Introduction

With regard to species richness, insects constitute the world’s most diverse taxonomic group (Homburg *et al.*, 2019; Cardoso *et al.*, 2020), representing extensive unique and overlapping functions. Pollination by Hymenoptera, Lepidoptera, and Diptera strongly influences crop yields and profits (Habel *et al.*, 2019) with around three-quarters of crop species dependent on pollination to some extent (Klein *et al.*, 2007). Additionally, insects contribute to biological pest control and organic matter recycling, as well as constituting a major link in the food web between primary producers and consumers (Sánchez-Bayo and Wyckhuys, 2019). The loss of these services threatens global ecosystem health and food security (Potts *et al.*, 2016), which is particularly apparent in the global south where reliance on insect pollinated crops is high (Dicks *et al.*, 2021).

Despite their invaluable contributions, insects are underrepresented in long-term biodiversity studies compared to vertebrates (Outhwaite *et al.*, 2020; Wagner *et al.*, 2021b). In a review by Titley *et al.* (2017) there was an even split between biodiversity papers reporting on vertebrates and invertebrates, a substantial difference to the proportions of species in existence where 95% are invertebrates. Possible reasons for this include the view of insects as pests and disease vectors (Lawton *et al.*, 1998; Miličić *et al.*, 2021), difficulty in identifying individuals to species level, as well as populations being particularly hard to monitor considering their inconspicuous nature and high annual variation (Fox *et al.*, 2019). Where insects are the focus, bees, butterflies, and moths are over-represented, limiting conclusions on the state of insects as a whole (Hallmann *et al.*, 2020). Therefore, while we may be experiencing the sixth mass extinction in evolutionary history (Dirzo *et al.*, 2014), it proves difficult to assess the extent to which insects are affected.

This underrepresentation has been somewhat rectified recently with a ten-fold increase in the number of insect decline papers between 2000 and 2010 (Eggleton, 2020), though this does not come without its drawbacks. A dearth of historical records hinders our ability to determine a baseline to which we should compare the current state of species, termed shifting baseline syndrome (Didham *et al.*, 2020). Any reported increases could be deceptively encouraging due to the possibility that the new figures are negligible compared to historical numbers. Additionally, the disparity between the one million insects described and the 5.5 million thought to exist (Stork, 2018) means studies continue to suffer from our lack of knowledge.

Although more long-term data is needed, current consensus is that insect decline is sufficient to warrant immediate further study and action (Montgomery *et al.*, 2020). Sánchez-Bayo and Wyckhuys (2019)'s speculations that 40% of insect species could go extinct in the next few decades have been prominent in bringing the issue to the forefront, though fundamental issues — particularly their biased literature search strategy, vote-counting methodology, and unjustified global extrapolation of findings — have been discussed (Simmons *et al.*, 2019; Saunders *et al.*, 2020). A similarly alarming seasonal decline of 76% of total flying insect biomass was observed in Germany (Hallmann *et al.*, 2017). Nevertheless, it is rare for a study to exclusively report declines (Saunders *et al.*, 2020); some insect populations are stable or increasing (Boyes *et al.*, 2019; Wagner *et al.*, 2021b) such as the 5.5% UK terrestrial insect occupancy increase (1970-2015) reported by Outhwaite *et al.* (2020). Crossley *et al.* (2020) conclude no overall trend in US insect abundance or diversity, though have been criticised for violating the assumption that records were collected consistently between datasets (Welti *et al.*, 2021).

A variety of reasons contribute to the contrasting results, one being geographical variation. Trends in carabids markedly differed across the UK from 50% declines in northern moorland to 50% increases in southern downland (Brooks *et al.*, 2012). Additional complexity stems from the hypothesis that areas largely surrounded by agricultural land will experience stronger rates of insect decline, possibly due to reduced dispersal ability in a fragmented habitat or increased pesticide exposure (Seibold *et al.*, 2019). Furthermore, most research to date has been restricted to human-dominated landscapes in Europe and North America. Recognising this, researchers have begun to search for population trends elsewhere including the tropics (wherein exists the highest biodiversity) (Lister and Garcia, 2018; Wagner *et al.*, 2021b) and the Arctic (Loboda *et al.*, 2018; Gillespie *et al.*, 2020).

Conflicting results may also be due to temporal or taxonomic variation. Ollerton *et al.* (2014) calculated that the highest extinction rates for British bee and flower-visiting wasps occurred in the 1920s to 1950s, likely coinciding with intensification of agricultural practise. Biesmeijer *et al.* (2006) exemplifies differences between species with bee richness decreasing in 52% of British cells, while no significant changes were observed for hoverflies. Similarly, Hallmann *et al.* (2020) reports declines in macro-moths, beetles, and caddisflies, but not true bugs and mayflies in the Netherlands. These findings indicate the difficulty of generalising research focused on specific species or timespans.

Studies that assess the status of insects at higher taxonomic levels may breach this gap, though concurrently overlook species-level trends (Wagner *et al.*, 2021b). Van Klink *et al.* (2020) found an average 9% decrease and 11% increase per decade of terrestrial and freshwater insects, respectively, but is criticised because the abundance and biomass metrics used are unable to account for changes in community structure such as the replacement of sensitive species with tolerant ones (Jähnig *et al.*, 2021), or even complete species turnover (Hillebrand *et al.*, 2018). It is also possible to observe decreases in species richness but not biomass, potentially explained by smaller species showing stronger declines than larger ones (Homburg *et al.*, 2019).

Identifying the patterns of variation in insect population trends is difficult, though it is an additional challenge to understand the drivers. The threats to insects are primarily human-caused (Eggleton, 2020) and include land-use change, climate change, habitat loss and fragmentation, pollution, and invasive species (Cardoso *et al.*, 2020). Of these, land-use — particularly agricultural expansion and intensification — has been widely discussed (Newbold *et al.*, 2014; Newbold *et al.*, 2016a; Newbold *et al.*, 2016b; Newbold *et al.*, 2018). Land-use change is associated with an increase in monoculture, which although can be a pollinator resource, the crops are often characterised by short flowering periods inadequate for pollinators with longer flight seasons (Vanbergen and Initiative, 2013). Moreover, effects are known to vary geographically and taxonomically. Millard *et al.* (2021) found pollinator species richness in non-tropical areas to be significantly higher in minimal-intensity cropland than primary vegetation, in contrast to the decrease observed in tropical regions. Land-use is thought to affect butterflies in particular with Engelhardt *et al.* (2022) observing decreases in butterfly habitat specialists, but not grasshoppers nor dragonflies. This is potentially because butterflies possess a high quantity of specialised taxa, the existence of which are associated with high quality habitats.

Climate change is also predicted to substantially impact insects with tropical species being particularly vulnerable due to their warming tolerance being roughly a fifth of that of higher latitude insects (Deutsch *et al.*, 2008). Climate change also indirectly affects insects through alteration to floral resource (Soroye *et al.*, 2020) and mismatches between symbiotic plants and pollinators. There has been conflicting evidence on the link between climate change and insect declines. Lister and Garcia (2018) report sustained biomass declines across 10 major taxa in a Puerto Rican rainforest between 1976 and 2012, concluding the findings are a result of climate warming due to average ambient temperature being a significant predictor in their model. Willig *et al.* (2019) later repeated some of these analyses and did not find evidence of declines due to climate change. The authors argue Lister and Garcia (2018) failed to account for drought or hurricanes in addition to temperature related aspects of climate change, neither did they adjust abundance data according to sampling effort. Additionally, Loboda *et al.* (2018) and Van Klink *et al.* (2020) found that most climate predictors could not explain the trends they observed.

It could be possible that climate change has more of an effect when in combination with other threats. Using PREDICTS data (Hudson *et al.*, 2017), Outhwaite *et al.* (2022) found that an increase in temperature led to larger declines in high-intensity than low-intensity agriculture when compared to primary vegetation with no warming, indicating less intensive agriculture may partially counteract the negative impacts of climate change. Nevertheless, there is still more to be understood about the drivers of insect trends, with many studies concluding that future work should focus on untangling these (Hallmann *et al.*, 2017; Habel *et al.*, 2019; Wagner *et al.*, 2021a; Wagner *et al.*, 2021b).

In addition to conducting further work to understand the drivers, it is also of paramount importance to investigate how species traits affect extinction risk. Rare species are often reported as faring worse than common ones (Powney *et al.*, 2019; Outhwaite *et al.*, 2020) though if common species are also declining, this could have stronger impacts on ecosystem functioning (Cardoso *et al.*, 2020). Declines are also more frequently reported in species which are habitat or dietary specialists (Biesmeijer *et al.*, 2006; Boyes *et al.*, 2019; Wagner *et al.*, 2021a), small (Homburg *et al.*, 2019), poor dispersers (Cardoso *et al.*, 2020), univoltine (Biesmeijer *et al.*, 2006; Wepprich *et al.*, 2019), or those that have a shorter flight season (De Palma *et al.*, 2015). Nevertheless, traits that increase survival probability may be as important to identify as those which predispose species to decline (Boyes *et al.*, 2019).

To overcome these gaps in our understanding and untangle the complex variation and drivers of insect population trends, we must synthesise information across literature to reduce the chance that scientists, media, and policy-makers place too much bearing on individual studies. A necessary step in achieving this is through collation of evidence into a database, as done by EntoGEM (Haddaway *et al.*, 2020; Grames *et al.*, 2022). This mapping of relevant literature allows easy identification of the distribution of evidence and access to additional information including the research methods.

Once sufficient data exists to answer a proposed hypothesis, there are a number of approaches available to draw conclusions across studies. These include synthetic analyses which build models based on collated primary data. Synthetic analyses are common in papers utilising data in PREDICTS (Hudson *et al.*, 2017), a database designed for the purpose of exploring how biodiversity reacts to land-use change (Newbold *et al.*, 2014; Gray *et al.*, 2016).

Alternatively, meta-analysis can be used to quantitatively summarise results across multiple studies (often as part of a systematic review) in a replicable process to answer pre-defined questions (Arnqvist and Wooster, 1995; Gurevitch *et al.*, 2018). Effect sizes are calculated for each primary study, weighted according to study size, and fed into a statistical model to determine overall effect size and a confidence measure. It is possible for multiple effect sizes to be extracted for a single study, and the model design must therefore take into account their relatedness. The routinely used metafor R package (Viechtbauer, 2010) is available to facilitate the process.

Building upon these methods, the natural advancement is to ensure these reviews do not remain static. This is the concept of living reviews (Elliott *et al.*, 2017) where the analytical process is repeated and results are updated as new evidence becomes available, allowing decisions to be based upon the best current evidence. The Metadataset website and its dynamic meta-analysis R Shiny app enables users to browse for relevant data — currently in the fields of invasive species and cover crops — and meta-analyse it (Shackelford *et al.*, 2021). The infrastructure already exists for this database to be a living review, so that when new meta-analyses are conducted, results are based on the best available evidence.

Furthermore, as increasing numbers of meta-analyses are completed, we are able to perform meta-meta-analyses, adding an additional layer of complexity to analysing, visualising, and interpreting, results. Here, I present a new Shiny app designed to run meta-meta-analytic models on the fly and produce graphical summaries of results. The app is designed with insect population trends as the focus, though it would be possible to repurpose it for other means.

The shiny app reads in data from a living review of meta-analysis studies, rather than primary studies as used within the dynamic meta-analysis app. Using this data, the user can run a custom model on the fly based on their hypotheses and interests. Estimations of change in insect biodiversity are outputted and are specific to the threats and biodiversity metrics — and in future other variables such as location and taxonomic group — the user has chosen to investigate. As new meta-analyses are conducted, users can upload these results so the figures can reactively update to these changes.

The creation of the app is motivated by the need to make best use of existing and future data to improve our understanding of the challenging field of insect population trends and thus increase the ability of scientists to convey messages to decision and policy makers, as well as the public on how insect declines can be mitigated.