concern. The first signs of a problem were honeybee colony deaths in the mid-2000s and declines of the iconic monarch butterfly, but now there is acknowledgment of widespread reductions in insect abundance.

There are two inter-related questions when considering insect declines: are we losing numbers of species (loss of diversity), or are populations of insects declining (loss of abundance)? These two questions have different consequences for ecosystem function. While traditional conservation efforts have focused on the preservation of rare species (i.e., combating loss of diversity), the loss of abundance is of greatest concern for ecosystem function. This is because the role a rare species takes in the ecosystem (e.g., as a pollinator) is often also fulfilled by a more common species. However, if the abundance of these common species declines, there won't be back-up to fulfil these roles.

To quantify insect decline, the gold standard is historical records of abundance that cover multiple time points. The lack of these is a major limitation in our ability to assess the problem. There are very few sites where records go back for more than 30 years—and if industrial agriculture is part of the problem, we need records that go back to a time before that.

The long-term records that we do have are heavily biased toward certain countries—unsurprisingly, in Europe and North America, with the best records coming from the UK, the Netherlands, and Germany (van Klink et al., 2020; Sánchez-Bayo & Wyckhuys 2019). There are very few long-term records for most of the globe, particularly in South America, Africa, and tropical Asia, i.e., the places with the greatest levels of biodiversity. Without better datasets, we won't be able to get a handle on whether this is truly a global phenomenon and thus determine what factors are driving the decline. Long-term records from Costa Rica, however, strongly hint at this being an issue of global concern (Salcido et al., 2020).

Image 1: Mint Images

The need for long-time series is highlighted by the meta-analysis by van Klink et al. (2020), who reported that freshwater insects were, in fact, increasing while terrestrial insects were declining. However, not only do most of the datasets used in the meta-analysis come from Europe and North America, the majority start sometime after 1975. Therefore, it is likely that the increases in freshwater insects observed is primarily due to reductions in gross pollution over the past 30 years and that the insect fauna in the rivers and streams was at a low point when collection started. We simply don't know what the freshwater insect fauna was like prior to this, so we don't know what our baseline should be. Given that the current datasets have serious geographic and taxonomic biases and the number of historical datasets is limited, there is a push to develop other ways to assess the problem. Optimal approaches are likely to involve a range of techniques.

A lot of the traditional methods of assessing insect diversity require an expert taxonomist to manually go through samples collected and tally up the individual insects collected. DNA barcoding will help to resolve some of this laboriousness, but current high-throughput methods are unable to reliably assess abundance. Development of technologies involving various sensor technologies linked to deep learning tools for species identification has challenges but the potential to resolve some of the complexities in monitoring of insect populations (Høye et al., 2021). However, these techniques only allow us to compare different sites. If drivers of the declines are universal (e.g., climate change), none of the sites will be a suitable "control."

Researchers are working on the temporal problem in two ways. First, there's the development of techniques to integrate different sources of information such as museum specimens to extend the coverage of these datasets. However, these too will have limitations; museum records, for example, provide presence-only data and are heavily biased toward certain species.

Second, researchers are developing techniques to better deal with heterogeneity within datasets. As populations fluctuate naturally, it can be hard to identify a 1%–2% annual decline in a population that might fluctuate by 2–3 orders of magnitude over a few years. This can require aggregating data at higher taxonomic or functional levels but requires a good understanding of the traits of the species in the dataset, so that trends in subset of taxa are not obscured (Wagner et al., 2021).

Developing additional approaches to measure changes in species abundance will allow us to ask more sophisticated questions about the roles of different drivers in causing species abundance changes. The three primary drivers of declines are climate change, land-use change, and pollution (Sánchez-Bayo & Wyckhuys 2019). However, myriad other factors, such as invasive species, will likely also contribute. It is most likely that all these factors play a role, and the relative effect of these factors is dependent on both the species and the habitat the species occurs in. Critically, declines have been reported from both within and outside protected areas. Substantial research is underway to better understand the different drivers and how they interact.

The most obvious effect of climate change is the increase in temperature. However, this is creating both winners and losers. For example, many species of British moths that are increasing in abundance are species that were formerly limited by temperature (Fox et al., 2014). However, the species at the southern edge of their range were declining, a pattern also seen in Massachusetts, USA (Breed et al., 2013). The change in distribution or abundance can be a direct effect of temperature on the insects or can be caused indirectly by changes in distribution or abundance of the host plant. Precipitation changes will also alter the distribution and abundances of both plants and insects, although the effects of this are largely unknown at the present.

A more insidious effect of climate change is that rising CO_2 levels decrease plant nutritive value. Recently, Welti et al. (2020) showed that in an unmodified grassland in Kansas, USA, plant biomass increased 30% between 1985 and 2016, but plant nitrogen declined by 42%, phosphorous by 58%, potassium by 54%, and sodium by 90%. Over the same time period, grasshopper abundance declined by 2.1%–2.7% annually, and the decline in plant nutrients directly accounted for 25% of this decrease. While changes in plant nutritional composition with climate change have been extensively recorded, this is the first study to link it to insect declines. Whether this is a general phenomenon remains unknown but has potential global consequences.

Pollution is almost certainly responsible for some of the declines, as evidenced by the increasing numbers of freshwater insects seen in Europe following various clean water initiatives. Pollution comes in myriad forms including light pollution and increasing atmospheric nitrogen. Neonicotinoids and fipronil, both agrochemicals, are suspected of driving declines. While we should perhaps be unsurprised that an insecticide isn't great for insects, we are still gaining an appreciation of the sublethal effects of insecticides and its population consequences. For example, Forister et al. (2016) correlated declines of lowland Californian butterfly fauna since the late 1990s to increasing neonicotinoid use. Major gaps in our understanding include how sublethal amounts of chemicals affect insect populations and how insects (and other taxa) respond to the complex mixtures of chemicals they encounter in their environment.

It almost goes without saying that converting natural habitats, such as tropical forests, to urban and agricultural landscapes involves a reduction in insect diversity and abundance. Approximately 40% of the world's land area is devoted to human food production, and this percentage is growing. Even within countries such as those in northern Europe, where forests were felled centuries ago, agricultural land use is intensifying, with larger fields and greater monocultures. The removal of hedgerows and ditches, loss of fallow fields, and elimination of weeds all lead to a reduction in plant biodiversity and thus insect diversity.

Insects are critical to the functioning of terrestrial ecosystems—they pollinate plants, break down dead and decaying matter, transmit disease, and are a critical food source for other animals. A reduction in insect abundance and diversity will have lasting consequences for all ecosystem function. While we need to better quantify the extent of the decline and establish which drivers are important for different taxa, in different habitats, or in different parts of the world, we need to acknowledge our responsibility. The drivers of the declines, be they climate change, land-use change, or pollution, are all within our power to change; it's a matter of political will.

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