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DOI: https://doi.org/10.1111/icad.12409

Didham, R.K., Barbero, F., Collins, C.M., Forister, M.L., Hassall, C., Leather, S.R., Packer, L., Saunders, M.E. and Stewart, A.J.A. 2020. Spotlight on insects: trends, threats and conservation challenges. *Insect Conservation and Diversity*.

4 March 2020

Insect Conservation and Diversity

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Journal:	*Insect Conservation and Diversity*
Manuscript ID	Draft
Manuscript Type:	Special Issue Article
Date Submitted by the Author:	n/a
Complete List of Authors:	Didham, Raphael; The University of Western Australia, School of Biological Sciences Barbero, Francesca; University of Turin, Department of Life Sciences and Systems Biology Collins, Tilly; Imperial College, Biology Forister, Matthew; University of Nevada, Reno, Biology Hassall, Christopher; University of Leeds, School of Biology; Leather, Simon; Harper Adams University Packer, Laurence; York University, Biology Saunders, Manu; University of New England, UNE Business School; University of New England, Environmental & Rural Sciences Stewart, Alan; University of Sussex, Biology & Environmental Science
Keywords:	citizen science, global insect decline, insect conservation, monitoring, population trends

SPECIAL ISSUE

Spotlight on insects: trends, threats and conservation challenges

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Running title: Spotlight on insects

Abstract

1. There is mounting concern over the conservation status and long-term trends in insect populations. Many insect populations have been reported to be falling and many species are threatened with extinction. While this is true, the evidence does not support unqualified

statements of ‘global insect decline’. Global environmental change does not affect all species equally, and there are clear winners as well as losers from anthropogenic impacts.

2. In this special issue of *Insect Conservation and Diversity*, we draw together articles that (i) identify key challenges in robust inference about insect population trends, (ii) present new empirical evidence for declines (and increases) in insect populations, spanning whole communities down to single species, in both aquatic and terrestrial ecosystems, and (iii) address the interacting drivers of population change, from empirical studies of environmental correlates, to experimental manipulation of driving mechanisms.

3. We argue that the way forward for insect conservation includes more nuanced language and approaches when communicating ecological evidence to peer and public audiences, beyond just a simplistic focus on the insect decline narrative. This will require an expanded portfolio of approaches to promote the value of insects to society, which in turn, should reinforce the social licence to prioritise insect conservation research. This should help us to deliver the rigorous science necessary to document ongoing trends, and understand the drivers and mechanisms of population change. Only then will we be able to mitigate or reverse declining populations.

Keywords: citizen science, global insect decline, insect conservation, monitoring, population trends

Clear, concise statements are needed to convey urgency to a broad audience – ‘Insects are declining’ – is one such statement that has received global attention. Unfortunately, the intent behind many of the scientific articles is often misinterpreted as a result of dramatic language which the media then amplifies, potentially leading to inaccurate sensationalism. As scientists, we have an obligation to weigh up the objective empirical evidence to support or refute such claims, over and above our subjective advocacy of a normative position that might influence policy (*cf* Vucetich & Nelson, 2010). Therefore, we might retort that the situation is indeed serious, because some (perhaps many) insect species are declining across most taxonomic lineages in most regions of world, and at potentially increasing rates as anthropogenic impacts intensify globally. 'But' (the scientists' qualifier) there are also many other insect species expanding their geographic ranges in response to changing climatic conditions, or increasing in abundance in cases where they benefit from human activities. Adding such qualifiers to general decline statements is more balanced, but presents a much more complex and nuanced picture that may not be as immediately comprehensible for non-scientists (and media reports). A similar challenge arises when communicating scientific evidence with respect to the causes of declines. It is abundantly clear from decades of scientific research and conservation management that habitat loss and degradation combined with climate change are the leading stressors for insects and other groups. That remains true even when it is challenging to rank the stressors in terms of impact for any one species or in different locations. Conveying that subtlety (what we know about drivers of decline in general versus for any one species) is an important challenge for scientists moving forward in an increasingly anthropogenically-modified world. For all of these issues, the challenge is to convey the seriousness of concern, without alarmist rhetoric.

Here, we compile a special issue of *Insect Conservation and Diversity*, 'Spotlight on insects: trends, threats and conservation challenges', comprising a collection of 12 articles that not only draws together new long-term empirical data on declines (and increases) in insect populations, spanning whole communities down to single species, in both aquatic and terrestrial ecosystems, but also identifies key challenges in making robust inferences about population trends, and addresses the interacting drivers of population change. Together, the articles in the special issue present a forward-looking prospectus for the future of insect population monitoring, that we hope will stimulate more robust integration and validation of available data, new opportunities for more creative exploitation of technological of computational advances, and an expanded portfolio of strategies for promoting the importance and value of insects to society.

In the lead article, our team of editors at *Insect Conservation and Diversity* presents a perspective on the inherent risks of making broad statements about 'global insect decline' if the quantitative evidence underpinning these statements is still a subject of ongoing investigation and even uncertainty (Didham *et al.*, 2020). Didham *et al.* (2020) identify seven key challenges in drawing robust inference about insect population declines, ranging from establishment of a reliable historical baseline, representativeness of site selection, robustness of time series trend estimation, and mitigation of detection bias effects, to the ability to account for potential artefacts of density-dependence, phenological shifts and scale-dependence in extrapolation from sample abundance to population-level inference. Meeting all of these issues head-on will be a challenge, but Didham *et al.* (2020) present pragmatic guidelines for best-practice approaches that will help avoid methodological errors, mitigate potential biases and produce more robust analyses of time series trends in the future.

Some of the most compelling evidence for changing insect population trends through time has come from long-term monitoring networks using standardised insect sampling devices, such as suction traps, light traps, pitfall traps or Malaise traps. Bell *et al.* (2020) present quantitative time series trends for aphids and moths in the UK, drawn from the world's longest standardised terrestrial insect time series at the Rothamsted Insect Survey. From light-trap data at 112 sites (25 for suction traps) and time series of up to 48 years in length, Bell *et al.* (2020) show that moths declined in abundance by over 30% from 1969-2016, while aphid populations did not exhibit directional change over the same time period. Moreover, moth declines were not ubiquitous across species or habitat types, with robust and biologically-significant declines only found in coastal, urban and woodland habitats, but not in agricultural, parkland or scrubland habitats (Bell *et al.*, 2020).

In the Netherlands, Hallmann *et al.* (2020) monitored populations of a number of different terrestrial and aquatic insect taxa using light trapping and pitfall trapping at up to 48 sites over time series of up to 26 years, and detected declines in abundance and biomass (of up to 40-60%) for moths, beetles and caddisflies, while true bugs, mayflies and lacewings did not exhibit similar changes. Even in those groups showing declines, not all species were affected equally. Moth species associated with grass or herb host-plants were more severely affected, as were ground beetle species that were closely associated with xerophytic habitats (Hallmann *et al.*, 2020). This would tend to suggest that land-use and land management changes were important drivers of population trends, but causal mechanisms could not be specifically identified.

Meanwhile, Roth *et al.* (2020), present one of the rare examples of long-term monitoring of insect species in freshwater pond ecosystems, over a 28-year period in southern Germany. The authors explicitly account for natural successional changes in water chemistry and habitat conditions that might lead to the loss of water beetle species from early-successional pond habitats over time. They found an overall decline in abundance and loss of species due to the eutrophication of mature fen and moorland ponds, although there was a trend to increasing abundance with some environmental attributes (Roth *et al.*, 2020). Together, these effects resulted in a decline in habitat specialist species, a reduction in overall water beetle diversity and homogenization of community composition across pond networks.

These themes of varying taxon-specific responses through time and strong context-dependence of responses to varying drivers of population change are exceptionally well demonstrated in the Catalan Butterfly Monitoring Scheme. Ubach *et al.* (2020) compiled citizen science monitoring records for 147 butterfly species at 54 sites in Catalonia, Andorra and Menorca over time series varying from 10 to 21 years, and found an overwhelming decline of open-habitat specialists and increase in forest habitat specialist species through time as widespread agricultural land-abandonment led to forest encroachment (at >75% of all sites). The winners and losers in long-term population trends are dependent on the causal driver(s) of decline. In this case, abandonment (not intensification) of agriculture leads to population decline in open-area specialists (Ubach *et al.*, 2020), at least some of which are of conservation concern.

Extensive use of citizen scientists in survey programmes and non-lethal approaches to monitoring insects also feature heavily in long-term single-species monitoring of iconic or threatened species of conservation concern. For instance, Gardiner & Didham (2020) present an 18-year time series of standardised transect survey counts of glowing adult female glow-worms at 19 sites in across south-east England. These transects were surveyed by a team of committed citizen scientists for nearly two decades. Average glowing counts declined by around 75% over the survey period (ca. -3.5% per annum), driven partly by a warming and drying climate (Gardiner & Didham, 2020), and accounting for advancing spring phenology. Temporal trajectories in abundance were inconsistent across sites, however, suggesting local-scale site factors such as unmanaged scrub encroachment might drive greater reduction in numbers at some sites than others (Gardiner & Didham, 2020).

Baur *et al.* (2020) also used a non-lethal transect count approach to survey trends in population abundance of a threatened flightless longhorn beetle at 13 sites in Switzerland, France and Germany over a 20 year time series. Overall population abundance declined by 90% through time, but with varying rates of decline at different sites (Baur *et al.*, 2020). Environmental correlates and the degree of synchronicity of population fluctuations across sites suggest that climate drivers probably only have a small influence on population changes, while the main drivers of decline are likely to be intensification of agricultural land-use, leading to strong shifts in plant species composition, reduction in host-plant availability and loss of warm sun-exposed microhabitats (Baur *et al.*, 2020).

In the USA, Belitz *et al.* (2020) compiled occurrence records for the endangered Poweshiek skipperling butterfly from 1872 to present, aggregating observation-based and specimen-based records from surveys, museum records, researchers and citizen scientists to build a composite picture of geographic range contraction through time. Despite being historically common in prairies across the upper mid-western USA (217 sites), populations have declined rapidly to local extinction in the last 20 years at all but five extant locations (Belitz *et al.*, 2020). Ecological niche models were constructed using climatic, landscape-scale habitat, pesticide and fragmentation data to test the putative drivers of decline, and evidence suggested that key causal drivers varied between regions and through time (Belitz *et al.*, 2020). Poweshiek skipperling occurrence in the period prior to its steepest decline was predominantly predicted by climate variables, whereas rapid range contractions in the 2000s and 2010s were driven by land-use variation, with eastern and western populations responding differently, and at different time intervals (Belitz *et al.*, 2020). Management strategies to conserve this butterfly species will hinge not only on local-scale site suitability, but also surrounding landscape-level drivers of population threat.

Although correlative associations and ecological niche modeling have important roles to play in identifying putative drivers of decline, it is rare to find explicit experimental tests of the causal mechanisms driving population change. One potential factor influencing the abundance of the iconic Monarch butterfly could be exposure to elevated levels of heavy-metals in their Milkweed foodplants where they grow along roadsides. Shephard *et al.* (2020) found that caterpillars experimentally exposed to different levels of zinc in artificial diet had reduced survival, but at levels above those reported from roadside areas studied in the Midwestern USA. For contrast, they also studied the generalist and ubiquitous Cabbage white butterfly and observed very different (even positive) responses to elevated zinc. Taken together, these results highlight the need for additional experimental work on toxin exposure, especially in non-pest insects, and more broadly that future studies should consider experimental discrimination of putative drivers of decline.

As Didham *et al.*, (2020) point out, there are many challenges and pitfalls involved in identifying generalised long-term trends for a given insect population, but we hope that the eight empirical articles presented here in this special issue provide compelling examples of the sorts of approaches that can help tease out some of the response diversity that is inherent in insect communities and provide more robust general estimates of overall trends. In contrast to some of the more 'depressing' media coverage on the subject, there is a promising future for insect population monitoring, with many opportunities available for creative analysis of existing baseline data.

Regardless of the data gaps and uncertainty around specific species, locations and drivers, we know enough about insect biodiversity and conservation threats to communicate more effectively with peer and public audiences. Saunders *et al.* (2020) provide an important reminder of how word choices affect messaging. Decline has become a common word used in scientific papers and popular media discussion of insect population trends. However, the use of this terminology can be subjective, has inherent negative connotations, and is not always the most appropriate or effective language choice to drive public engagement and conservation action. Increasing understanding of insect diversity through nuanced and objective discussion is essential to gain public and political support.

Despite the critical contribution of insects to ecosystem services and a general awareness that 'something is not right', insect conservation remains the poor cousin to mammal and bird conservation. Hart & Sumner (2020) broach the conversation on how we might better 'market' insects to increase public appreciation of their multiple values. They suggest that conservation of less-charismatic taxa, and of diverse ecosystems as a whole, could well be improved by adapting tools from the world of commercial marketing. Hart & Sumner (2020) propose the application of the '4Ps' framework (product, price, place and promotion) to insect conservation, and suggest that it can be used to foster greater adoption of pro-environmental behaviours and contribute to resolving the challenge of ‘selling’ insects to an often reluctant public. This idea builds from the existing ecosystem services framework, which already provides a scientific groundwork for measuring and classifying the many different ways that humans value insects. Hart & Sumner (2020) focus specifically on public engagement, arguing that commercial marketing approaches offer a lot of inspiration for campaigns to educate and engage public audiences about the wonderful world of insects.

There are many reasons to be positive about the future of insect conservation. Novel applications of old techniques, new technologies and increasing access to old and new data are revealing more about global insect biodiversity than ever before. A growing body of researchers from ecology and other disciplines are providing greater insight into how environmental conditions and anthropogenic drivers impact insect species and community interactions. The articles curated in this timely special issue provide many new paths forward for rigorous research and more engaging public discourse on the value of insect conservation.

Acknowledgements

We thank the fabulous teams of contributing authors who have toiled for many decades to bring empirical evidence to bear on the trends and drivers of insect population change. The compilation of articles would not have been possible without the commitment and contributions from the Editors at *Insect Conservation and Diversity*, and the efficient and timely efforts of the editorial management team at Wiley.

Conflict of Interest

The authors declare no conflict of interest.

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