Introduction

Insects constitute the most diverse taxonomic group on Earth (Homburg *et al.*, 2019; Cardoso *et al.*, 2020) and represent 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, pollination supports a variety of wild plants, which could prove vital in future drug discovery (Vanbergen and Initiative, 2013). Insects also offer highly valued biological pest control, organic matter recycling, and are a major link in the food web between primary producers and consumers (Sánchez-Bayo and Wyckhuys, 2019). Without these services, we threaten global ecosystem health and food security (Powney *et al.*, 2019), which is particularly apparent in the global south where reliance on insect pollinated crops is high (Dicks *et al.*, 2021).

Despite these invaluable services, insects have been underrepresented in long-term biodiversity studies compared to vertebrates (Outhwaite *et al.*, 2020; Wagner *et al.*, 2021b). Of the biodiversity papers analysed by Titley *et al.* (2017) there was an even split between those reporting on vertebrates and invertebrates, a substantial difference to the proportions of species in existence where 95% are invertebrates. Therefore, while we may be experiencing the sixth mass extinction in evolutionary history, it proves difficult to assess the impact on insects (Dirzo *et al.*, 2014) especially when only one million of the 5.5 million insects thought to exist have been described (Stork, 2018). Possible reasons for this lack of study include the view of insects as pests and disease vectors (Lawton *et al.*, 1998; Miličić *et al.*, 2021), as well as populations being particularly hard to monitor considering the high annual variation displayed by this group (Fox *et al.*, 2019).

This underrepresentation has been somewhat rectified in recent with a ten-fold increase in the number of published insect decline studies between 2000 and 2010 (Eggleton, 2020), though this does not come without its drawbacks. More records available for recent years confounds our ability to determine a historic baseline to which we should compare the current state of species, termed shifting baseline syndrome (Didham *et al.*, 2020). There is also the issue of over-representation of certain taxa including butterflies, bees, and moths, limiting conclusions that can be drawn on the state of insects as a whole (Hallmann *et al.*, 2020). Even now, studies are suffering from a lack of data. Wepprich *et al.* (2019) could not report on a fifth of regularly observed butterflies in Ohio due to insufficient data. Expert elicitation studies are often useful in cases where data is lacking, though even these have been known to report a high proportion of responses as unknown (Miličić *et al.*, 2021).

Although more long-term time series data is needed, the evidence so far suggests an overall insect decline considerable enough 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 media and subsequent literature, though fundamental issues - particularly around their biased literature search strategy, vote-counting methodology, and unjustified extrapolation of findings to a global scale - have been discussed (Simmons *et al.*, 2019; Saunders *et al.*, 2020). Hallmann *et al.* (2017) observed a similarly alarming seasonal decline of 76% of total flying insect biomass from 1989 to 2017 in Germany.

Nevertheless, it is important to recognise that not all insects are declining (Boyes *et al.*, 2019; Wagner *et al.*, 2021b) and it is a rare that a study does not report stable or positive trends for a certain proportion of taxa (Saunders *et al.*, 2020). Outhwaite *et al.* (2020) conclude that terrestrial insects have increased in average occupancy by 5.5% in the UK (1970-2015) while in the US, Crossley *et al.* (2020) report no overall trend in insect abundance and diversity across 68 long term ecological research sites, though this could have been impacted by the researchers violating the assumption that records were collected consistently between datasets (Welti *et al.*, 2021).

There are a variety of reasons for the hugely contrasting results observed. One of these is geographical variation. Trends in carabids markedly differed across the UK from 50% declines in northern moorland and western pasture, to 50% increase in southern downland (Brooks *et al.*, 2012). Similarly, Powney *et al.* (2019) found 55% decreases in upland species, whilst 12% increase in insects associated with crop pollination. Agricultural land surrounding natural sites has been linked with stronger rates of insect decline in those natural sites, possible due to reduced dispersal ability in a fragmented habitat or increased pesticide exposure (Seibold *et al.*, 2019). However, habitat is not always found to be associated with rate of decline — strong declines (overall 84%) of butterflies in the Netherlands were found in all of grassland, woodland, and heathland.

Most research has been restricted to human-dominated landscapes in Europe and North America meaning we do not currently have enough evidence to assume that patterns observed for Westernised countries also applies to other areas such as the tropics wherein exists the highest insect biodiversity (Lister and Garcia, 2018; Wagner *et al.*, 2021b). Researchers have recognised this geographic restrictiveness and have begun to search for population trends elsewhere including the Arctic (Loboda *et al.*, 2018; Gillespie *et al.*, 2020).

Studies may also report conflicting results due to temporal variation. Ollerton *et al.* (2014) inferred that the greatest extinction rates of bee and flower-visiting wasps in the 1920s to 1950s coincided with intensification of agricultural practise. Since the 1980s, Powney *et al.* (2019) reports all severe decline in Great British bees occurred since 2007, whereas hoverflies have experienced sustained declines from 1987 to 2012.

Another reason for differing results reflects the taxonomic level and the specific taxa researchers study. Studies that generalise across higher taxonomic levels provide necessary viewpoints on the general health status of insects, though likely overlook species-level trends that more focused studies may capture (Wagner *et al.*, 2021b). For example, Van Klink *et al.* (2020) found an average 9% decrease and 11% increase per decade of terrestrial and freshwater insects based on abundance and biomass. This study has been criticised for potentially overlooking species-level changes because these metrics are unable to account for changes in community structure such as the replacement of sensitive species with tolerant ones (Jähnig *et al.*, 2021). Biesmeijer *et al.* (2006)’s study exemplifies differences between species with bee richness decreasing in 52% of British cells, but no significant changes for hoverflies. Furthermore, Hallmann *et al.* (2020) reports declines in macro-moths, beetles, and caddisflies, but not true bugs and mayflies in the Netherlands.

Van Klink *et al.* (2020)’s study highlights the important differences that can arise through the use of different metrics. When no change is detected, it could be concluded that the population is stable, when in fact there could have been complete species turnover (Hillebrand *et al.*, 2018). This situation occurred in Homburg *et al.* (2019)’s study where an overall decline in species richness, but not biomass was observed, potentially explained via smaller species showing stronger declines. The best metric to choose will be based upon study design — for example, if the research is around pollination services, then abundance of species rather than species richness may be more important for the continuation of this service — though resource-allowing, studying insect declines in terms of multiple metrics will provide a better overview.

One aspect of our understanding of insect declines that is particularly lacking is the drivers causing the trends. Honey bees are known to suffer from colony collapse disorder and although pathogens seem to have an important role, it is still uncertain how an interaction of threats has such a devastating effect on worker bees (VanEngelsdorp *et al.*, 2009). Furthermore, although it is recognised that the threats to insects — including land-use change, climate change, habitat loss and fragmentation, pollution, and invasive species (Cardoso *et al.*, 2020) — are human-caused (Eggleton, 2020), they are likely to have differing geographic and taxonomic effects, complicated further by their intensity.

One threat that has been widely discussed is land-use, particularly the effects of agriculture (Newbold *et al.*, 2016a). Agricultural expansion and intensification can lead to large areas of monoculture, which can be a resource for pollinators, though crops are often characterised by short periods of flowering, which is inadequate for pollinators with longer flight seasons (Vanbergen and Initiative, 2013). A sequence of studies by (Newbold *et al.*, 2014; Newbold *et al.*, 2016b; Newbold *et al.*, 2018) link land-use to probability of species occurrence, generally with higher intensity land-use leading to fewer species. This is not necessarily true in all cases: for pollinators, Millard *et al.* (2021) found species richness in non-tropical areas to be significantly higher in minimal-intensity cropland than primary vegetation. This was in contrast to the decrease seen between the land-uses in tropical regions. These differences could stem from temperature regions having a longer history with agriculture and thus sensitive species may have already of been lost. Specific land-uses may also be particularly impactful upon certain taxa. For example, butterflies possess a high quantity of specialised taxa, the existence of which are associated with high quality habitats. (Engelhardt *et al.*, 2022) found butterfly habitat specialists to decrease across their study period, but did not find a significant trend for grasshoppers nor dragonflies, suggesting land-use is a potential driver which particularly affects butterflies.

Climate change is another driver predicted to substantially impact insect populations with tropical insects — which represent the highest biodiversity — being particularly vulnerable due to their warming tolerance being on average 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 could lead to a mismatch between symbiotic plants and pollinators if they go through differential rates of migration. There has been varying evidence that supports a link between climate change and insect declines. Lister and Garcia (2018) report sustained biomass declines across all 10 major taxa in a Puerto Rican rainforest between 1976 and 2012. As average ambient temperature was found as a significant predictor, the authors claim it is climate warming causing these declines. Willig *et al.* (2019) later repeated some of these analyses concluding no 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 decreases in abundance and richness in high-intensity than low-intensity agriculture when compared to primary vegetation with no warming. These findings indicate less intensive agriculture may partially counteract the negative impacts of climate change. Nevertheless, there is still much 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 that future work investigates 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). Interactions could also play a role here, with Seibold *et al.* (2019) observing declines mainly in rare species in grasslands, but both rare and abundant species affected in forests. Furthermore, the traits that increase survival probability may be as important to identify as those which lead species to decline (Boyes *et al.*, 2019).

Due to the very contradictory findings in the literature, we need an effective way of bringing together large amounts of data and visualising results. Many datasets in existence remain unanalysed or not analysed to their full potential (Outhwaite *et al.*, 2020; Wagner *et al.*, 2021b). Furthermore, therein exists sufficient meta-analyses that we can begin to perform meta-meta-analyses, adding an additional layer of complexity to visualising, interpreting, and explaining results, but an excellent tool to understanding the challenging field of insect population trends. Until now, no application exists that can produce graphical summaries of meta-meta-analyses reactive to changes as new meta-analyses are added to the database.

Here, I present an R shiny app designed to meet this necessity by making meta-meta-analysis results easy to interpret 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.

Run analysis on the fly, visualise results, upload your own data.

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