Moving On from the Insect Apocalypse Narrative: Engaging with Evidence-Based Insect Conservation

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Recent studies showing temporal changes in local and regional insect populations received exaggerated global media coverage. Confusing and inaccurate science communication on this important issue could have counterproductive effects on public support for insect conservation. The insect apocalypse narrative is fuelled by a limited number of studies that are restricted geographically (predominantly the United Kingdom, Europe, the United States) and taxonomically (predominantly some bees, macrolepidoptera, and ground beetles). Biases in sampling and analytical methods (e.g., categorical versus continuous time series, different diversity metrics) limit the relevance of these studies as evidence of generalized global insect decline. Rather, the value of this research lies in highlighting important areas for priority investment. We summarize research, communication, and policy priorities for evidence-based insect conservation, including key areas of knowledge to increase understanding of insect population dynamics. Importantly, we advocate for a balanced perspective in science communication to better serve both public and scientific interests.

Keywords: population biology, biodiversity, insect ecology, science communication, conservation

Insects are the most diverse and abundant group of animals on Earth and are critical drivers of ecosystem function in terrestrial and aquatic systems, but the majority of insect taxa are understudied, are publicly misunderstood, and face numerous environmental threats (Samways 2007, Cardoso et al. 2011). Public support is essential to address knowledge gaps and build global support for insect conservation. We need immediate solutions to human behaviors and management strategies that have detrimental impacts on insect biodiversity (e.g., habitat destruction, pesticide overuse), and we need broad support for publicly funded research that fills critical knowledge gaps. Science communication efforts can help build this support, but maintaining accuracy in communication narratives, whether they are presented via popular media platforms, scientific literature, or research institutions, is essential (Dahlstrom and Ho 2012). Sensationalizing geographically and taxonomically limited studies as evidence of global patterns may grab attention but can also have unwanted side effects. In particular, doom and gloom messaging rarely works to galvanize public support (McAfee et al. 2019) and strong negative messaging (e.g., apocalypse narratives) can undermine the credibility of science, especially as more facts become available (Horeis 2009).

The insect apocalypse narrative

"The Insect Apocalypse is here"
　　—*New York Times*, 27 November 2018

"Plummeting insect numbers 'threaten collapse of nature'"
　　—*The Guardian*, 11 February 2019

"Global insect decline may see 'plague of pests'"
　　—*BBC News*, 11 February 2019

Recent popular media coverage claimed that we are facing apocalyptic global insect declines and extinction of all insects within 100 years (e.g., Carrington 2017, Jarvis 2018, McGrath 2019). The only exceptions, according to some news reports, are pest insects, which are apparently on track to reproduce out of control (e.g., McGrath 2019). This exaggerated and unlikely narrative, which spread across multiple media platforms over the course of many months, grew from coverage of two empirical studies that show temporal changes in local insect populations in Germany (Hallmann et al. 2017) and Puerto Rico

(Lister and Garcia 2018) and a review paper that claimed to show evidence of worldwide decline of insect fauna (Sánchez-Bayo and Wyckhuys 2019). Although Hallmann and colleagues (2017) and Lister and Garcia (2018) did not specifically connote a global insect apocalypse in their peer-reviewed articles, the associated media releases from the lead authors' respective institutions extrapolated the limited results to suggest broader scale declines; in the case of Hallmann and colleagues (2017), a Radboud University (2017) release implied that the study demonstrated global declines, whereas a Rensselaer Polytechnic Institute release suggested Lister and Garcia's (2018) results represented declines across all of Puerto Rico's insects, with implications for tropical rainforests generally (Martialay 2018). In their peer-reviewed paper, Sánchez-Bayo and Wyckhuys (2019) extrapolated beyond the limitations of their review to suggest evidence of global decline across all insect taxa, and the associated University of Sydney (2019) release corroborated this. The insect apocalypse narrative spread unchecked via popular and social media platforms, and subsequent peer-reviewed articles have cited all of these studies uncritically as evidence of global-scale insect decline or ecosystem collapse (e.g., Gillespie et al. 2019, Pascal et al. 2019, Vilcinskas 2019).

Limitations of the apocalypse narrative

The aforementioned studies certainly deserve discussion and contribute to understanding the extent of our knowledge of insect communities. But they do not provide evidence of global-scale insect declines and impending extinction of all insect life on Earth. The reality is far more complex (Saunders 2019, Simmons et al. 2019, Thomas et al. 2019, Wagner 2019). The popular insect apocalypse narrative is largely based on a body of literature comprising Hallmann and colleagues (2017), Lister and Garcia (2018), and the 78 studies presented as evidence of global decline by Sánchez-Bayo and Wyckhuys (2019). The narrative is presented as fact, but despite the strong negative messaging, the evidence of global insect apocalypse is ambiguous (see the supplemental materials). Other researchers have published general critiques of these papers and their results (Simmons et al. 2019, Thomas et al. 2019, Wagner 2019, Willig et al. 2019), but there has been little critical assessment of the variation in methodological details and population trends behind the insect apocalypse narrative (see the supplemental materials). Most of these studies are from Europe and the United Kingdom (figure 1), and many are highly localized, collecting data from one specific location (e.g., one nature reserve) or from one region within a country. All of the studies showed increases or no changes for some of the focal taxa across the analyzed time period. Indeed, some studies could not confirm declines for any of the focal taxa (e.g., Petanidou et al. 2011, Gardner and Spivak 2014) and, in most studies, more taxa showed increases or no change relative to the number of taxa showing declines (see the supplemental materials).

The limitations of the insect apocalypse narrative become clear when attempting to scale these studies up to global long-term patterns. Most studies treated time as a categorical variable, analyzing differences between time periods rather than change over time. This approach can be misleading, because arbitrary time periods may be a poor proxy for environmental change or ecological interactions. In addition, analysis methods based on comparing occupancy across spatial grid cells in different time periods (Williams 1982, Desender and Turin 1989) can overlook correlations within the data set (e.g., codependent or interacting species) or other influential covariates that vary over time (e.g., land use change). More recently, trait-based analyses have been used to assess some of these confounding factors. For example, Paukkunen and colleagues (2018) investigated cuckoo wasp (Hymenoptera: Chrysididae) abundance and distribution over time in Finland. They found that trends of cuckoo wasps were positively correlated with those of their host species, and declining trends were more apparent in scarce, small-bodied species that used aboveground nesting hosts. Considering feeding habit and life cycle traits can also reveal pattern variation between species. Warren and colleagues (2001) show that specialist butterfly species in the United Kingdom have declined in distribution, whereas mobile generalist species have increased, and Ball-Damerow and colleagues (2014) showed contrasting patterns for migratory and habitat specialist Odonata in arid western parts of the United States.

Confirmed declines for a taxonomic group in one location do not always translate to other regions or similar species. Biesmeijer and colleagues (2006) found contrasting patterns for bees and hoverflies when comparing trends in Britain and the Netherlands, whereas Brooks and colleagues (2012) found that carabid (Coleoptera: Carabidae) abundance across the United Kingdom declined significantly in some regions and increased in others. Bumble bees (Hymenoptera: *Bombus* spp.) were one of the most commonly studied groups, with some species showing variable trends in different studies. For example, *Bombus pensylvanicus* has been identified as declining in southern Ontario (Colla and Packer 2008), data deficient in New Hampshire (Jacobson et al. 2018), and the most common and stable species in Oklahoma (Figueroa and Bergey 2015). Similarly, the diversity of community-level and population-level metrics used across studies make it difficult to identify patterns at larger scales, because different components of biodiversity can tell vastly different stories. Schuch and colleagues (2012) studied Auchenorrhyncha communities in central European grasslands and found declines in abundance but no change in species richness. Jacobson and colleagues (2018) found that abundance of some bumble bee species in New Hampshire have declined, but there was no trend apparent for plant–bumble bee interactions. The relevance of different metrics to identifying overall global population trends was also largely overlooked or misrepresented in popular media coverage; for example, *The*
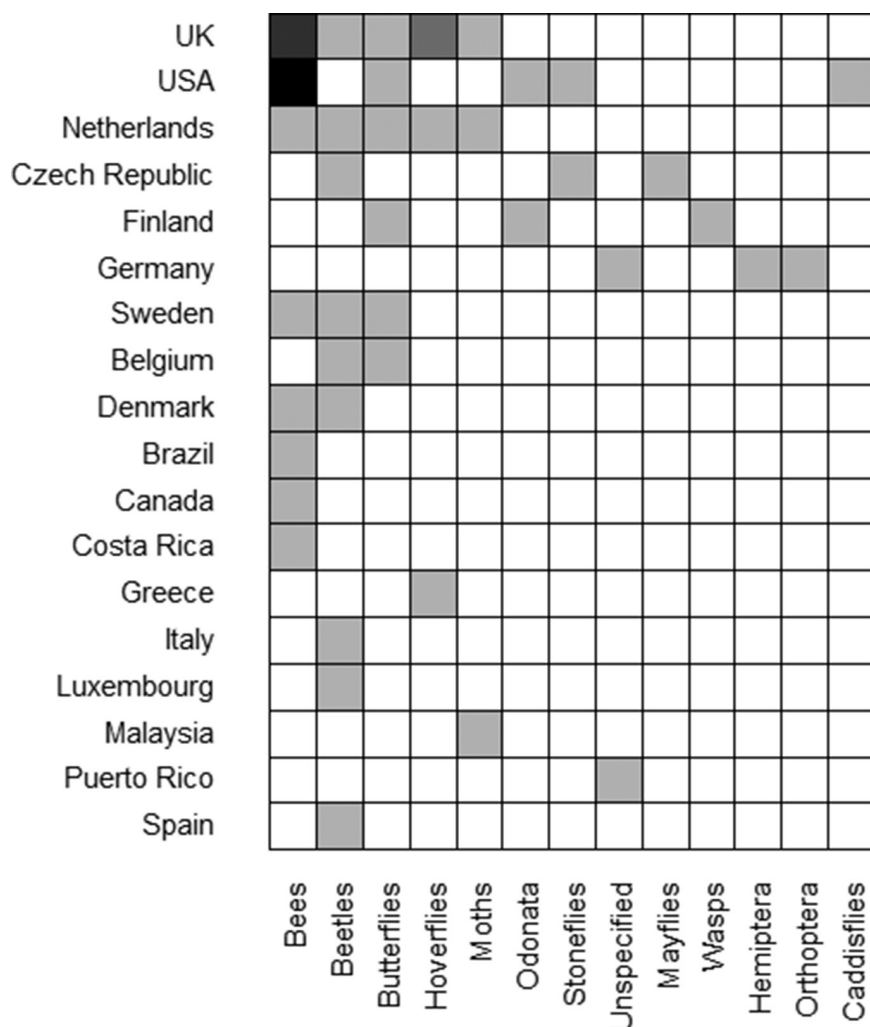
Figure 1. Geographic and taxonomic distribution of the body of literature behind the popular insect apocalypse narrative. This figure does not show trends, only the presence of an empirical study measuring changes in insect populations. See the supplemental materials for the full details of the studies depicted in the figure. The insect taxa are grouped on the basis of the groupings used within studies. "Unspecified" indicates studies that sampled insects generally without specifying particular taxa. Each cell indicates the number of studies focused on a particular taxonomic group in a particular country (i.e., country–taxa pairs). The white cells indicate no studies, and the cell color shade increases in darkness with a greater number of studies focused on that country–taxa pair.

population dynamics for nonspecialist audiences. We are still not certain how many insect species exist on Earth, nor do we know the distribution, life history, or ecology of most described species. Therefore, our current knowledge of global insect biodiversity is too limited to support strong negative messaging about global patterns in insect population dynamics.

Coordinated monitoring systems that collect standardized observations on multiple taxonomic orders across consecutive years (e.g., the United Kingdom's Rothamsted Insect Survey) are extremely valuable for identifying temporal patterns in insect populations but are not the only priority for understanding global insect diversity (Cardoso and Leather 2019). We believe that the insect apocalypse narrative detracts from the key issues of insect conservation and potentially damages public understanding of insect ecology. In the present article, we highlight a more constructive path for evidence-based discussion of insect conservation involving priorities for research, communication, and policy to support evidence-based insect conservation (box 1) and a more balanced presentation of insect ecology in science communication to better serve both public and scientific interests.

Priority areas for research and funding

Here, we summarize key knowledge gaps and highlight priorities for evidence-based insect conservation (box 1).

Population dynamics of insect species. Animal populations are never truly stable (Solomon 1949, Wallner 1987). They constantly fluctuate in response to multiple factors, including resource availability, climatic conditions, and biotic interactions (Wallner 1987, Gaston and Lawton 1988). Insects generally have short, seasonal life cycles, have large generation sizes, and can exhibit significant niche separation between life stages; therefore, insect population fluxes are incredibly dynamic (Wallner 1987, Gaston and Lawton 1988). Cyclic outbreaks are common for many species, often influenced by trophic interactions and resource pulses (Ostfeld and Keesing 2000). Indeed, mass insect outbreaks occur regularly with significant impacts on ecosystems, industry, and agriculture (Esper et al. 2007, Büntgen et al. 2009), and some systems, such as temperate

Guardian coverage of the Hallmann and colleagues (2017) study claimed that insect abundance had fallen, but the study only measured biomass (Carrington 2017).

The insect apocalypse narrative is built from exaggerated interpretations of a limited number of studies and ignores other recent empirical literature on insect populations showing long-term increases for some taxa (Herrera 2018, Gibb et al. 2019), no discernible trends in other taxa (Bell et al. 2015), and new species or records in understudied locations (Leijs et al. 2018, Meiners et al. 2019). Very few popular and social media reports on the insect apocalypse made an attempt to reconcile the complexities inherent in insect

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Box 1. Priorities for building support for evidence-based insect conservation.

Fundamental and applied research

Develop

- cost-effective nondestructive insect monitoring techniques.
- robust statistical methods for analyzing unverified citizen science data.
- trait-based frameworks for understanding human impacts on insect communities.
- guidelines to facilitate standardized protocols for the use and analysis of genetics-based monitoring (e.g., eDNA, metabarcoding, metagenomics) that complement field-based efforts.

Identify

- how species turnover influences population trends within communities and metacommunities.
- relationships between community-level processes and species population trends.
- how population fluctuations vary in time and space.
- how different components of insect biodiversity (including trait variability) contribute to ecosystem function and associated ecosystem services.

Increase

- the availability of unpublished long-term data sets.
- the use of multidisciplinary approaches to better understand species biology, interactions and overall community resilience, e.g., field survey + eDNA identification, pollinator network + metabarcoding, trophic assessments + metagenomics or metabarcoding of gut or feces, ecological + genetic distance or resistance layers to identify landscape drivers.

Communication and education

Develop

- robust citizen science programs that combine community education and training with long-term monitoring data collection
- new technologies for user-friendly insect identification

Increase

- school and community education programs focused on the value of natural history observation.
- funding and support for local and regional natural history journals, including digitization programs.
- taxonomy and entomology training in universities.
- media ethics training for scientists.
- science communication focused on scientific methods and processes.

Policy and management

Identify

- how policies and management strategies influence changes in insect communities.
- better regulatory frameworks for sale and use of insecticides and sustainable land management to protect insect biodiversity.

Increase

- incentives and consumer support for unconventional food production systems (e.g., organic, regenerative agriculture).
- the incorporation of genetic or genomic data with ecological data to better inform policy and management.

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forests and agroecosystems, are predicted to experience increasing insect outbreaks because of global climate change (Porter et al. 1991, Lovett et al. 2006). However, factors that contribute to outbreaks are numerous and often difficult to identify (Wallner 1987, Buma 2015).

Managed systems (e.g., crop fields or tree plantations) tend to be more susceptible to pest insect outbreaks because of frequent disturbance, low diversity, and spatial uniformity (Coyle et al. 2005, Dalin et al. 2009). Identifying variation in outbreaks between different groups of species (e.g., herbivores and predators) in managed and natural systems is important to understand how to manage systems sustainably to reduce pest impacts (Knops et al. 1999, Tscharntke et al. 2012). Such fluctuations are a fundamental component of

ecosystems (Buma 2015), but it is unclear how important these sporadic outbreaks are for the maintenance of insect populations in the long term. Community-level patterns and processes that influence local abundance also fluctuate as the size and distribution of local populations varies over time (Elton 1924). In addition, sex ratios for many insect species are often overdispersed (Godfray and Werren 1996) and can be readily adjusted by environmental drivers, such as resource limitation or mate competition (Charnov et al. 1981, Chapuisat et al. 1997). Invasive species can also alter population structure and long-term trends; for example, the arrival of an exotic gall wasp, *Andricus quercuscalicis*, in the United Kingdom has caused a significant male bias in the native parasitoid populations that emerge from the galls (Schönrogge et al. 2000), but it is unclear what long-term effect this will have on parasitoid populations in the long term. These are some of the reasons why relying on few sampling seasons or comparing surveys conducted many years apart can be misleading when attempting to pinpoint population declines.

Long-term monitoring of insect communities at particular sites can help elucidate these dynamics but can be costly and counterproductive if not designed effectively (Tepedino et al. 2015). In addition, any changes observed at individual sites can only be interpreted as variation in characteristics of that site, not true variations in the insect population (McArdle and Gaston 1993). For many species, local extinction is often impossible to confirm (McArdle 1990). To rigorously confirm a decline in populations requires ongoing censuses of those populations, which for insects, is rarely feasible, given their fast generation time, elusiveness, cryptic life cycles, and the inherent difficulties of defining a population in the first place. A more immediate solution is to invest in building knowledge of global insect diversity, insect species ecology and life histories, and the effect of human impacts and environmental change on taxonomic groups (box 1).

Accessible taxonomy. Estimates of numbers of insect species appear regularly in the literature, ranging from 3 million (Blaxter 2003) to over 30 million (Stork 1988). Whatever the correct number, we have described only a fraction of the hypothetical global diversity; approximately 1 million insect species are currently known (Stork 2018). Although all taxonomic levels and functional groupings are valuable units of enquiry, the species remains the basic unit of biology and conservation. To understand the ecology of an organism, it is essential to first accurately identify it (Mallet and Willmott 2003).

Our current identification system relies on people with highly specialized training and knowledge (i.e., taxonomists) using discipline-specific rules and hypotheses (Lipscomb et al. 2003). The process of describing a new species can take decades, but, in brief, a formal description is published and a type specimen is designated and then stored as a reference for all other material (Godfray 2002). The problems with

this system are numerous and well known: Type specimens can be lost or damaged, access to specialist knowledge for general users is limited (Tautz et al. 2003), complex descriptive terminology make existing keys inaccessible, and reference specimens are typically held in restricted access museum departments (Alberch 1993).

A more concerning issue is the decline in funding and succession for taxonomic specialists. Much information is lost when a specialist taxonomist retires (Tautz et al. 2003). The number of universities offering dedicated upper-level taxonomic and systematics courses is dwindling (Mallet and Willmott 2003). Reduced popularity and employability for taxonomic skills have resulted in fewer enthusiasts. Resources for museum collections are frequently cut back (Alberch 1993), and, for an individual, investing time in publishing user-friendly identification keys has limited rewards for career progression or recognition. A number of solutions can reduce the burden on specialists, promote information exchange, and contribute to the next generation of skilled specialists, including greater support for online collections, user-friendly identification initiatives, and more training opportunities (e.g., public workshops, formal classes, placement programs).

Cost-efficient genetic tools. An alternative to morphological taxonomy is genetic identification. DNA holds much promise in that it can be useful in delimiting species, populations, and individuals (Pons et al. 2006). However, genetic methods also present many challenges: The choice of molecular marker can profoundly affect the taxonomic resolution of a study (Dupuis et al. 2012), the cost of genetic methods and the amount of data generated can be prohibitive (Hunter et al. 2018), and specialists are still required to develop methods and training protocols. Environmental DNA (eDNA) and similar metabarcoding methods can survey large numbers of samples with relatively little investment (Shaw et al. 2017), thereby facilitating rapid, low-impact biodiversity surveys with comparable—and sometimes superior—detection rates to traditional survey methods (Hoffmann et al. 2016). Furthermore, more affordable next-generation sequencing, improved protocols and commercial sample collection kits, and portable third generation sequencers provide excellent opportunities to engage scientists in widespread, long-term monitoring.

However, such methods are a complementary approach, not an absolute replacement for on-ground field assessments. The efficacy of eDNA is currently limited by the number of known (i.e., previously described and sequenced) species available for building comparative genetic databases, and it is also difficult to statistically derive relative abundance information from eDNA samples (Deiner et al. 2017). Therefore, it is easier to answer the question of what is present rather than how many are present.

Despite their limitations, genetic methods continue to offer valuable insight into global biodiversity and its broader interactions. For example, it is often difficult to

directly study species- and population-level dynamics of rare, cryptic, or understudied organisms. However, genetic approaches can provide an indirect means of identifying species (Deiner et al. 2017), behavior (e.g., mating systems, Janes et al. 2016; trophic interactions de Vere et al. 2017; migration, Chapuis et al. 2009), demography (e.g., effective population sizes; Janes et al. 2018), and subsequent population-level changes (Gloss et al. 2016). Where possible, better integration of genetic approaches with traditional surveys could greatly advance our knowledge of insect biodiversity and biology (e.g., Cullingham et al. 2018). Integration of these methods is becoming increasingly time and cost effective because material for DNA-based work can often be collected during planned surveys or opportunistic site visits by nonspecialists; improved specimen preservation methods are increasing the longevity of samples for research (Matos-Maraví et al. 2019); commercial DNA extraction kits are decreasing the amount of starting material (e.g., a single leg) required to generate sufficient template (Richards and Murali 2015), meaning that a single specimen might be used multiple times; the yield of DNA is generally increasing, whereas the amount of DNA required for sequencing is typically decreasing, thereby facilitating numerous applications (Matos-Maraví et al. 2019); and sequencing costs continue to decline making genetic or genomic approaches more accessible. Finally, the increasing need and pressure to catalogue biodiversity and combat biodiversity declines continues to inspire novel and broad collaborations (e.g., academic, government, nongovernmental organizations, field naturalists, citizen scientists); these collaborations are essential to better combine observational and genetics-based methods and to better integrate these methods with policy and decision-making.

Insect behavior. The sheer diversity of insects and the huge variation in life histories and behavioral traits explain why there is such a variety of trapping methods in the entomologist's toolkit (e.g., observation, pitfall traps, pan traps, malaise traps, aerial traps, netting, light traps, Lindgren traps, beat trays). The most appropriate sampling method will depend almost entirely on the focal taxa and the system and season being sampled. This means there is no single trapping method that can identify population declines for all insect taxa at the global scale. Importantly, it means that any public discussion around studies showing declines of insect taxa need to clearly identify which taxa were targeted in the study's sampling methods.

Within species, insects can exhibit incredible plasticity in behavior and a range of personality syndromes (Kralj-Fišer and Schuett 2014, Modlmeier et al. 2015). The speed and flexibility with which behavioral responses occur give an insect greater capacity to deal with environmental change, particularly in the face of rapid or catastrophic events. Insects can respond to environmental changes behaviorally; for example, changes in temperature can lead insects to modify their dispersal, diapause, thermoregulation, foraging,

and reproductive behaviors (Parmesan 2006, Schilthuizen and Kellermann 2014). Furthermore, environmental change can exert differing selective pressures on behavioral traits. Invasive insects can exhibit drastic shifts in foraging behavior, activity, and boldness in their new environments, and some species have shown rapid behavioral changes in response to environmental variation (Singer et al. 1993, Lombaert et al. 2014).

The effect of evolutionary changes in behavior on insect population dynamics or measures of insect occurrence (e.g., trapping biases) remains to be seen. Currently data on the extent of behavioral plasticity in insects is scarce, and further research is needed to understand whether this capacity, in conjunction with genetic responses, will buffer insects against future environmental changes.

Natural history observation. Natural history observations are valuable information sources to help understand historical insect declines and identify potential drivers that can be tested as research hypotheses. A great example of this are the annual natural history notes from Inverness-shire, Scotland, published by G. W. Harper in The Entomologist's Record and Journal of Variation. Harper followed Lepidoptera populations in the highlands from 1952 until his death in 1973. In his 1970 record, he notes that "distinct climatic change" and "human destruction of our small local entomological habitats" have driven the decline in Lepidoptera he had witnessed over the previous 14 years (Harper 1971). Declines of some lepidopteran taxa in Great Britain have been confirmed more recently (Fox 2013), and it is uncertain whether these populations will recover.

Comprehensive records such as these are now rare in most countries, mostly because of declining support for traditional natural history among funding bodies and the broader research community (Tewksbury et al. 2014). It is never too late to start recording natural patterns. Observing nature can lead to discovery of new species, expand known ranges of species, build knowledge of a species's role in its community, and inform novel research hypotheses (Wheeler 2013, Saunders 2016). We must support and promote natural history observation as an essential component of scientific research and as a rewarding opportunity to leave a legacy of knowledge for future generations (box 1).

Links between insect communities and ecosystem function. Insects contribute to ecosystem function and associated ecosystem services in multiple ways throughout their life cycles (Losey and Vaughan 2006, Saunders 2018). Understanding the importance of insects in maintaining ecosystem function and human well-being is an excellent engagement tool to build public support for insect conservation. However, reductionist approaches to classifying an insect's role in the ecosystem and quantifying relevant ecosystem services have resulted in many complex interactions and functional roles being overlooked (Yang and Gratton 2014, Saunders et al. 2016). In addition, taxonomic biases in community

ecology and ecosystem function research mean we still have limited understanding of how insects mediate ecosystem function at different scales in many systems (Basset et al. 2019). Greater investment in cross-taxon (e.g., plant–insect, insect–vertebrate interactions) and cross-system (e.g., land–water, social–ecological) research is essential to fill these knowledge gaps. Network and trait-based analyses are promising approaches for understanding how complex interactions influence ecosystem function across different scales, including trait link frameworks (Hevia et al. 2017), species–habitat bipartite networks (Saunders and Rader 2019), and multilayer network frameworks (Bohan and et al. 2016).

Human impacts on insect communities. Human activity impacts insect taxa in many ways. Climate change is already causing phenological shifts in insect life cycles, resulting in potentially damaging effects on trophic interactions that influence ecosystem function (e.g., pollination and herbivory; Hegland et al. 2009, Bell et al. 2015). Human-mediated introduction of invasive alien insects can affect populations of native species in many ways. For example, the biological control agent Cotesia glomerata was introduced to the United States to control Pieris rapae, subsequently contributing to local declines of a native pierid butterfly in northeast United States (Benson et al. 2003). Effects of these complex interactions on the resilience of insect populations are still uncertain.

Overuse of synthetic chemicals (pesticides, herbicides, fungicides) has lethal and sublethal effects on many insect taxa, particularly beneficial species (Desneux et al. 2007). The physiological and biological effects that pesticides have on particular insect taxa is known, but, more broadly, we still know very little about how environmental concentrations of these chemicals interfere with biological and ecological processes at the scale of populations, communities, and ecosystems (Köhler and Triebskorn 2013, Wood and Goulson 2017). Synergistic interactions between pesticides, herbicides, and fungicides can enhance detrimental effects beyond what is observed in isolation, even for individual chemicals that are perceived as apparently harmless, but we know very little about the true extent of these interactions in environmental contexts (Desneux et al. 2007).

Habitat removal and landscape modification are also key drivers of change in local insect populations. In particular, the increasing amount of land converted to homogeneous crop production can provide ideal environments for more pest insect outbreaks and have detrimental effects on populations of beneficial insects (Haddad et al. 2011, Nicholls and Altieri 2013). Broad-scale land clearing and agricultural intensification reduce the diversity of habitats and resources available to insects at the landscape scale (Tscharntke et al. 2012). Most insect taxa have complex life cycles and require access to multiple different habitats and resources in different life stages. For example, adult dragonflies (Odonata) are winged predators in terrestrial systems, whereas their larval

stages live in water; some hoverfly species (Syrphidae) have predatory larvae that hunt herbivorous insects on plants, whereas the adult feeds on pollen and nectar. We still have very limited knowledge of how multiple drivers impact insects across the whole of their life cycle or of how these drivers affect community structure and functional diversity.

Communicating science for insect conservation

Communicating research results is an essential part of the research process and is critical to engage public audiences with insect conservation. This includes publishing results in scholarly literature and disseminating summaries through popular and social media. Using generalized framing or amplified language can be useful to grab audience attention, especially for critical issues such as biodiversity declines. However, this should never be at the expense of accuracy. Evidence of geographically restricted declines should not be framed as global in scale, and evidence of declines for particular species or taxonomic groups is not evidence that all insects are disappearing. Such misinformation can be counterproductive and affect public trust in scientific knowledge.

Hyping science is not a new phenomenon (Rinaldi 2012). However, in recent decades, it has arguably become more common and potentially more damaging because of enhanced competition among scientists and the rapid increase in an individual's potential global reach via online media (Bubela 2006, Caulfield and Condit 2012). The responsibility to support accuracy in science communication lies with all stakeholders, including scientists, institutions, communicators, journalists, and public audiences. We need public and political support for the informative and transformative power of scientific evidence, but to achieve this, we need to ensure that any text published under the auspices of scientific evidence is rigorous and accurate.

Achieving accuracy in ecological science communication also means discussing uncertainty. The role of science is not to produce absolute truths but to document and understand variation in patterns and processes. However, the deficit model of science communication (i.e., the belief that the public are ignorant of scientific truths and communication should focus on fact-based enlightenment) is common among scientists and science reporters (Frewer et al. 2003, Nisbet and Scheufele 2009). In reality, effective science communication should be a mutual relationship that focuses on engagement and dialogue and discusses uncertainty relative to the needs and beliefs of the audience (Rabinovich and Morton 2012, Fischhoff and Davis 2014). A critical point often missing in popular science communication is that uncertainty in scientific knowledge is relative to the breadth of literature on a specific topic. In the case of insect declines, there are not enough independent studies to reach the level of consensus needed to prove global declines of all insect species. However, we also stress that, whereas discussing uncertainty is essential to science communication, uncertainty is not a valid argument for doing nothing to reduce a potential harm (Oreskes 2004).

We may never know if global declines are truly happening, and we don't need to wait for proof. Uncertainty can frame a more constructive and hopeful message. To gain global support for insect conservation, we need people to believe the truth: We have not yet lost all insects, and there is still time to protect global insect diversity if we act now. Building knowledge of the mechanisms that may drive future insect declines and how those declines would affect ecosystems and human wellbeing presents valuable opportunities for conservation investment, engagement, and action.

Supplemental material
Supplemental data are available at *BIOSCI* online.

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