|  |  |
| --- | --- |
| Paper | Key point(s) |
| (Hallmann et al., 2017) | Hallmann et al., 2017 observed a seasonal decline of 76% total flying insect biomass from 1989 to 2016 in Germany regardless of habitat type, and the changes could not be explained by weather, land use, or habitat characteristics.  A major aim for future work is to investigate the causes of the decline, and where they have the biggest impact (Hallmann et al., 2017). |
| (Wagner et al., 2021b) | We currently do not have enough data to assume that patterns observed for Westernised countries — where most research has been focused — also applies to tropics where despite high insect biodiversity, long-term species-level data is deficient. Additionally, invertebrates are still understudied compared to vertebrates (Wagner et al., 2021b).  Furthermore, many datasets in existence remain unanalysed (Wagner et al., 2021b). Therefore, there is a need to develop new pipelines that will best utilise these.  Geography, time, and taxonomy all contribute to the wide variation that has been observed in insects (Wagner et al., 2021b).  It is also important to realise that not all insects are declining (Wagner et al., 2021b).  A major aim for future work is to investigate the causes of the decline, especially where they have the biggest impact, and any possible interactions (Wagner et al., 2021b).  Different types of studies provide a range of perspectives — for example, studies that generalise across datasets provide necessary viewpoints of the general health status of insects, though likely overlook species-level trends that more focused studies may capture (Wagner et al., 2021b). |
| (Sánchez-Bayo and Wyckhuys, 2019) | Sánchez-Bayo and Wyckhuys (2019) estimate alarming rates of decline that they predict will lead to the extinction of 40% of the world’s insect species within a few decades.  Don’t actually say it – but basically did vote counting using 73 historical reports.  It is likely that common and generalist species will be affected alongside habitat and food specialists (Sánchez-Bayo and Wyckhuys, 2019). Nevertheless, the increase in some adaptable, generalist species cannot be ignored (Sánchez-Bayo and Wyckhuys, 2019) and should be studied to observe traits that contribute to survival despite the increasing threats.  Lepidoptera: pollination, natural pest control, prey items. Hymenoptera: bees for pollination and economic value. Diptera: pollinators, natural enemies of agricultural pests. Coleoptera: pest control and recycling of organic matter. Hemiptera: true bugs. Orthoptera: grasshoppers, locusts, crickets. Odonata: dragonflies and damselflies. Control mosquitos and agricultural pests.  Sánchez-Bayo and Wyckhuys (2019) compared invertebrate to vertebrate decline, concluding the current proportion of insects in decline is twice as high as it is for vertebrates.  Nearly half of the studies reviewed by Sánchez-Bayo and Wyckhuys (2019) indicated habitat change to be the largest contributor to insect declines. |
| (Simmons et al., 2019) | Simmons et al., 2019 highlight some key issues with the Sánchez-Bayo and Wyckhuys (2019) paper: their search strategy was biased towards finding studies which report insect declines due to [declin\*] being a requirement; the study findings cannot be extrapolated globally as they are based mainly on studies conducted in North America and Europe; and the threats identified are simply stated, rather than being statistically tested. |
| (Powney et al., 2019) | Powney et al. (2019) studied wild bees and hoverflies in the UK using occupancy models between 1980 and 2013. The results indicated that a third of species have decreased, a tenth have increased. Rare species fared worse, and habitat influenced the decline — 55% decrease in species associated with uplands, 12% increase in dominant crop pollinators. All severe declines in bees occurred since 2007, whereas hoverflies have experienced sustained steady declines from 1987 to 2012.  There has been increasing focus on insects in recent years, with more records collected, though studies do tend to suffer from a lack of a standardised protocol, along with geographic and temporal restrictiveness (Powney et al., 2019). |
| (Outhwaite et al., 2020) | Outhwaite et al. (2020)’s findings that terrestrial insects increased in average occupancy by 5.5% in the UK from 1970 to 2015 go against findings of many studies.  It is important that future research makes best use of existing data by analysing it with up-and-coming research methods (Outhwaite et al., 2020).  Insects under-represented in large-scale BD trend studies.  Rare species show greater change.  Determining drivers will aid mitigation of future losses.  Need to consider shifting baseline syndrome. |
| (VanEngelsdorp et al., 2009) | Honey bees are known to suffer from colony collapse disorder, which involves the loss of worker bees. No single driver is thought to be responsible, though pathogens appear to play a major role (VanEngelsdorp et al., 2009). |
| (Deutsch et al., 2008) | Climate change affects intrinsic rates of population growth. It is predicted that tropical insects will suffer more due to the warming tolerance of tropical insects being, on average, a fifth of that of higher-latitude insects. This makes tropical insects particularly sensitive to increases in temperature, especially considering they are currently living close to their thermal optimum. It is also especially concerning seeing as biodiversity is greatest in the tropics (Deutsch et al., 2008). |
| (Biesmeijer et al., 2006) | Biesmeijer et al. (2006) found significant decreases in bee richness observed in 52% and 67% of British and Dutch cells, respectively. This was based on rarefaction methods applied before and after 1980. They also observed increased in 10% and 4%, respectively. Hoverflies showed no significant change in the UK, but increases in 34% and decreases in 17% of Dutch cells.  Declines were more frequent in habitat/food specialists, univoltine species, and/or nonmigrants, and the changes led to an increase in domination by a smaller number of species. |
| (Ollerton et al., 2014) | (Ollerton et al., 2014) used historical records to assess the extinction rate of bee and flower-visiting wasp species in Britain. They inferred that the greatest decline of nearly 3.5 species per decade in the 1920s to 1950s coincided with intensification of agricultural practice. Following this, roughly 0.98 species were loss per decade. |
| (Cardoso et al., 2020) | Along with species, we also lose abundance, biomass, diversity, unique functions, traits, and services and end up with more homogenised communities and networks with weaker and fewer connections (Cardoso et al., 2020).  Habitat loss and fragmentation, pollution, invasive species, climate change, over-exploitation, often acting synergistically (Cardoso et al., 2020). But there is still much to be understood.  We tend to see specialist, rare species faring worse than common species, though it has been highlighted that this could be due to rarer species being harder to monitor. Additionally the trends are rarely universal and display much variation both geographically and temporally. If common species are also declining, this could have much stronger impacts on ecosystem functioning (Cardoso et al., 2020).  Major branch of tree of life, most successful taxonomic group on our planet.  Traits are extremely important for inclusion in future studies to determine the traits that increase extinction risk. So far, it is believed that specialists, very small or very large species, and poor dispersers are particularly prone to extinction, though by combining and analysing multiple datasets, we could get a better idea of this (Cardoso et al., 2020). |
| (Hallmann et al., 2020) | Macro-moths, beetles, and caddisflies declined by 3.8, 5.0, and 9.2% in mean number of individuals, respectively from 1997-2017 in the Netherlands. Whereas true bugs were stable and mayflies had uncertainty surrounding their trend (Hallmann et al., 2020).  Extrapolating over 27 years, macro-moths and ground beetles declined in biomass by 61 and 42%, respectively (Hallmann et al., 2020).  Divergent patterns were found between abundance and biomass measures. For abundance, abundant ground beetles had steeper declines than rare ones. Contrastingly for biomass, rare species fared worse (Hallmann et al., 2020). These results demonstrate that a decline in biomass cannot be directly assumed as a corresponding decline in abundance.  There is a bias towards monitoring butterflies, dragonflies, bees, and moths, which limits the extent to which we can draw conclusions for the state of insects as a whole (Hallmann et al., 2020).  Identifying causes of decline was beyond the scope of the study. |
| (Lister and Garcia, 2018) | Our knowledge of insect population trends in the tropics is severely limited (Lister and Garcia, 2018).  (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 of abundance, the authors believe it is climate warming causing these declines. The authors disregard theories that the warming is caused by land-use change — for example, clearing of the rainforest increasing surface temperature — because the rainforest has not undergone significant human disturbance during the study period. Further, the authors also note that range shifts could play a role, though this was not investigated. |
| (Seibold et al., 2019) | Based on more than a million arthropod records, Seibold et al (2019) generally observed decreases in Germany grassland and forest sites from 2008 to 2017. Biomass, abundance, and number of species declined by 67%, 78% and 34%, respectively in grasslands. In forests, biomass and species number—but not abundance—decreased by 41% and 36%, respectively. These number demonstrate the big difference in results observed based on the metric used.  There appears to be differences in how rare and abundant species react depending on habitat type. In grasslands, declines were mainly observed in rare species, whereas in forests, both rare and abundant species were affected (Seibold et al., 2019).  The use for land around more natural sites may influence the rate of decline. For example, in Seibold et al (2019), the researcher found that grassland sites surrounded by land with a higher proportion of agricultural land shower stronger declines. This could be due to dispersal ability of species being reduced in a fragmented habitat or effects of pesticide pollution. |
| (Habel et al., 2019) | Habel et al. (2019) believe agricultural intensification to be the main cause of insect decline, though climate change could be magnifying the effects. They also highlight the that the effects of drivers vary depending on time and space.  There will be a high price to pay if declines continue, for example pollination has huge impacts on crop yields, and hence has high economic value (Habel et al., 2019).  Future work should focus on determining the full effects of drivers, which is increasingly possible using large data sets and modern analysis tools (Habel et al., 2019). |
| (Dirzo et al., 2014) | We may be experiencing the sixth mass extinction in evolutionary history, though it is hard to determine how hard insects are being hit due to limited data. Only around 1% of insect species have been assessed by the IUCN red list (Dirzo et al., 2014).  The risk of extinction is usually determined by a combination of nature of the threat (type and intensity) and species attributes (Dirzo et al., 2014).  Via a meta-analysis, Dirzo et al. (2014) found species richness of Lepidoptera to be on average 7.6 times higher in undisturbed than disturbed sites. |
| (Gillespie et al., 2020) | In the Arctic where data spanning more than 10 years was available, Gillespie et al. (2020) found significant declines in 7 of the 14 species of muscid fly studied between 1996 and 2014. The researchers were unable to report on the majority of taxa due to insufficient data. |
| (Homburg et al., 2019) | (Homburg et al., 2019) did not observe a decline in abundance or biomass, but in species richness, functional diversity and phylogenetic diversity of carabids in Germany over 24 years.  Homburg et al. (2019) observed smaller species to have stronger declines. This could explain why an overall decline in species richness, but not biomass, was observed.  Researchers often speculate reasons for decline rather than empirically investigating the drivers. For example, Homburg et al. (2019) assume climate change and pollution to cause the observed declines, but do not include this in their study design. They do, however, investigate which species traits influence trends, concluding smaller body size to be particularly important.  Insects are most diverse taxon on Earth in terms in species numbers (see ICUN stats table). |
| (Brooks et al., 2012) | Three-quarters of UK carabids declined in Brooks et al. (2012) between 1994 and 2008, though there were marked difference between habitat types. Trends varied from 50% declines in northern moorland and western pasture, to 50% increases in southern downland. Furthermore, certain taxa were found to be stable in certain habitats, whilst declining elsewhere.  Brooks et al. (2012) highlight the debate over whether we should be studying species-level trends or gathering a more holistic opinion. |
| (Fox et al., 2019) | Insect populations prove particularly hard to monitor due to their highly dynamic nature. High variation between years is very common, hence the need for long-term data sets to reduce the effects of yearly variation (Fox et al., 2019).  When assessing whether insect species met the threshold to be classified as threatened, varying the start year of trends in butterfly and moth species influence the number of species classified as such (Fox et al., 2019). |
| (Didham et al., 2020) | Shifting baseline phenomenon may be influencing our opinions on insect trends. It is hard to find solid evidence to counter this due to a lack of historical records of insect trends (Didham et al., 2020).  High variation from year to year also affects the usefulness of short-term studies (Didham et al., 2020).  Detection bias – nearly impossible to monitor complete census of all individuals in a population. |
| (Montgomery et al., 2020) | We have enough evidence that we need to do more to mitigate insect declines but we do not yet fully understand the extent and reasons (Montgomery et al., 2020).  So far, the geographical restrictiveness of studies to human-dominated landscapes mainly in western and northern Europe as well as taxonomic restrictiveness makes it hard to generalise how the strength of trends on a global scale. This is worsened by insects displaying large variation in population size between years, as well as our lack of knowledge on the majority of species, many of which have not even been described (Montgomery et al., 2020).  Future papers should also report stable or positive trends, to ease publication bias and improve meta-analyses (Montgomery et al., 2020). |
| (Loboda et al., 2018) | 16 species of muscid flies were monitored by Loboda et al. (2018) in Greenland between 1996 and 2014. The researchers found a significant decrease of 80% of total abundance, which affect abundant species as well as rare ones. At species level, most climate predictors could not explain the trend.  For pollination services, the abundance of species, rather than species richness, may be more important in the continuation of this service (Loboda et al., 2018). |
| (Boyes et al., 2019) | One example of a paper which focuses on increasing species is the reporting of increasing British moths by Boyes et al. (2019). Nevertheless, though the researchers focused on the 51 species that increased in abundance ad occupancy, it cannot be ignored that the remaining moths of the 330 that had sufficient data, declined. Further, these trends may prove transient — the trends could reverse over time. However, this paper does well at highlighting that not all species are in decline.  The majority of the increasing moth species were generalists (Boyes et al., 2019).  The traits that mean species survive may be as important to identify as those which lead species to decline (Boyes et al., 2019). |
| (van Strien et al., 2019) | Van Strien et al. (2019) report an overall 84% decline in butterflies in the Netherlands between 1890 and 2017. Declines were strong in all of grassland, woodland, and heathland. This study relies on historical and opportunistic records, likely to underestimate the abundance of common species once enough specimens had been collected. This could result in the increase of common species being over-estimated. |
| (Wagner et al., 2021a) | There is high heterogeneity in insect population trends, which is highlighted for moths by Wagner et al. (2021a). Habitat and dietary specialists show stronger rates of decline than generalists. Although the overall pattern is decline, some proportion of species are increasing.  There is an urgent need for more data to untangle the geographical and temporal effects of drivers, and identify examples where there drivers interact (Wagner et al., 2021a). |
| (Saunders et al., 2020) | Saunders et al. (2020) believe we have a long way to go before we can fully speculate about the state of insect populations. They argue Sanchez-Bayo and Wyckhuys paper was damaging due to geographical extrapolation of findings beyond the scope of the study, but has which nevertheless become prominent in the media and subsequent papers as evidence of an ‘Insect apocalypse’. The research conducted so far has left major gaps in our understanding of the drivers of trends too. Further, many studies focus on declines when in fact, it is rare that a study does not report stable or positive findings for a certain proportion of taxa. |
| (Van Klink et al., 2020) | Van Klink et al. (2020) found an average 9% decline per decade of terrestrial insect abundance but an 11% increase in freshwater insects over 41 countries between 1925 and 2018 using a meta-analysis. A combined model of both terrestrial and freshwater insects showed no clear trend, though the influence of freshwater species could be over-estimated due to freshwater only covering 2.4% of the Earth’s terrestrial surface.  Unprotected areas displayed stronger trends than protected areas. This implies Van Klink et al. (2020) may have missed areas where the strongest effects occur due to an overrepresentation of protected areas in the study.  Van Klink et al. (2020) found no association between climate change and insect population trends, either at local or regional scale. |
| (Jähnig et al., 2021) | Jähnig et al. (2021) criticise Van Klink et al. (2020) for disregarding that the differences in abundance and biomass do not take into account changes in community structure by the replacement of sensitive species with tolerant ones. Further, the non-randomly selected sites cannot be used to report global trends. |
| (Wepprich et al., 2019) | For 81 species of butterfly in Ohio from 1996-2016, 3 times as many species had negative population trends compared to positive trends. Of the species which declines, common and invasive species were also affected. Univoltine species were more strongly negatively affected (Wepprich et al., 2019).  Even now, studies are suffering from a lack of data. For example, (Wepprich et al., 2019) could not report on a fifth of regularly observed butterflies in Ohio due to this. |
| (Outhwaite et al., 2022) | (Outhwaite et al., 2022) report on the importance of the interaction between land-use change and climate change on impacting insect population trends. Using PREDICTS data from 1992 to 2012, the researchers found that an increase of 1 standard deviation from the baseline temperature in high-intensity agriculture reduced abundance and richness by 49 and 27%, respectively, compared to primary vegetation with no warming. The equivalent figures for low-intensity agriculture were 30 and 23%, respectively. The results indicate that less intensive agriculture partially buffers insects against the negative impacts of climate warming. |
| (Crossley et al., 2020) | Crossley et al. (2020) is one of the few studies to report no overall trend in insect abundance and diversity since 1970. The lack of an increase or decrease was consistent across insect feeding groups or the intensity of land-use based on data collected in 68 US long term ecological research sites. Temperature and precipitation were unable to predict the direction of trends. |
| (Dicks et al., 2021) | From an expert elicitation process, Dicks et al. (2021) concluded land cover and configuration, land management and pesticides to be the main drivers of insect declines.  The risks of insect losses — particularly pollinators — is a particular risk to the global south where a high proportion of insect-pollinated crops are grown, compared to highly industrialised areas of Europe (Dicks et al., 2021). This is a big risk when demand for food is at an all time high.  Expert elicitations are good when data is deficient and could gleam additional insights, though it is subjective due to its basis in personal opinions. |
| (Welti et al., 2021) | Welti et al. (2021) highlight issues with Crossley et al. (2020) in that the results are flawed due to the researchers violating the assumption that records were collected consistently between datasets. |
| (Soroye et al., 2020) | Soroye et al. (2020) point to climate change as the main driver of bumblebee declines they found across North America and Europe. Increasing occurrence of hotter temperatures was able to predict extinction risk and chance of colonisation. Climate affects species by changing environmental conditions so the temperature exceeds the tolerance of a species, causing extinction or range shifts, or making new areas more suitable for survival. Climate change not only directly affects bumblebees by affecting fecundity and mortality, but also indirectly through alteration to floral resource. |
| (Vanbergen and Initiative, 2013) | Threats to pollinators are well-described by Vanbergen and Initiative (2013), who highlight complex interactions between multiple drivers.  Loss of pollinators is likely to have serious ecological and economic consequences. Crop yields will suffer from lack of pollination, along with wild plants dependent on insect pollination, which could see the loss of undiscovered drugs (Vanbergen and Initiative, 2013).  Agricultural expansion and intensification leads to large areas of monoculture, which although can provide a resource for pollinators, the crops are often characterised by short periods of flowering, which is inadequate for pollinators with longer flight seasons (Vanbergen and Initiative, 2013).  Climate change is likely to lead to differential rates of migration by plants and insects leading to a mismatch between species which rely on one another (Vanbergen and Initiative, 2013).  Alien species outcompete native insect for resources and can additionally spread pests and diseases. Honey bees particularly suffer from pest and diseases (Vanbergen and Initiative, 2013). |
| (Miličić et al., 2021) | An alternative study approach is to collect expert knowledge. Though prone to subjectivity, this is especially useful when data are deficient and can provide fresh perspectives. However, even this study reported a high proportion of responses as unknown trend, highlighting how understudied this group are (Miličić et al., 2021).  The most important drivers of insect trends according to experts in (Miličić et al., 2021)’s study were agriculture and climate change. The main disadvantages of insects were identified as pest damage to crops and their impact as invasive species.  Paper made me think about local vs global drivers – climate change affects everywhere (not necessarily to the same extent) but volcanoes will be very localised. |
| (Eggleton, 2020) | Of the 5.5 million insects estimated to exist, we have only described just over 1 million of these (from (Stork, 2018)). This combined with patchy data, especially in the tropics, makes it difficult to properly assess the current state of insects. It appears there is enough evidence for concern though it is unlikely that insects are declining everywhere. We cannot extrapolate local extinctions to global extinctions. Furthermore, with a ten-fold increase in the number of studies published which include ‘insect decline’ from 200 to 2010, it is really the case that insects are declining alarmingly now, or that we are only just becoming aware of it (Eggleton, 2020)?  The lack of focus on insects in the past may be due to over-focus on the disadvantages of insects including agricultural pests, disease vectors, and general nuisances. The outweighing positive services including pollination, pest control, and nutrient cycling have been widely overlooked until recently (Eggleton, 2020).  It is human-caused changes that are driving the observed declines (Eggleton, 2020). |
| (Titley et al., 2017) | Insects continue to be undervalued by researchers. Of the papers analysed by (Titley et al., 2017), an even split was found between papers reporting on vertebrates in invertebrates. This is a substantial difference to the proportions of species in existence where 95% are invertebrates. This lack of representation in the literature could result in a lack of funding for these so-called ‘unimportant’ species. |
| (Stork, 2018) | (Stork, 2018) approximate there to be 5.5 million insects in existence, though only 1 million have been described. |
| (Willig et al., 2019) | (Willig et al., 2019) replicate some of the analysis performed by Lister and Garcia (2018), concluding completely contrasting results. They report no evidence that declines are occurring due to climate warming. This could be due to Lister and Garcia (2018) failing to account for effects such as droughts and hurricanes in addition to temperature related aspects of climate change. Further, abundance data was not adjusted according to sampling effort, which could lead to erroneous results. |
| (Lawton et al., 1998) | We cannot generalise results from studies on species other than invertebrates to invertebrates due to Lawton et al. (1998)’s findings that no one animal group could be used as a reliable predictor for change in species richness across a gradient of increasing disturbance of other groups. |
| (Newbold et al., 2018) | Newbold et al. (2018) report that land-use change is causing a shift to more widespread species, and thus resulting in a homogenisation. This was true for plants and vertebrates, as well as invertebrates using the PREDICTS database records. |
| (Hillebrand et al., 2018) | Hillebrand et al. (2018) highlight the important differences between the use of different biodiversity metrics and why we should proceed with caution when reporting on trends using just one metric. Species richness alone cannot reflect changes in community composition, thus masking changes in species identity and functional traits. It could be therefore be concluded that the population is stable, when in fact there has been complete species turnover. |
| (Engelhardt et al., 2022) | Engelhardt et al. (2022) use Bayesian occupancy models to study trends in butterflies, grasshoppers, and dragonflies in Germany from 1980 to 2019. Overall, 37%, 30%, and 33% of species have decreased, increased, and stayed stable, respectively.  Temperature preference and habitat specificity both impacted the trends observed, with the former being most significant. Species with higher temperature preferences increased the most in occupancy across all taxa. Butterfly habitat specialists decreased across the study period, but the same was not true for grasshoppers and dragonflies. This may be due to butterflies possessing a higher proportion of specialised taxa, the existence of which are associated with high quality habitats. These results indicate land-use as a potential driver which particularly affects the butterfly taxa (Engelhardt et al., 2022).  (Engelhardt et al., 2022)’s study highlight the importance of best utilising existing datasets, rather than having the expend additional resources on new data collection. |
| (Hudson et al., 2017) | (Hudson et al., 2017) introduces the PREDICTS database. |
| (De Palma et al., 2015) | It is useful to understand which traits have most impact on insect population trends. De Palma et al. (2015) studied 257 European bee species, concluding that flight season duration was the most important trait for predicting sensitivity to land-use, with foraging range also playing a role. This may be due to shorter flight seasons being more likely to lead to a mismatch between flowering time and presence of pollinator.  Larger foraging range may affect insect population trends positively by allowing resource availability in a fragmented habitat — it could also mean a higher risk of pesticide exposure (De Palma et al., 2015).  It has been shown that the interaction between species attributes and land-use is important, with (De Palma et al., 2015)’s models which excluded interactions explaining 13% and 37% less variation in occurrence and abundance of bees, respectively.  Data analysed here will be included in PREDICTS. |
| (Gray et al., 2016) | Gray et al. (2016) found higher biodiversity inside protected areas using data from PREDICTS, though this was not solely focused on insects. |
| (Newbold et al., 2014) | (Newbold et al., 2014) used PREDICTS data to study how land-use affects biodiversity of invertebrates, ‘herptiles’ (reptiles and amphibians), mammals and birds in tropical forests. Land-use significantly impacted the probability of occurrence of species, with declines in human-modified habitats. These habitats also consisted of dominance by fewer species. |
| (Newbold et al., 2016b) | It has been shown that land-use can have varying effects depending on location. For example, land-use has a greater effect on beta diversity in tropical compared to temperate regions (Newbold et al., 2016b). |
| (Newbold et al., 2016a) | With some researchers predicting land-use has already biotically compromised over half of the Earth’s terrestrial surface measured in terms of Biodiversity Intactness Index (Newbold et al., 2016a). |
| (Millard et al., 2021) | Generally, intensification of land-use is associated with decreases in biodiversity. However, this is not true in every case. For pollinators, Millard et al. (2021) found species richness and total abundance in non-tropical cropland was significantly higher in minimal-intensity than primary-vegetation. This was in contrast to the decrease seen between primary vegetation and high intensity crop land in tropical areas. These differences could stem from non-tropical areas having a longer history of agriculture, meaning sensitive species have previously gone extinct. These extinctions could still happen in tropical regions, but extinction-debt effects may be inhibiting detection. |
| (Klein et al., 2007) | Over 75% of the crops examined by Klein et al. (2007) relied upon animal pollination. |

BIESMEIJER, J. C., ROBERTS, S. P., REEMER, M., OHLEMULLER, R., EDWARDS, M., PEETERS, T., SCHAFFERS, A., POTTS, S. G., KLEUKERS, R. & THOMAS, C. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science,* 313**,** 351-354.

BOYES, D. H., FOX, R., SHORTALL, C. R. & WHITTAKER, R. J. 2019. Bucking the trend: the diversity of Anthropocene ‘winners’ among British moths. *Frontiers of Biogeography,* 11.

BROOKS, D. R., BATER, J. E., CLARK, S. J., MONTEITH, D. T., ANDREWS, C., CORBETT, S. J., BEAUMONT, D. A. & CHAPMAN, J. W. 2012. Large carabid beetle declines in a United Kingdom monitoring network increases evidence for a widespread loss in insect biodiversity. *Journal of applied Ecology,* 49**,** 1009-1019.

CARDOSO, P., BARTON, P. S., BIRKHOFER, K., CHICHORRO, F., DEACON, C., FARTMANN, T., FUKUSHIMA, C. S., GAIGHER, R., HABEL, J. C. & HALLMANN, C. A. 2020. Scientists' warning to humanity on insect extinctions. *Biological conservation,* 242**,** 108426.

CROSSLEY, M. S., MEIER, A. R., BALDWIN, E. M., BERRY, L. L., CRENSHAW, L. C., HARTMAN, G. L., LAGOS-KUTZ, D., NICHOLS, D. H., PATEL, K. & VARRIANO, S. 2020. No net insect abundance and diversity declines across US Long Term Ecological Research sites. *Nature Ecology & Evolution,* 4**,** 1368-1376.

DE PALMA, A., KUHLMANN, M., ROBERTS, S. P., POTTS, S. G., BÖRGER, L., HUDSON, L. N., LYSENKO, I., NEWBOLD, T. & PURVIS, A. 2015. Ecological traits affect the sensitivity of bees to land‐use pressures in E uropean agricultural landscapes. *Journal of Applied Ecology,* 52**,** 1567-1577.

DEUTSCH, C. A., TEWKSBURY, J. J., HUEY, R. B., SHELDON, K. S., GHALAMBOR, C. K., HAAK, D. C. & MARTIN, P. R. 2008. Impacts of climate warming on terrestrial ectotherms across latitude. *Proceedings of the National Academy of Sciences,* 105**,** 6668-6672.

DICKS, L. V., BREEZE, T. D., NGO, H. T., SENAPATHI, D., AN, J., AIZEN, M. A., BASU, P., BUCHORI, D., GALETTO, L. & GARIBALDI, L. A. 2021. A global-scale expert assessment of drivers and risks associated with pollinator decline. *Nature Ecology & Evolution,* 5**,** 1453-1461.

DIDHAM, R. K., BASSET, Y., COLLINS, C. M., LEATHER, S. R., LITTLEWOOD, N. A., MENZ, M. H., MÜLLER, J., PACKER, L., SAUNDERS, M. E. & SCHÖNROGGE, K. 2020. Interpreting insect declines: seven challenges and a way forward. *Insect Conservation and Diversity,* 13**,** 103-114.

DIRZO, R., YOUNG, H. S., GALETTI, M., CEBALLOS, G., ISAAC, N. J. & COLLEN, B. 2014. Defaunation in the Anthropocene. *science,* 345**,** 401-406.

EGGLETON, P. 2020. The state of the world's insects. *Annual Review of Environment and Resources,* 45**,** 61-82.

ENGELHARDT, E. K., BIBER, M. F., DOLEK, M., FARTMANN, T., HOCHKIRCH, A., LEIDINGER, J., LÖFFLER, F., PINKERT, S., PONIATOWSKI, D. & VOITH, J. 2022. Consistent signals of a warming climate in occupancy changes of three insect taxa over 40 years in central Europe. *Global Change Biology*.

FOX, R., HARROWER, C. A., BELL, J. R., SHORTALL, C. R., MIDDLEBROOK, I. & WILSON, R. J. 2019. Insect population trends and the IUCN Red List process. *Journal of Insect Conservation,* 23**,** 269-278.

GILLESPIE, M. A., ALFREDSSON, M., BARRIO, I. C., BOWDEN, J. J., CONVEY, P., CULLER, L. E., COULSON, S. J., KROGH, P. H., KOLTZ, A. M. & KOPONEN, S. 2020. Status and trends of terrestrial arthropod abundance and diversity in the North Atlantic region of the Arctic. *Ambio,* 49**,** 718-731.

GRAY, C. L., HILL, S. L., NEWBOLD, T., HUDSON, L. N., BÖRGER, L., CONTU, S., HOSKINS, A. J., FERRIER, S., PURVIS, A. & SCHARLEMANN, J. P. 2016. Local biodiversity is higher inside than outside terrestrial protected areas worldwide. *Nature Communications,* 7**,** 1-7.

HABEL, J. C., SAMWAYS, M. J. & SCHMITT, T. 2019. Mitigating the precipitous decline of terrestrial European insects: Requirements for a new strategy. *Biodiversity and Conservation,* 28**,** 1343-1360.

HALLMANN, C. A., SORG, M., JONGEJANS, E., SIEPEL, H., HOFLAND, N., SCHWAN, H., STENMANS, W., MÜLLER, A., SUMSER, H. & HÖRREN, T. 2017. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PloS one,* 12**,** e0185809.

HALLMANN, C. A., ZEEGERS, T., VAN KLINK, R., VERMEULEN, R., VAN WIELINK, P., SPIJKERS, H., VAN DEIJK, J., VAN STEENIS, W. & JONGEJANS, E. 2020. Declining abundance of beetles, moths and caddisflies in the Netherlands. *Insect Conservation and Diversity,* 13**,** 127-139.

HILLEBRAND, H., BLASIUS, B., BORER, E. T., CHASE, J. M., DOWNING, J. A., ERIKSSON, B. K., FILSTRUP, C. T., HARPOLE, W. S., HODAPP, D. & LARSEN, S. 2018. Biodiversity change is uncoupled from species richness trends: Consequences for conservation and monitoring. *Journal of Applied Ecology,* 55**,** 169-184.

HOMBURG, K., DREES, C., BOUTAUD, E., NOLTE, D., SCHUETT, W., ZUMSTEIN, P., VON RUSCHKOWSKI, E. & ASSMANN, T. 2019. Where have all the beetles gone? Long‐term study reveals carabid species decline in a nature reserve in Northern Germany. *Insect Conservation and Diversity,* 12**,** 268-277.

HUDSON, L. N., NEWBOLD, T., CONTU, S., HILL, S. L., LYSENKO, I., DE PALMA, A., PHILLIPS, H. R., ALHUSSEINI, T. I., BEDFORD, F. E. & BENNETT, D. J. 2017. The database of the PREDICTS (projecting responses of ecological diversity in changing terrestrial systems) project. *Ecology and evolution,* 7**,** 145-188.

JÄHNIG, S. C., BARANOV, V., ALTERMATT, F., CRANSTON, P., FRIEDRICHS‐MANTHEY, M., GEIST, J., HE, F., HEINO, J., HERING, D. & HÖLKER, F. 2021. Revisiting global trends in freshwater insect biodiversity. *Wiley Interdisciplinary Reviews: Water,* 8**,** e1506.

KLEIN, A.-M., VAISSIERE, B. E., CANE, J. H., STEFFAN-DEWENTER, I., CUNNINGHAM, S. A., KREMEN, C. & TSCHARNTKE, T. 2007. Importance of pollinators in changing landscapes for world crops. *Proceedings of the royal society B: biological sciences,* 274**,** 303-313.

LAWTON, J. H., BIGNELL, D. E., BOLTON, B., BLOEMERS, G., EGGLETON, P., HAMMOND, P. M., HODDA, M., HOLT, R., LARSEN, T. & MAWDSLEY, N. 1998. Biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest. *Nature,* 391**,** 72-76.

LISTER, B. C. & GARCIA, A. 2018. Climate-driven declines in arthropod abundance restructure a rainforest food web. *Proceedings of the National Academy of Sciences,* 115**,** E10397-E10406.

LOBODA, S., SAVAGE, J., BUDDLE, C. M., SCHMIDT, N. M. & HØYE, T. T. 2018. Declining diversity and abundance of High Arctic fly assemblages over two decades of rapid climate warming. *Ecography,* 41**,** 265-277.

MILIČIĆ, M., POPOV, S., BRANCO, V. V. & CARDOSO, P. 2021. Insect threats and conservation through the lens of global experts. *Conservation Letters,* 14**,** e12814.

MILLARD, J., OUTHWAITE, C. L., KINNERSLEY, R., FREEMAN, R., GREGORY, R. D., ADEDOJA, O., GAVINI, S., KIOKO, E., KUHLMANN, M. & OLLERTON, J. 2021. Global effects of land-use intensity on local pollinator biodiversity. *Nature communications,* 12**,** 1-11.

MONTGOMERY, G. A., DUNN, R. R., FOX, R., JONGEJANS, E., LEATHER, S. R., SAUNDERS, M. E., SHORTALL, C. R., TINGLEY, M. W. & WAGNER, D. L. 2020. Is the insect apocalypse upon us? How to find out. *Biological Conservation,* 241**,** 108327.

NEWBOLD, T., HUDSON, L. N., ARNELL, A. P., CONTU, S., DE PALMA, A., FERRIER, S., HILL, S. L., HOSKINS, A. J., LYSENKO, I. & PHILLIPS, H. R. 2016a. Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment. *Science,* 353**,** 288-291.

NEWBOLD, T., HUDSON, L. N., CONTU, S., HILL, S. L., BECK, J., LIU, Y., MEYER, C., PHILLIPS, H. R., SCHARLEMANN, J. P. & PURVIS, A. 2018. Widespread winners and narrow-ranged losers: Land use homogenizes biodiversity in local assemblages worldwide. *PLoS biology,* 16**,** e2006841.

NEWBOLD, T., HUDSON, L. N., HILL, S. L., CONTU, S., GRAY, C. L., SCHARLEMANN, J. P., BÖRGER, L., PHILLIPS, H. R., SHEIL, D. & LYSENKO, I. 2016b. Global patterns of terrestrial assemblage turnover within and among land uses. *Ecography,* 39**,** 1151-1163.

NEWBOLD, T., HUDSON, L. N., PHILLIPS, H. R., HILL, S. L., CONTU, S., LYSENKO, I., BLANDON, A., BUTCHART, S. H., BOOTH, H. L. & DAY, J. 2014. A global model of the response of tropical and sub-tropical forest biodiversity to anthropogenic pressures. *Proceedings of the Royal Society B: Biological Sciences,* 281**,** 20141371.

OLLERTON, J., ERENLER, H., EDWARDS, M. & CROCKETT, R. 2014. Extinctions of aculeate pollinators in Britain and the role of large-scale agricultural changes. *Science,* 346**,** 1360-1362.

OUTHWAITE, C., MCCANN, P. & NEWBOLD, T. 2022. Agriculture and climate change reshape insect biodiversity worldwide. *Nature*.

OUTHWAITE, C. L., GREGORY, R. D., CHANDLER, R. E., COLLEN, B. & ISAAC, N. J. 2020. Complex long-term biodiversity change among invertebrates, bryophytes and lichens. *Nature ecology & evolution,* 4**,** 384-392.

POWNEY, G. D., CARVELL, C., EDWARDS, M., MORRIS, R. K., ROY, H. E., WOODCOCK, B. A. & ISAAC, N. J. 2019. Widespread losses of pollinating insects in Britain. *Nature communications,* 10**,** 1-6.

SÁNCHEZ-BAYO, F. & WYCKHUYS, K. A. 2019. Worldwide decline of the entomofauna: A review of its drivers. *Biological conservation,* 232**,** 8-27.

SAUNDERS, M. E., JANES, J. K. & O’HANLON, J. C. 2020. Moving on from the insect apocalypse narrative: engaging with evidence-based insect conservation. *BioScience,* 70**,** 80-89.

SEIBOLD, S., GOSSNER, M. M., SIMONS, N. K., BLÜTHGEN, N., MÜLLER, J., AMBARLı, D., AMMER, C., BAUHUS, J., FISCHER, M. & HABEL, J. C. 2019. Arthropod decline in grasslands and forests is associated with landscape-level drivers. *Nature,* 574**,** 671-674.

SIMMONS, B. I., BALMFORD, A., BLADON, A. J., CHRISTIE, A. P., DE PALMA, A., DICKS, L. V., GALLEGO‐ZAMORANO, J., JOHNSTON, A., MARTIN, P. A. & PURVIS, A. 2019. Worldwide insect declines: an important message, but interpret with caution. *Ecology and evolution,* 9**,** 3678-3680.

SOROYE, P., NEWBOLD, T. & KERR, J. 2020. Climate change contributes to widespread declines among bumble bees across continents. *Science,* 367**,** 685-688.

STORK, N. E. 2018. How many species of insects and other terrestrial arthropods are there on Earth? *Annual review of entomology,* 63**,** 31-45.

TITLEY, M. A., SNADDON, J. L. & TURNER, E. C. 2017. Scientific research on animal biodiversity is systematically biased towards vertebrates and temperate regions. *PloS one,* 12**,** e0189577.

VAN KLINK, R., BOWLER, D. E., GONGALSKY, K. B., SWENGEL, A. B., GENTILE, A. & CHASE, J. M. 2020. Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances. *Science,* 368**,** 417-420.

VAN STRIEN, A. J., VAN SWAAY, C. A., VAN STRIEN-VAN LIEMPT, W. T., POOT, M. J. & WALLISDEVRIES, M. F. 2019. Over a century of data reveal more than 80% decline in butterflies in the Netherlands. *Biological Conservation,* 234**,** 116-122.

VANBERGEN, A. J. & INITIATIVE, T. I. P. 2013. Threats to an ecosystem service: pressures on pollinators. *Frontiers in Ecology and the Environment,* 11**,** 251-259.

VANENGELSDORP, D., EVANS, J. D., SAEGERMAN, C., MULLIN, C., HAUBRUGE, E., NGUYEN, B. K., FRAZIER, M., FRAZIER, J., COX-FOSTER, D. & CHEN, Y. 2009. Colony collapse disorder: a descriptive study. *PloS one,* 4**,** e6481.

WAGNER, D. L., FOX, R., SALCIDO, D. M. & DYER, L. A. 2021a. A window to the world of global insect declines: Moth biodiversity trends are complex and heterogeneous. *Proceedings of the National Academy of Sciences,* 118.

WAGNER, D. L., GRAMES, E. M., FORISTER, M. L., BERENBAUM, M. R. & STOPAK, D. 2021b. Insect decline in the Anthropocene: Death by a thousand cuts. *Proceedings of the National Academy of Sciences,* 118.

WELTI, E. A., JOERN, A., ELLISON, A. M., LIGHTFOOT, D. C., RECORD, S., RODENHOUSE, N., STANLEY, E. H. & KASPARI, M. 2021. Studies of insect temporal trends must account for the complex sampling histories inherent to many long-term monitoring efforts. *Nature Ecology & Evolution,* 5**,** 589-591.

WEPPRICH, T., ADRION, J. R., RIES, L., WIEDMANN, J. & HADDAD, N. M. 2019. Butterfly abundance declines over 20 years of systematic monitoring in Ohio, USA. *PLoS One,* 14**,** e0216270.

WILLIG, M., WOOLBRIGHT, L., PRESLEY, S., SCHOWALTER, T., WAIDE, R., SCALLEY, T. H., ZIMMERMAN, J., GONZÁLEZ, G. & LUGO, A. 2019. Populations are not declining and food webs are not collapsing at the Luquillo Experimental Forest. *Proceedings of the National Academy of Sciences,* 116**,** 12143-12144.