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Editorial overview: Global change biology (2023) — Novel perspectives on futures, mechanisms, and the human element of insect conservation in the Anthropocene

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The Greek philosopher Plato famously referred to lands overused for agriculture as a "body wasted by disease" [2], and this concern for human impacts on the natural world has ancient roots in nearly every society. In modern times, the field of conservation biology as a distinct academic endeavor is about 45 years old [1]. Thus, it is curious to say that widespread concern for insects feels like something new. Many species of individual insects have been the focus of modern conservation efforts before and during the 21st century, and nonscientists have been familiar with biodiversity declines and catchphrases like "save the bees," even if it is not always clear what the research or management goals of such slogans might be. Something did, however, change with the publication of Hallmann et al.'s [3] report on massive declines in the biomass of flying insects across protected areas in Germany, which set off a cascade of popular media attention and similar reports from different parts of the world, including the introduction of the idea that the "Insect Apocalypse" is a quintessential component of the Anthropocene.

Before 2017, many entomologists had argued for the functional and aesthetic importance of individual species and communities, which involved much fine work but did not generate the attention that insects have had in the last few years. In hindsight, it is hard to know where the failure of imagination was most critical. Was it with the general public who perhaps relate best to the importance of insects when measured in bulk? Or was it the failure of scientists for not recognizing that reality sooner? In any event, there is no doubt that we are in the era of insect declines. Or we might just as well call it the era of *reviews* of insect declines, as the subject has been heavily treated in both quantitative and qualitative reviews as well as in opinion pieces and scientific editorials, yet actual, analyzable long-term data sets, especially from tropical ecosystems, are still needed.

Given the context of a heavily reviewed topic, our goal in this issue was to look for new perspectives on insects in the Anthropocene not always captured in other treatments of insects and global change. We start by looking to the future with the critical issue of ecological forecasts. Bahlai reviews analytical tools and approaches that show the most promise for predicting the densities of individual populations in coming years. Special consideration is given to the challenges that derive from the great diversity

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of insect natural histories and intrinsic population dynamics. One conclusion is that species-specific models might indeed be possible in many cases where demographic knowledge is sufficient, but qualitative models might in other cases be more valuable for motivating conservation and guiding management. Mayekar and Rajpurohit also investigate forecasting tools, but with the complementary objective of understanding extinction risk, discussing foundational topics such as inbreeding depression from an insect genomic perspective. The optimism of those pragmatic and tool-oriented reviews is tempered when we remember that the vast majority of insect diversity is at lower latitudes that have received less attention. The review by Slade and Ong investigates the future of tropical insect diversity, highlighting the need for collaboration between ecologists and taxonomists and for capacity building and the involvement of parties historically excluded from scientific discovery.

Although uncertainty pervades forecasts and our understanding of complex systems moving forward, we fundamentally understand that the most important global change stressors can be parsed (with some fuzzy membership in multiple categories) into climate change, habitat loss, and habitat degradation, including pesticide contamination, invasive species, light pollution, and other factors. Habitat loss and degradation were dominant forces throughout much of the 20th century, but the multifaceted importance of climate change is now becoming increasingly apparent. The next five reviews form the climate change core of the special issue, starting with Neupane et al. and a deep dive into the practice of using species distribution models to understand the impacts of a shifting climate on insects, including a quantitative summary of 53 published studies from the past 5 years. Results include the possibility that pest species are more likely to benefit from warming conditions, and Guo et al. advance grasshoppers as a model taxon for tracking climate change impacts. They make that case by discussing important interactions between climate change and land use, including grazing, that have been revealed by the study of grasshopper populations and diversity. A similar thesis with a focal taxon of economic importance is developed by Lemic et al. who use citrus blackfly (*Aleurocanthus woglumi*) to discuss the intersection of climate change and the regulation and management of pest species. They advocate for a multipronged approach to the problem, including proactive biocontrol, surveillance, and sensible regulations.

The fourth and fifth reviews in our group of climate-focused papers tackle mechanisms and organismal processes that will likely be productive areas of research in the coming decade. Mason and Shikano take on the web of interactions involving rising temperatures, insect immunity, and gut microbiomes, including pathogens. Not surprisingly, the organismal outcomes of these interactions are not well understood and reported effects, thus far, are often species-specific. Among other potential findings, this review highlights the possibility of key trade-offs between how insects handle abiotic stressors while coping with specific pathogenic microbes. Organismal complexity is also the focus of the review by de Carvalho, who summarizes our current understanding of epigenetic effects on insects responding to climate change, primarily rising temperatures. They call for more studies before we can know if epigenetic mechanisms will mitigate or exacerbate the effects of abiotic stressors.

Although the impending threats of climate change dominate much public and scientific thinking about global change, it is essential that we not lose

sight of the diversity of threats faced by insects in the Anthropocene. In many cases, other threats are far more proximate and will reduce populations below levels where they can respond effectively to climate change. Schmidt-Jeffris takes on the essential issue of nontarget pesticide effects, whose importance has only grown in recent decades in the context of widespread neonicotinoid use and ever-intensifying pressures on agricultural systems to produce for a growing human population. Among other issues, this review discusses the topic of sublethal pesticide effects, which are potentially far more pervasive and impactful than outright lethal effects in many contexts. They stress the need for more synthetic work to scale laboratory results to field-realistic levels. This is a crucial but daunting challenge, given the diversity of the chemical marketplace and the speed with which the application landscape changes.

In the landscapes that have been most intensively modified by human activity, insects are not only exposed to pesticide contamination but also to plant communities that have been transformed by the naturalization of exotic plants. Braga asks if exotic plants are ecological traps for herbivorous insects, focusing on butterflies where the question has a long history of research. One of the positive aspects of this subfield of study is that the global change question (of exotic plants affecting native insects) has the benefit of advancing our basic understanding of many aspects of insect herbivory. This review delves in particular into the genetic basis of host plant use and top-down effects. Other intriguing plant issues emerge in the review by Salazar et al., who look at the effects of salinization on insects as mediated through changes in plant chemistry. At least for entomologists, salinization is a less frequently studied aspect of global change, but these authors make a convincing case that salinization has powerful effects on all aspects of plant growth, including the production of specialized secondary metabolites. This topic has almost exclusively been examined in agricultural systems with pest insects but clearly deserves attention in natural systems and encompassing other interactions, including pollination and natural enemies. Along with potential global change effects that propagate through plants, wildfires (especially catastrophic fires) have become more common in the current century. Dole et al. dissect the issue from the perspective that smaller fires can play an essential and positive role in the maintenance of insect diversity, while the largest fires increase the risk of extirpation and extinction because refugia are destroyed and recolonization is much slower.

The next four reviews turn the focus more specifically on humans and human spaces, starting with Diamond et al. who discuss the ecology of urban spaces and the need to design or modify cities so that the urban islands can support viable populations of the insects coping and adapting with those intensely modified spaces. We need a more mechanistic understanding of urban effects on insects, especially climate change in order to make the best infrastructure decisions moving forward. The next two reviews by Leandro and Fukano and Soga address the most daunting human aspects of global change, including political and psychological barriers to insect advocacy and conservation. It seems likely that negative emotional responses that many people have in response to insects are getting worse in more dense urban areas and with less exposure to nature. In response to that problem (human separation from the natural world), Prudic et al. offer one of the more hopeful reviews in this issue by outlining the scope and efforts of insect community science. The incorporation of community-generated and community-outsourced data into core questions of global change biology has the potential to dramatically advance our understanding of insect distribution and abundance.

Although many of the perspectives represented by these papers are new, the problems being addressed all stem from the biodiversity crisis, which of course is not new. The recent trend of referring to "insect declines" as something distinct has perhaps been a logistical necessity to motivate and organize attention. And, given the importance and magnificence of insects, why should their crisis not be a distinct area of study? We hope that the diversity of the reviews in this issue adds to that area of study and prompts even more creative thinking, research, and action in the coming decades.

Declaration of Competing Interest

The authors declare that the content of this paper was not affected by any financial, commercial, legal, or professional interest.

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