Challenges in measuring global insect decline

Clive Hambler[a,*] and Peter A. Henderson[b]

[a] Department of Zoology, University of Oxford, OX1 3PS UK

[b] PISCES Conservation Ltd, Pennington, Lymington, Hants, SO41 8GN, UK

* corresponding author

Email address: clive.hambler@zoo.ox.ac.uk

Telephone +44 1856 279436

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ABSTRACT

Global rates of insect decline will be very hard to measure. Conclusions regarding drivers and rates of declines can be unreliable due to biases - including sampling location and omission of relevant publications through narrow search terms. Extrapolation of global species declines from a few regions or a sample disproportionately including population loss at range-margins is indefensible, and the projected global rate of loss can be seriously overestimated. Samples of insect declines (*e.g.* reviewed publications) must not overlap in space and time, which would violate observation independence. The threat from climate change can be inflated if declines are not separated from the effects of seasonality and activity. Measures of density, not activity-abundance, are most valuable. No extinction can be firmly attributed to anthropogenic climate change unless the climate trend can also be attributed to humans. The role of pesticides will be inflated if developed nations dominate in the samples. We suggest some minimal methodological requirements when reviewing declines and extinctions. Given these strictures, we reaffirm that declines in most non-marine invertebrate groups will have to be estimated using previously calibrated indicators such as birds and freshwater fish.

Keywords:

Climate Change

Extinction

Invertebrate

Red List

Threat

1. Introduction

Meeting policy targets on preventing biodiversity loss requires measures of rates of loss, and insects will likely be a major fraction of terrestrial extinctions. Recent reports of insect decline (Lister and Garcia, 2018; Sánchez-Bayo and Wyckhus, 2019) have received considerable and often uncritical media reporting (*e.g.* BBC, 2019, Carrington, 2019) which, if overstating the rates, will erode public confidence in science and be detrimental to conservation. Here we demonstrate that it is not possible to measure directly the overall global rates of population decline, biomass decline or extinction in insects, since data are too sparse and measuring insect abundance is challenging, even in the short term.

General reviews of threat and extinction rates (*e.g.* Thomas et al., 2004; Stork, 2010; Hambler et al., 2011; Hambler and Canney, 2013) reveal the challenges of estimates and the paucity of data on most invertebrate taxa. The shortage of taxonomists and studies render extinction risks in most groups of organism very poorly known and controversial (Minelli et al., 2010; Stork, 2010; Lockwood, 2011; Costello et al., 2013).

It has been proposed (Hambler et al., 2011) that in addition to measuring loss of habitat area, calibrated indicator taxa such as birds and freshwater fish can provide the best information available on extinction rates - now and in the future. Some work suggests extinction rates and the proportions threatened are similar for insects and vertebrates (May et al., 1995; Hambler and Speight, 2004; Hambler et al., 2011; Hambler and Canney, 2013). Regional extinction rates for British butterflies are higher than for British birds, although many reported global and regional rates for invertebrates are much lower than for vertebrates (Thomas et al., 2004; Hambler et al., 2011). Similarity of extinction rates is in accord with habitat loss as the main driver of declines and extinction through species area effects (Hambler et al., 2011).

We consider here the requirements when performing direct measurement of large-scale trends in invertebrate populations, biomass or species. We examine how bias can arise in a review of global rates of loss of and how to reduce bias.

2. Methodology

2.1 Regional bias

To obtain a general global extinction rate would require a representative sample of population changes, such as a random sample from the planet. If the sample used is spatially unrepresentative (as in Sánchez-Bayo and Wyckhus, 2019) then extrapolation cannot be defended.

2.2 Range margin bias

Global extrapolation of the declines would require a sample from a representative part of each species' range. In contrast Sánchez-Bayo and Wyckhus (2019) use numerous regional declines, several from range margins of species. The range margin species may have higher extinction rates (Shaw, 2005; Hambler et al., 2011; Henderson and Magurran, 2014).

The use of regional or national 'red lists' in a review (such as Sánchez-Bayo and Wyckhus, 2019) will inflate the calculated extinction rate. The percentage of 'endangered' species will be overstated because regional red lists include species that are globally *not* threatened - for example butterfly species in Britain. Regional 'red listing' using IUCN trend criteria is unacceptably influenced by short term-trends and start dates (Fox et al., 2018).

In a long-term study of an entire fish and crustacean community the core community was notably stable while a larger number of transient species fluctuated greatly and often went locally extinct. These transient or tourist species were typically adapted to conditions found elsewhere, predominately the more species-rich waters to the south (Magurran and Henderson, 2003; Henderson and Magurran, 2014). There is now an extensive literature showing the existence of core and transient components of stable ecosystems with continual loss and gain of species on the edge of their range.

2.3 Taxon bias

'Red lists' for insects are unrepresentative of insects: they are mainly available for species-poor, conspicuous, charismatic groups (*e.g.* butterflies, odonates) and tend to focus on groups already known to be at high risk (*e.g.* saproxylic insects; odonates). Several of the taxa used in Sánchez-Bayo and Wyckhus (2019) are relatively thermophilous and are at the high end of regional extinction rates in Britain (Hambler et al., 2011) or Scotland (Shaw, 2005). There has been a long debate on how typical termophilous taxa (such as butterflies) are of other taxa (*e.g*. Thomas et al., 1994; Hambler and Speight, 2004; Thomas et al. 2004; Thomas and Clarke, 2004).

Regional rates of decline have been recorded for very few insect taxa. Sánchez-Bayo and Wyckhus (2019) were able to discover fewer than 100 reports meeting their very narrow criteria. These authors gave a headline figure of insect species in decline which appears to be an average only of the taxa in their review, rendering their conclusions on global declines indefensible.

When comparing rates with taxa such as vertebrates, the samples of other taxa should also be representative. In contrast, Sánchez-Bayo and Wyckhus (2019) suggest the global rate of extinction of vertebrates to be "a large margin" lower than for insects, yet fish do not appear to be included.

2.4 Search Term scope and bias

The search terms used in any literature review must be fit for purpose: a sole focus on decline (as in Sánchez-Bayo and Wyckhus, 2019) will bias against trends of population growth, and miss extinctions or population stability. Searching only for "insect*" will miss some titles on invertebrates, or on animals, which include insects. Terms such as "trend" or "extinction" would reveal other studies of declines.

A limited search can lead to factual inaccuracy, as in Sánchez-Bayo and Wyckhus (2019) who make false statements on lack of data for ants, saproxylic beetles and Orthoptera. Yet Hambler et al. (2011) list regional extinctions in these groups over a specified timeframe (200 years) in Britain, and other highly relevant data are available (Shirt, 1987; Bratten, 1991; Shaw, 2005). Hambler et al. (2011) provide data on aquatic insects but these were not found by Sánchez-Bayo and Wyckhus (2019), and only one study was found for Hemiptera - missing the major long-term study by Southwood et al. (2003).

Search bias could lead to oversights: for example Sánchez-Bayo and Wyckhus (2019) do not include the evidence on extinction rates from several relevant studies (*e.g.* May et al., 1995; Shaw, 2005; Stork, 2010; Hambler et al., 2011; Hambler and Canney, 2013).

2.5 Literature bias

A broad net is required to capture published data in invertebrate declines. Sánchez-Bayo and Wyckhus (2019) "aimed at compiling all long-term insect surveys conducted over the past 40 years that are available through global peer-reviewed literature databases." This was reportedly attempted primarily through a search on the online Web of Science. Such a specialised database can omit books, book chapters and possibly relevant grey literature (all of which can be peer-reviewed, although this is no guarantee of quality).

2.6 Reporting bias

We suggest few ecologists are motivated to publish a report on 'healthy' insect populations. A notable exception is Shortall et al. (2009).

2.7 Extrapolation risks

Net trends are required for extrapolations. If only declining trends are extrapolated, it will erroneously lead to exaggerated conclusions of losses. For example Sánchez-Bayo and Wyckhus (2019) and Sánchez-Bayo (quoted 2019) apparently extrapolate an estimated 2.5% annual loss in a sample of publications to complete loss of all populations and species of insect by the year 2100!

Extrapolation from declining species ignores the chance that some of these would be temporary declines, or population cycles, as with fish (Henderson and Magurran, 2014). Moreover, rates may diminish after the initial loss of the most sensitive species (Hambler et al., 2011) or during relaxation after habitat loss (Hambler and Canney, 2013).

Consider also the reverse trend: if search terms acquire selectively publications showing species *gains* over a specified timescale, this could be extrapolated to suggest that the world would have a larger number of species by 2100. Indeed, depending on the studies used and the net rate of species gain a prediction could be made that Earth would trend to holding an infinite number of species.

2.8 Driver attribution

The subjective selection of types of potential driver of decline (habitat change, pollution, biological traits, climate change) can inevitably make some factors appear important. If driver categories are lumped, or split, in alternative ways then their relative contributions can be arbitrarily adjusted. Terminology on threat is also likely to vary between the various publications, with some authors more likely or prepared to use some terms.

When performing meta-analysis of a range of reviews, it is crucial that the number of species in each case is accommodated: otherwise declines in taxa with many species such as Hymenoptera will be given equal weight to taxa with far fewer such as butterflies. If each study is given equal weight the proportion of global species being driven by each factor cannot be calculated - yet Sánchez-Bayo and Wyckhus (2019) attempt this.

It will be very difficult to make attributions of population declines to anthropogenic climate change, given uncertainties in attributing global, and particularly regional, climate trends to pollutants (IPCC, 2013). It is more difficult to distinguish an anthropogenic climate signal distinct from natural variation prior to 1950 (IPCC, 2013). Sánchez-Bayo and Wyckhus (2019) conclude (on the basis of only 3 tropical studies) that climate change is "particularly important in tropical regions". Yet the higher levels of endemism of tropical insects are evidence of how robust to climate changes the tropical species have been and should remain (Hambler and Canney, 2013).

It is crucial that there is not double-counting of drivers, for example in climate categories. In Sánchez-Bayo and Wyckhus (2019) the method of attribution of climate change as a driver in 6.9% of studies is insufficient for replication, but perhaps assumes 5% from "climate warming" plus all "bushfires" (1.9%). However, some bushfires are natural. Globally, the area burnt decreased from 1996 and 2012 and regional attribution of fire is highly problematic (Doerr and Santín, 2016; Ward et al., 2018). Moreover, bushfires might be caused by warming (Doerr and Santín, 2016) so these criteria are not independent - yet are apparently treated as such in Sánchez-Bayo and Wyckhus, (2019). The net result of overlooking these considerations would be to inflate the role of climate change, as may subsequent media reports (*e.g.* BBC, 2019).

Alternatively, the global Red List (IUCN, 2019) can be searched by 'threat' for putative drivers of declines. For example, this reveals four 'extinct' insect species assessed as possibly impacted by climate change (natural or anthropogenic), and none of these global insect extinctions can be firmly attributed to post 1950 climate change.

As another example, the proportion of species allegedly affected by pesticides could be an artefact if there is location bias towards industrialised regions with more surveys in intensive agricultural landscapes, as in Sánchez-Bayo and Wyckhus (2019).

2.9 Statistical rigour

Any review of declines must not make statistical errors.

Independence of data points is a typical requirement of statistical tests such as ANOVA. Yet several of the 73 studies reviewed by Sánchez-Bayo and Wyckhus (2019) are non-independent in space and / or time. For example trends in butterflies in the U.K. are in more than one study, and also overlap with data for Europe. The trend in Odonata for the world may include the regional studies of this taxon.

It can be problematic to test for differences in rates of species in decline using ANOVA. Sánchez-Bayo and Wyckhus (2019) compare percentage declines in various regions and taxa.

This is unwise as these data inevitably lack independence in the observations, the residuals will not be normal and the data will not be homoscedastic. A possible approach would be to use a generalized linear model, but this may still be problematical if the various data sets are not independent.

Similarly, non-independence of studies could render the overall proportion of publications reporting a driver of decline potentially invalid as a summary statistic. This introduces errors of pseudoreplication and duplication (double-counting) as in Sánchez-Bayo and Wyckhus (2019).

2.10 Reproducibility of methods, and standard IUCN criteria

It is important to be able to replicate some key results of a review of declines. This is not always the case: Sánchez-Bayo and Wyckhus (2019) claim "conservation status of individual species follows the IUCN classification criteria (IUCN 2009)", but this reference is omitted from the review's references. However, for some taxa the review uses national lists explicitly distinguished from IUCN criteria (*e.g.* New Zealand carabid beetles, McGuinness, 2007).

Assigning the actual levels of threat such as "endangered" and "vulnerable" in a review should be done in a consistent way for different taxa (Stork, 2010), if relevant specifying the regional or global IUCN sub-criteria used (*e.g.* Fox et al., 2018). Attempts by non-specialist authors to convert various declines into IUCN threat status using percentage declines over unclear timeframes are problematic.

2.11 Accurate citation of past studies

It is important to represent accurately the results in any paper that is included in a review of declines. As an example of inaccurate interpretation, Sánchez-Bayo and Wyckhus (2019) state that vertebrates in Puerto Rico declined "as a result of invertebrate food shortages", which misrepresents Lister and Garcia (2018). It confuses correlation with causation - which was unproven by Lister and Garcia (2018).

2.12 Measure abundance, not activity-abundance

Any study of decline requires accurate measures of abundance. In contrast, we argue Lister and Garcia (2018) is deeply flawed because it misrepresents 'activity-abundance' measures (Henderson and Southwood, 2016) as 'abundance'. The efficiency of sampling using traps and visual observations will be dependent on weather and climate. Any trends in climate could influence movements and phenology of invertebrates and vertebrates, even in the absence of population change. Activity-dependent methods should not be used without consideration of weather. Absolute samples (density measures) including knockdown sampling and vacuum sampling are required (Hambler and Canney, 2013; Henderson and Southwood, 2016) yet many published studies use pitfall traps, flight interceptor traps, baited traps, visual observations or similar (*e.g.* Hallmann et al., 2017; Lister and Garcia, 2018).

2.13 Adequate time series, and measuring past rates

A reliable proof of trend cannot be obtained from sampling at only two points in time, a notable failing of Lister and Garcia (2018). Consistent methods are required for long-term monitoring (Hambler and Canney, 2013, and due to allegedly inconsistent climatology Lister and Garcia (2018) is currently subject to a retraction request (Homewood 2019). This is one of the tiny number of tropical studies (n = 3) in Sánchez-Bayo and Wyckhus (2019); it is thus absolutely crucial to that review's conclusions on climate and tropical insect decline, and to implied subsequent effects.

In order to know if extinction rates are relatively rapid - perhaps even a mass extinction, previous rates need to be known. This is extremely hard for insects. Yet Sánchez-Bayo and Wyckhus (2019) claim that rates of loss are the largest since two mass extinctions (Late Permian and Cretaceous. This conclusion is not possible for most invertebrates, even for the mid Holocene. Subfossils reveal numerous insect species went extinct during the deforestation of Britain in the Holocene (*e.g.* Buckland, 2008; Elias et al., 2009); the peak extinction rate in this period and before it is unknown. Hambler *et al*. (2011) list numerous 19th Century regional insect extinctions, demonstrating high losses before pesticides and anthropogenic climate change.

2.14. Rates of loss of biomass

The rate of loss of worldwide insect biomass will be particularly hard to estimate, despite requiring less taxonomic effort. The average mass of a representative sample of regions and taxa would have to be known, and these data are not available given the limited work in the tropics. Sánchez-Bayo and Wyckhus (2019 attempt to derive such a rate from a review of studies showing biomass decline, yet these are unrepresentative taxonomically.

3. Conclusion and synthesis of recommendations

Any review of declines must not have structural bias and its methods and uncertainties must be presented. We argue a review of declines with numerous methodological problems (Sánchez-Bayo and Wyckhus, 2019) has already facilitated damaging uncritical reporting that all insects on the planet may be extinct by the end of the century (*e.g*. BBC, 2019).

In the light of the biases and other problems discussed above, we suggest these minimal standards for reviews of population trends and extinctions:

a) Representativeness of the locations of regional samples if claims are to be made about global loss.

b) Representativeness of taxa if claims are to be made about much higher taxonomic levels and about biomass.

c) Representativeness of search terms for population time series, including those that can detect gains, losses, declines, increases, regional and global extinctions, colonisations and no trends. Terms should ideally be in a range of languages. Publication and reporting bias against studies showing no trend should be acknowledged.

d) Avoidance of pseudoreplication in reviewed studies. Studies of declines must be independent in space and time, or if not, suitably nested in analysis.

e) Avoidance of double-counting of drivers, using nested classifications and interaction terms if appropriate.

f) Searches need to include a wide range of literature not listed in the Web of Science.

g) Clarify when the IUCN has made or endorsed a threat assessment, such as "Endangered", as opposed to authors claiming to have used IUCN classification methods.

h) Clarify the use of 'endangered', 'threatened' and 'extinct', if these are only regional, at all points in a publication in which they might be misinterpreted.

i) Methods should be presented in sufficient detail for reproducibility.

j) If population trends are extrapolated to the future, or to other taxa, state the assumptions being made.

k) Do not extrapolate trends from time series with an inadequate number of data points (times).

l) Prioritise studies with consistent methods through time.

m) In headline statistics, give the error range and uncertainty.

In sum, we argue these requirements make direct measurements of invertebrate declines impossible for the foreseeable future. Even if a very large number of insect density monitoring stations were set up globally, and sampled frequently, it could take many decades to detect trends - let alone attribute drivers. Without taxonomic knowledge and autecology sufficient to assign species quality (Hambler and Canney, 2013) it would be hard to know if trends were of concern.

Proxies such as rates of loss of birds, fish and habitat area are the only realistic methods of assessing global wildlife decline. We may indeed be in a mass extinction (Barnosky, 2011; Hambler and Canney, 2013), but the best evidence for this is presently from vertebrates.

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