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PERSPECTIVE

Missing the bigger picture: Why insect monitoring programs are limited in their ability to document the effects of habitat loss

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Abstract

The fate of insects in the Anthropocene has been widely discussed in the scientific literature, the popular media, and in policy circles. This recent attention is justified because reductions in insect abundance and diversity have the potential to undermine the stability of terrestrial ecosystems. Reports of insect declines have also been accompanied by skepticism that is healthy and to be expected in scientific discussion. However, we are concerned about a prevalent misconception that equates reports from monitored natural areas with the global status of insects. In the vast majority of cases, areas monitored for arthropods are undeveloped and thus do not record or even necessarily reflect the masses of insects that are continuously being impacted by habitat loss to urban, suburban and agricultural expansion. We address this misconception and discuss ways in which conservation and policy can be enhanced by correctly locating results from insect monitoring programs within our broader knowledge of biodiversity loss.

KEYWORDS
Anthropocene, biodiversity, extinction, insect declines, monitoring

1 | INSECT DECLINES AND A COMMON MISCONCEPTION

Although concern for insect biodiversity is not new, attention for insect conservation has been elevated in recent years, in particular following the report by Hallmann et al. (2017) of declines exceeding 75% in the biomass of flying insects across Germany over the course of three decades.

Since then, there has been increasing motivation in the conservation biology community to not only protect individual insect species and restore habitat, but also to monitor the structural integrity of ecosystems as the many services provided by insects (pollination, pest control, decomposition, and others) are at risk. Dramatic declines in insect abundance and diversity have now been reported from many countries (Wagner, 2019), along with examples of increases in insect density in some areas, for example where cold temperatures have historically been limiting (van Klink et al., 2020). Other researchers have expressed skepticism and caution regarding the generality of early reports of insect declines (Saunders et al., 2020). Undoubtedly, scientific findings have in some cases been overly amplified by the popular press (Cardoso et al., 2019), and there are important methodological pitfalls that workers should be more aware of, including issues with snapshot sampling and the choice of historical baselines that can influence estimated rates of change in time series analysis (Didham et al., 2020). We appreciate the value of this scientific dialogue, but we have noticed a persistent misconception that impedes both scientific inquiry and conservation actions.

In many cases, results from long-term monitoring studies have revealed declines at some sites but stable or increasing numbers at others (Crossley et al., 2021; Macgregor et al., 2019), or a mix of species that are increasing along with species that are decreasing (Bowler et al., 2021; Lamarre et al., 2022; Wagner et al., 2021a). One interpretation of such results is that insects are resilient to the stressors of the Anthropocene. This inference suffers from the fallacy of composition, that is, transferring onto the whole attributes that belong solely to component parts (Finocchiaro, 2015). In this case, the parts are field locations where insects are monitored, and the whole is insect diversity and abundance at landscape, regional, and global scales.

With very few exceptions, sites that are monitored for insects are chosen as natural habitats in locations that are expected to be free from direct habitat destruction (Wagner et al., 2021b). This is true both of locations chosen by academic scientists to be part of national ecological networks (e.g., the Long Term Ecological Research Sites in the United States), and, to a lesser extent, of sites chosen by community scientists (e.g., butterfly counts organized each summer by the North American Butterfly Association or the European Butterfly Monitoring Scheme). Of course, many kinds of stressors do not involve outright habitat destruction, for example, climate change, invasive species impacts, and nontarget effects of pesticide application. However, field sites that have been continuously monitored have, with few exceptions, not been directly impacted by suburban or agricultural expansion, logged, paved, plowed, mined, or otherwise severely compromised. Therein lies the problem: while insect populations within any given study location might or might not be stable, much of the available habitat nearby or in the region has often been lost to human modification, along with all or many of the individual insects that were previously on those lands.

Globally, more than 75% of the land surface has been directly modified by human activity (Watson et al., 2018), with particular biomes including temperate grasslands and tropical dry forests being most intensely impacted (Riggio et al., 2020). Each year 10 million hectares of forests are cut, with nearly half of this area converted into agriculture, residences, and other human uses (FAO, 2020). Annual rates of urban land expansion approach 5% globally, outpacing even the growth of human populations in many parts of the world (Güneralp et al., 2020).

Historically, habitat destruction has been the primary driver pushing species towards extinction (Hogue & Breon, 2022), many before they have been taxonomically described (Lees & Pimm, 2015). While agricultural margins and urban green areas can be ecologically productive, they support only a small fraction of the diversity that existed prior to development. In one study of urbanization effects on insects that is remarkable for spanning more than 100 years of development, the magnitude of species loss in Rome, Italy was considerable, ranging from 32% in tenebrionid beetles and 45% in butterflies to as high as 65% fewer species of coprophagous scarab beetles (Fattorini, 2011). Thus, if we consider lands that have been developed and are no longer suitable for monitoring, in addition to the remaining undeveloped lands that are monitored, the realities of biodiversity loss for insects and other organisms become incontrovertible.

2 | LIFE RAFTS AND A SINKING SHIP

Monitored locations are immensely important for our understanding of insects in the Anthropocene. Indeed, populations in relatively undisturbed habitats are essential to our knowledge of climate change impacts (Halsch et al., 2021), and without studies of remnant natural areas in fragmented landscapes we would not have the tools to restore and rebuild population connectivity (M'Gonigle et al., 2015). However, the status of insects in monitored locations is only part of the picture, and tells us little about the accelerating numbers of insects that are being lost to intensive agriculture, commercial and residential development, changes in land management, and other kinds of direct habitat loss and degradation.

In many cases, monitored populations in intact habitats will remain stable or be slow to change even when nearby areas are developed. In this way and with few exceptions, insects differ greatly from larger and highly mobile animals like many birds, where a monitoring station on a flyway might provide an accurate index of an entire, regional population or where sampling might be sufficiently dense to capture population changes across relevant land cover types. With most insects, ecologists are cautious to extrapolate beyond local sites, and we do not assume without evidence that population dynamics recorded in, for example, one montane meadow reflect dynamics in another mountain range or even another nearby meadow. To the contrary, spatially decoupled population dynamics are the essence of metapopulation structure, for which insects have provided the most convincing case studies

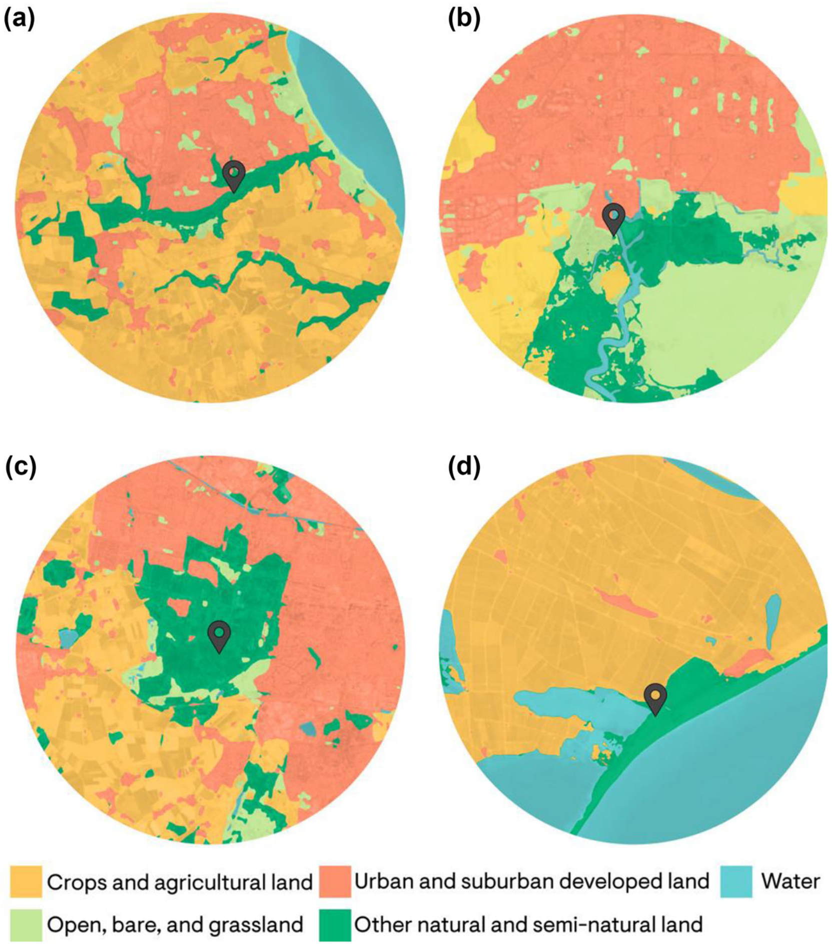

FIGURE 1 Modified lands surrounding four areas monitored for insects. (a) The Castle Eden site from the Rothamsted network in England; (b) Suisun Marsh from the Shapiro transect across Northern California; (c) a nature reserve near Tilburg in the Netherlands; and (d) a natural area included in the Catalan Butterfly Monitoring Scheme. These four locations illustrate the fact that sites monitored for insects are in some cases isolated bits of natural areas in landscapes otherwise dominated by conversion to agriculture or urban and suburban development. Time series data from remnant natural areas such as these are valuable for a great many ecological questions, but will not always be accurate indices of the many insect species and populations that have been lost in the surrounding areas. Each image represents a circle of 10 km diameter, and markers indicate parts of the natural areas surveyed. Land use categories are derived from the ESRI 2020 Global Land Use Land Cover from Sentinel-2 layer at 10 m resolution (Karra et al., 2021).

(Ovaskainen & Saastamoinen, 2018). Beyond the dynamics of individual species, beta diversity (spatial turnover in species composition) is high in insects because many have fine-scale niches such that even proximate areas often support different assemblages of insects.

We suggest an analogy to help contextualize monitoring programs within our understanding of biotic change in the modern era: intact, natural locations such as those included in insect monitoring programs are like life rafts leaving a sinking ship. What happens on the life rafts is of great importance for our understanding of the history and future of life on earth, but treating those rafts as representative of the ship is making the mistake of the fallacy of composition. Many of the controversies about insect declines in the scientific literature are inextricably anchored to the life rafts, with discussion centered on population trends in reserves, biological stations, and natural areas (Figure 1).

The problem of unquantified loss of insects in unmonitored habitats that have been degraded or completely lost is not simply a matter of experimental design. The Breeding Bird Survey in the United States maintains an exemplary network of monitored stations across a variety of landscapes including modified and anthropogenic habitats (Veech et al., 2017). It would be informative to have a similar network for insects, deliberately encompassing altered landscapes, but it would not address the problem of habitat-specialist or geographically restricted insects that might already have been lost from a region in response to human modification of the land. Furthermore, increasing population trends for insects will in some cases be reported from degraded or heavily modified areas including but not limited to pest species in agriculture or human commensals in urban areas. Such increases in anthropogenic spaces might involve great densities of individual insects, but in terms of biodiversity they do not compensate for the vast majority of species lost when a forest or native grassland is converted to intensive agriculture or other uses.

3 | CORRECTING A MISCONCEPTION CAN FACILITATE POLICY DEVELOPMENT AND CONSERVATION

Recognizing the fallacy of composition allows us to gain an important perspective on historical trends in abundance and diversity revealed in monitored locations. When insect populations at monitored locations are found to be stable or even increasing, this should not be interpreted as an indication that all is well in the adjacent areas, especially where these are being lost to development, agriculture, deforestation, shifts in land management, and other processes (Figure 1). Further, the life raft perspective elevates concern for regions where widespread declines have been discovered at monitored locations (Forister et al., 2021; Hallmann et al., 2017; Rada et al., 2019; Salcido et al., 2020; Wepprich et al., 2019). These are often in regions where multiple drivers of decline, including pesticide accumulation, excessive nitrification, and extreme climatic events, are acting in concert and synergistically (Wagner et al., 2021b).

Globally, there has been considerable movement in recent years to invest in the conservation of insects and their habitats. International organizations such as the Species Survival Commission of the International Union for Conservation of Nature have worked to assess many groups of insects such as butterflies, dragonflies, bumblebees, and fireflies (Samways, 2018). The Convention on Biological Diversity established the International Pollinators Initiative (Byrne & Fitzpatrick, 2009) which includes the development of methods and protocols for monitoring pollinators in partnership with other organizations in Argentina, Brazil, China, Colombia, France, Ghana, India, Indonesia, Kenya, Nepal, Norway, Pakistan, South Africa and Zimbabwe. Recently Germany announced a €100 million "action plan for insect protection" (Vogel, 2019), and in the United States the US Food, Conservation and Energy Act (the Farm Bill) makes pollinator habitat a priority for every US Department of Agriculture (USDA) land manager and conservationist and encourages the inclusion of pollinator habitat in all USDA conservation programs (Stine et al., 2015).

Despite those many advances, it has been our experience that policy makers and government biologists tasked with allocating resources to this issue are often uncertain about the extent to which insect declines are a widespread or ecologically important phenomenon. That uncertainty has percolated from high-profile papers that have found mixed historical trajectories (Crossley et al., 2020; van Klink et al., 2020). We are concerned with how such papers are interpreted among scientists, the general public, and policy makers. It is our hope that recognizing that we should not equate monitored lands with entire regions will facilitate a much-needed and broader perspective for the crucial work of policy makers and applied biologists, and add urgency to efforts to preserve the planet's arthropod biodiversity. The biomass of species already lost (and being lost) to habitat destruction and degradation, climate change, agriculture, invasive species, and myriad other anthropogenic stressors is largely unquantified and includes an unknown combination of global extinction and local extirpations. Although unquantified, insect losses almost certainly parallel the well-documented global declines of mammals, birds, and amphibians (Dirzo et al., 2014), and we can be certain that the losses are sufficiently great that there should be no hesitation with respect to the need and urgency to take conservation action.

To be clear, our goal is not to argue for the creation of new monitoring networks for insects in degraded or modified habitats, although support for such efforts would of course be welcome and would add to our knowledge of insects and anthropogenic stressors. Instead, our purpose here has been to encourage all parties, from scientists to policy makers and journalists, to use caution when extrapolating from studies of insect populations in intact or relatively unmodified landscapes. The fallacy of composition, as we have described it here, has the potential to impede the momentum that is building for insect conservation. With continued support and encouragement from scientists, new protections for natural areas, habitat restoration, insect-friendly practices for artificial lighting, and pesticide regulation, are among the many actions that can have immediate and long-lasting benefits for insects, ecosystems, and humans that depend on the ecosystem services of nature.

AUTHOR CONTRIBUTIONS

MF conceived of the manuscript. EG and CH created the figure. All authors contributed to the writing.

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The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

No new data were collected during the writing of this paper.

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