

1 **Understanding the evidence informing the insect apocalypse myth**

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8

9 **Abstract**

10 Recent studies showing temporal changes in local and regional insect populations have
11 received exaggerated global media coverage. Confusing and inaccurate science
12 communication on this important issue could have counter-productive effects on public
13 support for insect conservation. The ‘insect apocalypse’ media narrative is fuelled by a
14 limited number of studies that are very restricted geographically (predominantly the UK,
15 Europe and the USA) and taxonomically (predominantly bees (mostly *Bombus* spp.),
16 macrolepidoptera, and ground beetles). Biases in sampling and analytical methods limit the
17 relevance of these studies as evidence of overall global insect decline. Therefore, the value of
18 existing research lies in highlighting important areas for priority investment. We summarise
19 research, communication and policy priorities for evidence-based insect conservation,
20 including key areas of knowledge to increase understanding of insect population dynamics.
21 Importantly, we advocate for a balanced perspective in science communication to better serve
22 both public and scientific interests.

23 “The Insect Apocalypse is here” - *New York Times*, 27 November 2018
24 “Plummeting insect numbers ‘threaten collapse of nature’” - *The Guardian*, 11 February
25 2019

26 “Global insect decline may see ‘plague of pests’” - *BBC News*, 11 February 2019

27

28 Recent popular media coverage claimed that we are facing apocalyptic global insect declines
29 and extinction of all insects within 100 years. The only exception, according to some news
30 reports, is pest insects, which are apparently on track to reproduce out of control. These
31 exaggerated and unlikely claims are largely based on two recent empirical studies that show
32 temporal changes in local or regional insect populations (Hallmann et al. 2017; Lister and
33 Garcia 2018), and a review paper that claimed to show evidence of “worldwide decline” of
34 insect fauna (Sánchez-Bayo and Wyckhuys 2019). These studies are valuable contributions to
35 understanding the extent of our knowledge of insect communities, and they certainly deserve
36 attention. But they do not provide evidence of global insect declines and impending
37 extinction of all insect life on Earth; the reality is far more complex (Saunders 2019; Wagner
38 2019; Thomas et al. 2019; Simmons et al. 2019). A recent study showed a long-term increase
39 in pollinator abundance (particularly solitary bees) in relatively undisturbed habitats in
40 southeast Spain(Herrera), while a repeat survey in a California national park discovered 48
41 new bee species records (Meiners et al. 2019). Recent examination of old and new bee
42 specimens from arid regions of southern and western Australia, including many collected on
43 a citizen science BushBlitz survey, resulted in 26 new species of *Leioproctus* (Leijs et al.
44 2018). These stories, and many others, are an important reminder that our current knowledge
45 of global insect biodiversity is extremely limited. Yet science reporters and communicators
46 made little attempt to reconcile these apparent contradictions for non-specialist audiences.

47

48 Public support is essential to address knowledge gaps and build global support for insect
49 conservation: we need immediate solutions to human behaviours and management strategies
50 that have detrimental impacts on insect biodiversity (e.g. pesticide overuse), and we need
51 broad support for publicly-funded research that fills critical knowledge gaps. Accurate
52 science communication in the public domain, by media platforms, scientists and research
53 institutions, is essential to foster this support. Sensationalising geographically-restricted
54 studies as evidence of global insect declines may grab attention, but can also have unwanted
55 side effects. Doom and gloom messaging rarely works to galvanise public support
56 (Swaissgood and Sheppard 2010) and exaggerated science communication increases the risk
57 of more sceptical audiences (Nisbet and Scheufele 2009). A more constructive discussion
58 focuses on the questions: (i) What is the current extent of insect declines informing the insect
59 apocalypse myth? (ii) How can we increase understanding of insect populations to better
60 support evidence-based conservation?

61

62 **Reassessing the evidence**

63 To assess the accuracy of the apocalyptic claims in recent media coverage, we reviewed the
64 full set of 82 papers collated by Sánchez-Bayo and Wyckhuys (2019), as this was the main
65 source of the ‘insect apocalypse’ media coverage and is the most recent review of studies
66 showing apparent insect population declines. For a more detailed critique of the limitations of
67 this review paper, see Saunders (2019), Simmons et al. (2019), and Wagner (2019). Out of
68 the 82 references that Sánchez-Bayo and Wyckhuys (2019) collated as evidence of declines,
69 we removed 34 unsuitable studies for the following reasons: duplicate analyses of a dataset
70 from another study in the list; reviews, summaries or opinion-based articles that lacked

empirical data (including summaries of IUCN Red List categories; Simmons et al. 2019); simulation modelling; short-term studies (1-2 years); studies focused on particular species known to be in decline; and accounts of managed honey bee stocks (see Table S1 for full details). This left a total of 39 papers from Sánchez-Bayo and Wyckhuys' review that were legitimate empirical studies showing evidence of temporal change in wild insect assemblages. We also included eight recently-published empirical studies that were not included in the Sánchez-Bayo and Wyckhuys (2019) list but were referenced in media coverage, including Hallmann et al. (2017) and Lister and Garcia (2018), resulting in a total of 47 empirical studies that assessed long-term changes in insect assemblages at a specific location (Table S2).

Our reassessment shows that the popular global insect apocalypse myth is based on a small body of evidence that is geographically restricted, focused on specific taxa, and shows variable results across locations and groups (Box 1; Table S2). Two-thirds (67%) of the countries covered by these studies are in Europe (including UK). Some studies are highly localised, with 19% of studies collecting data from one specific location (e.g. one nature reserve) and most others focused on one region within a country. Site selection in all studies was non-random, a sampling bias which can potentially drive apparent declines even if no underlying trend is present (Fournier et al. 2019). All studies found increases or no changes for some taxa across the time period. Indeed, some studies could not confirm declines for any of the focal taxa (e.g. Lindhe et al. 2010; Petanidou et al. 2011; Gardner and Spivak 2014; Zedková et al. 2015) and, in most studies, more taxa showed increases or no change relative to the number of taxa showing declines (Table S2).

Data sources, sampling methods, and analysis techniques varied across studies (Box 1). Most studies (81%) treated time as a categorical variable, analysing differences between time periods rather than change over time. This approach can be misleading, as arbitrary time periods may be a poor proxy for environmental change or ecological interactions. In addition, many analysis methods based on comparing occupancy across spatial grid cells in different time periods (e.g. Williams 1982; Desender and Turin 1989; Carpaneto et al. 2007) can overlook correlations within the dataset (e.g. co-dependant 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 et al. (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 above-ground nesting host species. Considering feeding habit and life cycle traits can also reveal pattern variation between species. Warren et al. (2001) show that specialist butterfly species in the UK have declined in distribution, while mobile generalist species have increased, and Ball-Damerow et al. (2014) showed contrasting patterns for migratory and habitat specialist Odonata in arid western parts of the United States.

The limitations of the current body of evidence become clear when attempting to scale up to global patterns. Confirmed declines for a taxonomic group in some locations do not translate to other regions or similar species. Biesmeijer et al. (2006) found contrasting patterns for bees and hoverflies when comparing trends in Britain and the Netherlands, while Brooks et al. (2012) found that carabid (Coleoptera: Carabidae) abundance across the UK 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, *B. pensylvanicus* was 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 in these studies (Box 1) make it difficult to identify patterns at larger scales. Of the few studies that analysed more than one metric, most highlighted how different components of biodiversity can tell vastly different stories. Schuch et al. (2012) studied Auchenorrhyncha communities in central European grasslands, and found declines in abundance but no change in species richness. Jacobson et al. (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 Guardian coverage of the Hallmann et al. (2017) study claimed that insect ‘abundance’ had fallen, when the study only measured biomass (Carrington, 2017).

Box 1: Scope of evidence underlying recent claims of global insect declines

Number of studies assessed. 47.

Global distribution. 18 countries (9% of world nations): Europe (12 countries), Americas (5 countries), Asia (1 country). Five studies considered more than one country (Figure 1).

Taxonomic coverage. 10 taxonomic orders (37% of insect orders). Butterflies, beetles and bees were the most commonly analysed taxa (Figure 1). Some orders represented by very few families or groupings: e.g. Diptera, one family (Syphidae) out of 118 recognised families;

Coleoptera (Carabidae, Coccinellidae, Cerambycidae, Cicindelidae, dung beetles);
Hymenoptera (bees, cuckoo wasps) (Figure 1).

Data sources. A total of 23 studies were based only on field data collected *in situ*; 19 studies were based solely on museum collections, databases or taxon-specific recording schemes; and 5 studies compared recent field surveys with historical museum/database records.

Continuous time series vs. categorical time periods. 9 studies analysed data as continuous time series from the same locations, while 38 studies divided observations into distinct categorical time periods for analysis. Of the categorical studies, 15 were repeat surveys at the same location (most using similar sampling methods), 15 were analyses of museum collections or database records, and 7 compared contemporary field surveys with historical collections or database records.

Biodiversity metrics. 15 studies focused on more than one metric; abundance/relative abundance/counts/density/frequency (17), number of species (17), occurrence/occupancy/presence (17), community composition (8), biomass (3), plant-

pollinator interactions (2), calculated index (2).

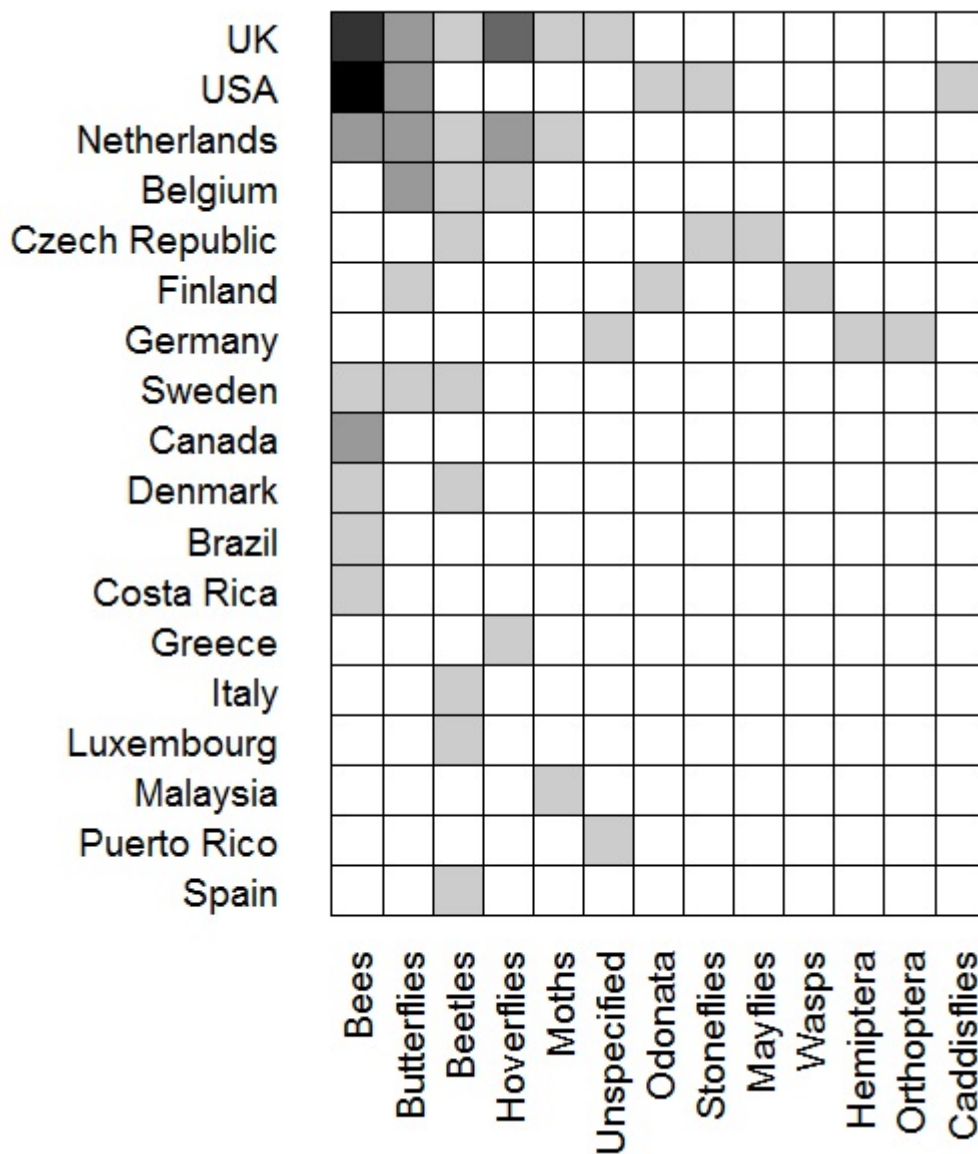


Figure 1: Geographic and taxonomic distribution of current evidence underlying recent claims of global insect declines. Insect taxa are grouped based on the groupings used within studies. 'Unspecified' indicates studies that sampled insects generally without specifying particular taxa. Each cell indicates the number of studies focused on each country-taxon pair. White cells indicate no studies, darker coloured cells indicate a greater number of studies focused on that particular taxon in that location.

The studies being cited as evidence of ‘insect apocalypse’ highlight the taxonomic and geographic biases of existing data, as well as the challenges involved in identifying global declines. Longitudinal datasets covering long time periods, the gold standard for identifying potential population declines, are limited. Very few countries support coordinated monitoring systems that collect standardised observations on a range of taxa across consecutive years (e.g. UK’s Rothamsted Insect Survey). These systems are extremely valuable for identifying temporal patterns in insect populations (Leather 2018), but are not the only priority for understanding global insect diversity. 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, we argue that current knowledge is insufficient to support apocalyptic claims of global declines in overall insect populations. Declines are confirmed for some species in some locations, but we caution against extrapolating catastrophe beyond the limits of available data. Here, we highlight a constructive path forward for evidence-based insect conservation involving: (i) priorities for research, communication and policy to support evidence-based insect conservation (Box 2); (ii) key areas of knowledge that help us understand global insect populations; and (iii) a more balanced presentation of insect ecology in science communication to better serve both public and scientific interests.

Box 2: Priorities for building support for evidence-based insect conservation

Fundamental and applied research

Develop:

- cost-effective non-destructive insect monitoring techniques.
- robust statistical methods for analysing unverified citizen science data.

- trait-based frameworks for understanding human impacts on insect communities.
- guidelines to facilitate standardised protocols for the use and analysis of genetic-based monitoring (e.g. eDNA, metabarcoding, metagenomics) that complement field-based efforts.

Identify:

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

Increase:

- availability of unpublished long-term datasets.
- 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/metabarcoding of gut/faeces; ecological + genetic distance/resistance layers to identify landscape drivers.

Communication and education

Increase:

- school and community education programs on the value of natural history observation.

209 - funding and support for local and regional natural history journals, including digitisation
210 programs.

211 - taxonomy and entomology training in universities.

212 - media ethics training for scientists.

213 - science communication focused on scientific methods and processes.

214

215 *Policy and management*

216 Identify:

217 - how policies and management strategies influence changes in insect communities.

218 - better regulatory frameworks for sale and use of insecticides and sustainable land
219 management to protect insect biodiversity.

220 Increase:

221 - incentives and consumer support for non-conventional food production systems (e.g.
222 organic, regenerative agriculture).

223 - incorporation of genetic/genomic data with ecological data to better inform policy and
224 management.

225

226 **Priority areas for research and funding**

227 *Population dynamics of insect species*

228 Animal populations are never truly stable (Solomon 1949; Wallner 1987). They constantly
229 fluctuate in response to multiple factors including resource availability, climatic conditions,

and biotic interactions (MacArthur 1955; Wallner 1987; Gaston and Lawton 1988). Insects generally have short, seasonal life cycles, large generation sizes, and can exhibit significant niche separation between life stages; hence, 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 (Myers 1993; Esper Jan et al. 2007; Büntgen et al. 2009) and some systems, such as temperate forests and agroecosystems, are predicted to experience increasing insect outbreaks because of global climate change (Porter et al. 1991; Lovett et al. 2006). Yet factors that contribute to outbreaks are numerous and often difficult to identify (Mattson and Haack 1987; 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 (Altieri et al. 1984; Knops et al. 1999; Tschardt 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 Michel 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 UK has caused a significant male bias in native parasitoid populations that emerge from the galls (Schönrogge et al. 2000), but it is unclear what 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 understand these dynamics, but can be costly and counter-productive 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.

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, ‘species’ remain 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-specialised 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: (i) type specimens can be lost or damaged; (ii) access to specialist knowledge for general users is limited (Tautz et al. 2003); (iii) complex descriptive terminology make existing keys inaccessible; and (iv) 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 reward 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 programmes).

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). Yet 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 (Luikart et al. 2003; 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). Further, more affordable next-generation sequencing (NGS), 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 (Bohmann et al. 2014; Deiner et al. 2017). Thus, it is easier to answer the question of ‘what is present?’ rather than ‘how many are present?’.

327 Despite limitations, genetic methods continue to offer valuable insight into global
328 biodiversity and its broader interactions. For example, it is often difficult to directly study
329 species- and population-level dynamics of rare, cryptic or under-studied organisms. However,
330 genetic approaches can provide an indirect means of identifying: species (Deiner et al. 2017);
331 behaviour (e.g. mating systems (Janes et al. 2016), trophic interactions (de Vere et al. 2017),
332 migration (Chapuis et al. 2009)); demography (e.g. effective population sizes (Janes et al.
333 2018)); and subsequent population-level changes (Gloss et al. 2016). Where possible, better
334 integration of genetic approaches with traditional surveys could greatly advance our
335 knowledge of insect biodiversity and biology (e.g. Severson and Behura 2012; Cullingham et
336 al. 2018 Oct 18). Integration of these methods is becoming increasingly time- and cost-
337 effective because: (i) material for DNA-based work can often be collected during planned
338 surveys or opportunistic site visits by non-specialists; (ii) improved specimen preservation
339 methods are increasing the longevity of samples for research (Matos-Maraví et al. 2019); (iii)
340 commercial DNA extraction kits are decreasing the amount of starting material (e.g. a single
341 leg) required to generate sufficient template (Richards and Murali 2015), meaning that a
342 single specimen might be used multiple times; (iv) the yield of DNA is generally increasing
343 while the amount of DNA required for sequencing is typically decreasing, thereby facilitating
344 numerous applications (Matos-Maraví et al. 2019); and (v) sequencing costs continue to
345 decline making genetic/genomic approaches more accessible. Lastly, the increasing need and
346 pressure to catalogue biodiversity and combat biodiversity declines continues to inspire novel
347 and broad collaborations (e.g. academic, government, non-government organizations, field
348 naturalists, citizen scientists); these collaborations are essential to better combine
349 observational and genetic-based methods and to better integrate these methods with policy
350 and decision-making.

351

352 *Insect Behaviour*

353 The sheer diversity of insects, and the huge variation in life histories and behavioural traits,
354 explains why there is such a variety of trapping methods in the entomologist's toolkit (e.g.
355 observation, pitfall traps, pan traps, malaise traps, aerial traps, netting, light traps, Lindgren
356 traps, beat trays etc.). The most appropriate sampling method will depend almost entirely on
357 the focal taxa and the system and season being sampled (D'Arcy-Burt and Blackshaw 1987;
358 Saunders and Luck 2013). This means there is no single trapping method that can identify
359 population declines for all insect taxa at the global scale. Importantly, it means that any
360 public discussion around studies showing declines of insect taxa need to clearly identify
361 which taxa were targeted in the study's sampling methods.

362

363 Within species, insects can exhibit incredible plasticity in behaviour and a range of
364 personality syndromes (Kralj-Fišer and Schuett 2014; Modlmeier et al. 2015). The speed and
365 flexibility with which behavioural responses occur give an insect greater capacity to deal with
366 environmental change, particularly in the face of rapid or catastrophic events. Insects can
367 respond to environmental changes behaviourally; for example changes in temperature can
368 lead insects to modify their dispersal, diapause, thermoregulation, foraging, and reproductive
369 behaviours (Parmesan 2006; Schilthuizen and Kellermann 2014). Furthermore,
370 environmental change can exert differing selective pressures on behavioural traits. Invasive
371 insects can exhibit drastic shifts in foraging behaviour, activity and boldness in their new
372 environments, and some species have shown rapid behavioural changes in response to
373 environmental variation (Singer et al. 1993; Lombaert et al. 2014).

374

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

380

381 *Natural history observation*

382 Natural history observations are valuable information sources to help understand historical
383 insect declines, and identify potential drivers that can be tested as research hypotheses. A
384 great example of this are the annual natural history notes from Inverness-shire (Scotland)
385 published by G. W. Harper in ‘The Entomologist’s Record and journal of variation’. Harper
386 followed Lepidoptera populations in the highlands from 1952 until his death in 1973. In his
387 1970 record, he notes that “distinct climatic change” and “human destruction of our small
388 local entomological habitats” have driven the decline in Lepidoptera he had witnessed over
389 the previous 14 years (Harper 1971). Declines of some lepidopteran taxa in Great Britain
390 have been confirmed more recently (Fox 2013), and it is uncertain whether these populations
391 will recover.

392

393 Comprehensive records such as these are now rare in most countries, mostly because of
394 declining support for traditional natural history among funding bodies and the broader
395 research community (Tewksbury et al. 2014). It is never too late to start recording natural
396 patterns. Observing nature can lead to discovery of new species, expand known ranges of
397 species, build knowledge of a species’ role in its community, and inform novel research
398 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.

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. Yet 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.

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 (Visser Marcel E and Both Christiaan 2005; 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 USA to control *Pieris rapae*,

423 subsequently contributing to local declines of a native pierid butterfly in northeast USA
424 (Benson et al. 2003). Effects of these complex interactions on the resilience of insect
425 populations are still uncertain.

426

427 Synthetic chemicals (pesticides, herbicides, fungicides) can have lethal and sub-lethal effects
428 on many insect taxa, particularly beneficial species (Desneux et al. 2007). The physiological
429 and biological effects that pesticides have on particular insect taxa is known but, more
430 broadly, we still know very little about how environmental concentrations of these chemicals
431 interfere with biological and ecological processes at the scale of populations, communities
432 and ecosystems (Köhler and Triebkorn 2013; Wood and Goulson 2017). Synergistic
433 interactions between pesticides, herbicides and fungicides can enhance detrimental effects
434 beyond what is observed in isolation, even for individual chemicals that are perceived as
435 apparently ‘harmless’, yet we know very little about the true extent of these interactions in
436 environmental contexts (Desneux et al. 2007).

437

438 Habitat removal and landscape modification are also key drivers of change in local insect
439 populations. In particular, the increasing amount of land converted to homogeneous crop
440 production can provide ideal environments for more pest insect outbreaks and have
441 detrimental effects on populations of beneficial insects (Altieri et al. 1984; Haddad et al.
442 2011; Nicholls and Altieri 2013). Broad-scale land clearing and agricultural intensification
443 reduce the diversity of habitats and resources available to insects at the landscape scale
444 (Hendrickx et al. 2007; Tschardt et al. 2012). Most insect taxa have complex life cycles
445 and require access to multiple different habitats and resources in different life stages. For
446 example, adult dragonflies (Odonata) are winged predators in terrestrial systems, while larval

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

451

452 **Communicating science for insect conservation**

453 Communicating research results is an essential component of the research process. This
454 includes publishing results in scholarly literature and disseminating summaries through
455 popular and social media. Using generalised framing or amplified language can be useful to
456 grab audience attention, especially for critical issues like biodiversity declines. However, this
457 should never be at the expense of accuracy. Evidence of geographically-restricted declines
458 should not be framed as global in scale, and evidence of declines for particular species or
459 taxonomic groups is not evidence that all insects are disappearing. Such misinformation can
460 be counter-productive and affect public trust in scientific knowledge.

461

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

rigorous and accurate. Peer review is an essential community service and a critical process to achieve this, and requires strong commitment from all levels of the research community.

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. Yet the deficit model of science communication (i.e. the belief that the public are ignorant of scientific truths and effective 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-scale declines of all insect species. However, we also stress that, while 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, but we don't need to wait for evidence. 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 save global insect diversity. Building knowledge of the mechanisms that may drive future insect declines, and how those declines would impact

494 ecosystems and human wellbeing, presents many opportunities for conservation investment,
495 engagement and action.

496

497 **Author contributions**

498 MES conceived the idea and led the study; all authors contributed equally to content and
499 manuscript development.

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