Preliminary reading on PREDICTS database

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| (Hudson et al., 2017) | 12/04/22 | **The database of the PREDICTS**  **Abstract**  Projecting Responses of Ecological Diversity In Changing Terrestrial Systems  Collated from published studies a large, reasonably representative database of comparable samples of biodiversity from multiple sites that differ in the nature or intensity of human impacts relating to land use.  We have used this evidence base to develop global and regional statistical models of how local biodiversity responds to these measures.  We describe and make freely available this 2016 release of the database, containing more than 3.2 million records sampled at over 26,000 locations and representing over 47,000 species.  We outline how the database can help in answering a range of questions in ecology and conservation biology.  **Intro**  Indicators needed to assess progress toward goals such as the Convention on Biological Diversity’s 2010 target or the newer Aichi Biodiversity Targets (Pereira et al., 2013; Tittensor et al., 2014).  Most of the available indicators are taxonomically or ecologically narrow in scope, and many are based on the global status of species (e.g., Butchart et al., 2010; Tittensor et al., 2014).  Average responses of species to human impacts typically vary among higher taxa and ecological guilds (Lawton et al., 1998; McKinney, 1997; Newbold et al., 2014; WWF International, 2014), meaning that indicators need to be broadly based and as representative as possible, if they are to be used as proxies for biodiversity as a whole.  Although many of the ultimate drivers behind biodiversity loss are global, the most important pressure mechanisms usually act much more locally (Brook, Ellis, Perring, Mackay, & Blomqvist, 2013).  Most ecosystem services and their underpinning processes are mediated by local rather than global biodiversity (Cardinale et al., 2012; Grime, 1998): It is local rather than global functional diversity, for example, that determines how ecosystems function in a given set of conditions (Steffen et al., 2015).  Local changes are likely to be detected before large global changes or extinction.  There is a need to model the response of local biodiversity to human pressures and, thus, to estimate biodiversity changes at local scales, but across a wide spatial domain (ideally globally) and for a wide range of taxa.  Although large temporal datasets are available (e.g., Butchart et al., 2004; Collen et al., 2009; Dornelas et al., 2014; Vellend et al., 2013), they may not be sufficiently representative of anthropogenic pressures for the trends they show to be taken at face value (Gonzalez et al., 2016). Furthermore, in the absence of contemporaneous site-specific information about pressures, it is not straightforward to use these data to model how biodiversity responds to pressures or to project changes into the future (but see Visconti et al., 2015).  Since 2012, the PREDICTS project has been collating data on local biodiversity at different levels of human pressure from published papers, where necessary contacting those papers’ corresponding authors to request the underlying biodiversity data, species’ identities, and precise sampling locations.  We have enhanced the collated data by scoring site characteristics relating to human pressures such as the predominant land use and how intensively the land is used by humans.  The database was first described by Hudson et al. (2014).  **Methods**  The data were arranged in a hierarchical structure. The data from an individual published work, constituted a “DataSource.” Where different sampling methods were used within a DataSource, the data were divided into separate “Studies.” Data from a given DataSource were also split into multiple Studies if they covered large geographic areas (e.g., several countries), to reduce the effect of biogeographic differences within Studies. Each Study contained a set of sampled “Sites” and “Taxa”.  At each Site a set of “Measurements” (typically the abundance or occurrence of a set of taxa) were taken.  **Results**  The data represent all of the world’s 14 terrestrial biomes, in approximate proportion to their contribution to global total primary productivity.  The sampled Sites span 94 of the world’s countries.  Records in the PREDICTS database represent 47,044 species, which is over 2% of the number thought to have been formally described (Chapman, 2009)—29,737 animals, 15,545 plants, 1,759 fungi, and three protists.  Vertebrates— and especially birds—are overrepresented owing to biases in the published literature (Figure 4), but less so than in many other data compilations.  We focused primarily on data sampled since 2000.  **Discussion**  The PREDICTS database is designed to be able to address a range of questions about how land use and related pressures have influenced the occurrence and abundance of species and the diversity of ecological assemblages.  Other projects have collated or are collating large compilations of structured biodiversity data, such as BIOFRAG (Pfeifer et al., 2014; habitat fragmentation), BIOTIME (The BioTIME Research Group, 2016; detailed time-series data, still being compiled) and GLOBIO3 (Alkemade et al., 2009; pristine versus disturbed habitats, not publicly available). The largest open compilation of biodiversity data is the Global Biodiversity Information Facility (GBIF; www.gbif.org), which aggregates mostly unstructured species occurrence data. The unstructured nature of most GBIF data limits the range of questions to which they can easily be put.  Drawbacks of PREDICTS   * Our individual datasets seldom take a whole-ecosystem perspective, being instead taxonomically or ecologically restricted; consequently, our data shed little light on how trophic webs or other interactions are affected by human pressures. * Even within the groups sampled, our data do not provide complete inventories of the species that would be found with comprehensive sampling; thus, failure to record a species from a Site does not provide strong evidence of absence * Because our database was designed to test hypotheses about local-scale variation in biodiversity, it is not particularly informative about large-scale biodiversity patterns such as the latitudinal gradient in species richness.   Questions that could be answered with PREDICTS   * What factors influence the occurrence and/or abundance of a particular focal species? - Filter to remove species not of interest. Merge PREDICTS data with data on any additional site-level characteristics of interest. One possible analytical approach is to model effects of site characteristics on presence-absence and log (abundance when present) separately, the first with binomial errors and the second with Gaussian errors, while accounting for among-Study differences (e.g., using mixed effects models). * Which ecological attributes of species make them more or less sensitive to human pressures? Merge PREDICTS data with species-level data on traits of interest. Model how site and species characteristics affect presence-absence and log (abundance when present) separately as above, accounting for Study-level and taxon-level differences (e.g., using mixed effects models). See Newbold et al. (2014), De Palma et al. (2015) * How do land use and other pressures reduce compositional intactness? – See Newbold, Hudson, Arnell, et al. (2016) * Which characteristics of Sites (e.g., duration of human impact and rate of climate change) mean that given land-use changes have particularly severe effects on biodiversity? - Merge Site-level diversity data with Site-level data on characteristics to be tested and assess the interaction of these variables with land use. See Gray et al. (2016) * Is beta diversity lower in human-dominated than more natural land uses? – See Newbold, Hudson, Hill, et al. (2016) | (Hudson et al., 2017) introduces the PREDICTS database. |
| (De Palma et al., 2015) | 12/4/22 | **Ecological traits affect the sensitivity of bees to land‐use pressures in European agricultural landscapes**  **Summary**  Understanding which types of species are most vulnerable under which land uses is an important step towards effective conservation planning.  We collated occurrence and abundance data for 257 bee species at 1584 European sites from surveys reported in 30 published papers (70 056 records) and combined them with species-level ecological trait data. We used mixed-effects models to assess the importance of land use (land-use class, agricultural use-intensity and a remotely-sensed measure of vegetation), traits and trait \* land-use interactions, in explaining species occurrence and abundance.  Species’ sensitivity to land use was most strongly influenced by flight season duration and foraging range, but also by niche breadth, reproductive strategy and phenology, with effects that differed among cropland, pastoral and urban habitats.  Rather than targeting particular species or settings, conservation actions may be more effective if focused on mitigating situations where species’ traits strongly and negatively interact with land-use pressures.  The majority of data included in this analysis will be published as part of the PREDICTS database.  **Intro**  Bees are key providers of pollination services, which are vital for food security and the persistence of many wild plants (Klein et al. 2007; Ollerton, Winfree & Tarrant 2011).  However, many bee species are threatened by changing and intensifying land use (Potts et al. 2010; Ollerton et al. 2014).  Urbanization, agricultural expansion and abandonment are ongoing drivers of land use change in Europe, which can affect bee diversity through reduced floral and nesting resources.  These pressures are unlikely to affect all species identically, but are expected to be mediated by species’ traits (Murray, Kuhlmann & Potts 2009; Roulston & Goodell 2011). In general, species with narrower niches – in terms of space, time, phenotype, or interspecific interactions – are predicted to be more sensitive than generalists (Den Boer 1968; Kassen 2002).  Bee species’ traits may specifically influence vulnerability to land use; for instance, larger foraging ranges facilitate foraging in fragmented landscapes, but may increase the likelihood of contact with pesticides and indicate greater resource needs.  Williams et al.’s (2010) global multi-species analysis, which found that some traits correlated with vulnerability to multiple threats: for instance, above-ground versus below-ground nesting influenced species’ susceptibility to fire, isolation and agricultural management practices. Unlike the study by Williams et al. (2010), we analyse multiple traits within the same models.  Social species may be more sensitive in intensively used cropland – where enhanced foraging capacity can increase exposure to pesticides and thus affect mortality and colony success – but relatively less sensitive in urban areas, where greater foraging capacities may enable persistence (Banaszak-Cibicka & Zmihorski, 2011).  We aim to identify the traits and land-use pressures associated with a species having low probability of occurrence and low abundance; we also aim to estimate the relative importance of land use, traits and the interaction between them in shaping species’ occurrence and abundance. We hypothesize that resource and phenological niche breadth, foraging range and reproductive strategy will all influence species’ sensitivity to land use.  **Methods**  Relevant data were available from 30 papers, hereafter referred to as sources.  The analysis was carried out in two stages, equivalent to a hurdle model, using mixed-effects models (lme4 package). Species presence (and detection) was modelled using a binomial error structure; then, the (log-transformed) abundance of present species was modelled using normal errors.  We used mixed-effects models to account for non-independence of data due to differences in collectors (source), sampling methodologies and biogeography (study), the spatial structure of sites (block), and taxonomy (family and species).  We used backwards stepwise model simplification based on likelihood ratio tests to reduce model complexity as far as possible and to determine whether interactive effects between traits and land use were retained in the final model.  **Results**  Models where interactions were excluded (additive models) explained 13% and 37% less variation in occurrence and abundance, respectively, than the interactive models did (marginal R2 GLMM).  Traits were relatively more important than land use: the traits-only model explained 85% and 70% as much variation in occurrence and abundance, respectively, as the additive model, while land-use-only models only explained 9% and 17% as much variation in occurrence and abundance as the additive model (marginal R2 GLMM)  In human-dominated land uses, species with shorter flight seasons were associated with lower probabilities of occurrence than species with longer flight seasons, although the magnitude of the relationship varied among land uses.  Other traits were less important in determining species’ occurrence and abundance (Fig. 1), but still had significant effects on species sensitivity (Tables 2 and 3).  Oligolectic (exhibit a narrow, specialized preference for pollen sources), solitary, univoltine, long-tongued and nest-excavating species were less likely to be present in human-dominated land uses relative to secondary vegetation, particularly in intensively-used cropland and urban areas. If present, however, the abundances of these species did not differ strongly from secondary vegetation.  The effects of ecological traits on species’ sensitivity were not always consistent across land uses. For example, species that were not obligately solitary were more sensitive than solitary species to lightly-used cropland (Fig. 3b), but less sensitive to pasture.  **Discussion**  Land-use change and intensification are considered to be major pressures on European bees. However, our analyses suggest that these pressures alone explain little of the variation in the presence and abundance of bee species, as effects are often indirect (through reduced floral and nesting resources) and are masked by heterogeneity in species’ responses.  Shorter flight seasons – the most important trait in explaining occurrence and abundance patterns – maybe because this trait confers a higher risk of asynchrony with key floral resources?  Small species were also particularly sensitive to intensive agriculture, perhaps because larger species are able to forage further from their nest?  Our results are congruent with previous studies that have found a negative impact of urbanization on bees.  Our data set is large, but only contains 12.5% of European bee species, with biases towards Western Europe and bumblebees.  In addition, little of the variation in species’ diversity was explained by fixed effects in our models: most was attributed to heterogeneity between sources (Table S4.3), reflecting differences in sampling methodology, intensity and timing, as well as land-use practices or pressures that we did not consider.  Some effects may be influenced by differential detectability; for instance, larger species that are active for longer are more likely to be sampled.  First, many of the traits affecting species’ sensitivities to land use also influence pollination efficiency (de Bello et al. 2010). Secondly, trait-based vulnerability of species also reduces functional diversity (Forrest et al. 2015), which is important for insurance against disturbances, pollination efficiency (Albrecht et al. 2012) and stability under climate change (Bartomeus et al. 2013b). | 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) | 13/4/22 | **Local biodiversity is higher inside than outside terrestrial protected areas worldwide**  **Abstract**  Globally, species richness is 10.6% higher and abundance 14.5% higher in samples taken inside protected areas compared with samples taken outside, but neither rarefaction-based richness nor endemicity differ significantly.  The positive effects of protection are mostly attributable to differences in land use between protected and unprotected sites.  **Intro**  Here we assess the effect of protection on species and assemblages using collated primary data rather than effect sizes, quantifying the effects of protection both among and within land uses, while controlling for potentially confounding variables.   * i.e. a synthetic analysis (rather than a meta-analysis, which would pull out effect sizes)   Using the PREDICTS (Projecting Responses of Ecological Diversity In Changing Terrestrial Systems) database.  We calculate four biodiversity measures based on sampled abundances and occurrences at each site.  Use mixed-effects models to assess the effects of protection while accounting for among-study differences in sampling methodology.  **Results**  Samples from protected sites (Fig. 1b) contained 10.6% more species (95% CI: 4.1 to 17.6%; w2 ¼ 9.99, df ¼ 1, P ¼ 0.002; Fig. 2a) and 14.5% more individuals (95% CI: 2.0 to 28.7%; w2 ¼ 5.09, df ¼ 1, P ¼ 0.024; Fig. 2b) than samples from unprotected sites.  As all analyses above accounted for differences in elevation, slope and agricultural suitability, differences in land use are the most likely explanation for higher species richness and total abundance. We included site-specific land use as a fixed effect in our models; and second, we restricted our dataset to sites matched by land use across the protected area boundary.  The effect of protection on within-sample species richness, abundance and endemicity varied among land uses but again the effect on rarefied richness did not.    Analysing only the sites within each study for which land use could be matched across the protected area boundary (Fig. 1d), we found no significant effect of protection on any biodiversity measure for any management category group, taxonomic group or latitudinal zone.  The greatest differences in species richness and abundance occurred across land uses: protected areas are most effective where they minimize human-dominated land use, especially where they safeguard primary or mature secondary vegetation. More restrictive protected area management across the current network could be as important as extending the network. The network is not currently effective for all measures of local biodiversity.  **Methods**  We used generalized linear mixed-effects models to account for differences in response variables due to study-specific methodologies and the spatial structure of sites.  We sequentially compared models with and without each fixed effect and at each step dropped the term with the highest P-value, until all terms had Po0.05.  We tested for biodiversity differences between sites inside and outside protected areas using the all-sites data, treating protection status (inside vs outside a protected area) as a fixed effect.  Using the all-sites data, we modelled the response of each biodiversity measure to protection status, land use, and their interaction. We also tested for the three-way interaction between land use, protection and either use intensity, latitudinal zone or taxonomic group. | 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) | 13/4/22 | **A global model of the response of tropical and sub-tropical forest biodiversity to anthropogenic pressures**  **Abstract**  Tropical forests harbour among the highest levels of terrestrial species diversity and are likely to experience rapid land-use change in the coming decades.  Synthetic analyses of observed responses of species are useful for quantifying how land use affects biodiversity and for predicting outcomes under land-use scenarios.  First worldwide synthetic analysis of how individual species in four major taxonomic groups—invertebrates, ‘herptiles’ (reptiles and amphibians), mammals and birds—respond to multiple human pressures in tropical and sub-tropical forests.  We show significant independent impacts of land use, human vegetation offtake, forest cover and human population density on both occurrence and abundance of species, highlighting the value of analysing multiple explanatory variables simultaneously.  **Intro**  Not all species respond equally to land-use changes: some species are ubiquitous in anthropogenic habitats, whereas others are entirely absent [6].  Large, slower-breeding, less-mobile species that are dietary and habitat specialists are typically more vulnerable to land-use change than other species [7–13].  Empirical data from individual studies can be pooled in order to develop synthetic statistical models of the relationship between land-use changes and local occurrence or abundance of species [21,22]; this is the approach we take in this paper. Synthetic analyses take advantage of the widespread availability of multi-species occurrence and abundance data at different sites, often in different land-use types and land-use intensities. Such data can offer a relatively good representation of different taxonomic groups, including traditionally under-represented groups such as invertebrates.  Because such studies have usually analysed the effect sizes seen in the source papers rather than the underlying data, they have generally analysed the average response of the whole community rather than the response of individual species, precluding any consideration of different responses among taxonomic or ecological groups.  Using data collated as part of the projecting responses of ecological diversity in changing terrestrial systems (PREDICTS) project.  Four measures of anthropogenic environmental pressure were considered as potential explanatory variables for differences in the occurrence and abundance of species: the major land-use type, forest cover, removal of vegetation in the 3 years prior to sampling and human population density.  The abundance data modelled used several different measures, and both the occurrence and abundance values will have been influenced by study-specific methodological details and by species identity. To control for these effects, the responses of species were fitted using mixed-effects models.  Only 26% of the abundance records were non-zero. Therefore, we used a two-stage modelling approach [37], modelling separately the occurrence (assuming detection) of species, using generalized linear mixed-effects models (GLMMs) with a binomial error distribution, and (given presence) log-transformed abundance of species, using linear mixed-effects models (LMMs).  The fit of the final models to the data was assessed by calculating R2 GLMM values.  For all models, land use, forest cover, iNDVI and human population density were fitted as fixed effects.  The best model, in terms of fixed effects, was selected using backward stepwise variable selection.  Site, nested within study, was fitted as a random effect in a random-intercept model to account for different measures and methodologies among studies.  We tested the effect of habitat specialization and geographical range size on responses to environmental variables in separate post hoc analyses, by refitting the minimum adequate model to separate datasets where all species were divided into broad- and narrow-ranged species, or where birds and mammals were divided into forest/habitat specialists and generalists.  Species abundance and occurrence are likely to show spatial patterns unrelated to the anthropogenic environmental variables considered. To test the potential for such non-independence to bias our results, we tested for spatial autocorrelation in the residuals of the best models, separately for each major taxonomic group and for each study, using Moran’s I tests as implemented in the ‘spdep’ package in R.  **Results**  The probability that species occurred at a site was strongly related to the major land-use type, and this response differed markedly among taxonomic groups.  **Discussion**  Overall, the probability of occurrence of species in all taxonomic groups declined in human-modified habitats, whereas persisting species often increased in abundance. These effects together led to increased dominance by smaller numbers of taxa.  We show that the taxa benefiting from land-use change are generally the more geographically widespread species, and the species that are more generalist in terms of habitat use.  Most of the variation in the occurrence and abundance of species within studies remained unexplained. | (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) | 13/4/22 | **Global patterns of terrestrial assemblage turnover within and among land uses.**  **Abstract**  Effects on the turnover of species composition between locations (beta diversity) are less clear, with previous studies focusing on particular regions or groups of species.  Overall, we show a strong impact of land use on assemblage composition.  NB: high beta diversity means low similarity index between 2 places.  **Intro**  Human-modified habitats have been shown to benefit a few widespread species at the expense of many narrowly distributed species.  Previous studies on compositional turnover have typically focused on particular geographic regions, or on single or few taxonomic groups.  **Methods**  Taken from the PREDICTS.  Where sampling effort differed among sites within a study and data had not already been corrected for this (<20% of studies), we adjusted abundance values assuming that recorded abundance increases linearly with effort.  We calculated pairwise compositional similarity between all sites within each study in the dataset.  Three explanatory variables were used to model similarity between paired sites: geographic distance, environmental distance and the combination of land uses in which sites were located (for example, primary vegetation versus cropland).  Owing to the heterogeneity of the collated datasets, the main analyses were done using hierarchical mixed-effects models (Pinheiro and Bates 2000) as implemented in the ‘lme4’.  We then fit models, all of which had the best-fitting combination of the two distance measures and realm, but with different combinations of land use, realm and their interaction. The fits of these models to the data were compared using Akaike information criterion (AIC) values.  **Results**  Sørensen similarity declined strongly with increasing geographic distance between sites (objective 1; ΣAICw ≈ 1; Fig. 2a). This relationship differed between the tropical and temperate realms (objective 3; ΣAICw0.78), with a steeper decay of similarity with distance in the tropics.  When effects of distance were controlled for, land use (within and among land uses) had a strong overall effect on Sørensen similarity (objective 1; ΣAICw ≈ 1), and the effect of land use differed strongly between the temperate and tropical realms (ΣAICw0.93).  **Discussion**  Effects of land use on assemblage composition were weaker overall in the temperate than in the tropical realm. | 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) | 13/4/22 | **Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment**  We estimate that land use and related pressures have already reduced local biodiversity intactness—the average proportion of natural biodiversity remaining in local ecosystems—beyond its recently proposed planetary boundary across 58.1% of the world’s land surface.  We modelled how sampled richness and abundance respond to land-use pressures using data from the PREDICTS database.  The hierarchical mixed-effects models we used considered four pressure variables—land use, land-use intensity, human population density, and proximity to the nearest road—as fixed effects (figs. S2 and S3), whereas random effects accounted for among study differences in sampling (methods, effort, and focal taxonomic groups) and for the spatial arrangement of sampled sites within studies.  We asked how much of the Earth’s land surface is already “biotically compromised” (exceeds the boundaries of 10% loss of abundance or 20% loss of species).  Assuming that only originally present species contribute to ecosystem function, most of the world’s land surface is biotically compromised in terms of BII (Biodiversity Intactness Index) (58.1% of terrestrial area; 95% CI, 40.4 to 70.2%) (Fig. 1A) and within-sample richness of originally present species (62.4%; 95% CI, 20.0 to 72.7%). | 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) | 13/4/22 | **Global effects of land-use intensity on local pollinator biodiversity**  **Abstract**  Pollinating species are in decline globally, with land use an important driver. However, most of the evidence on which these claims are made is patchy, based on studies with low taxonomic and geographic representativeness.  Here, we model the effect of land-use type and intensity on global pollinator biodiversity, using a local-scale database covering 303 studies, 12,170 sites, and 4502 pollinating species.  Within most anthropogenic land-use types however, increasing intensity is associated with significant reductions, particularly in urban (43% richness and 62% abundance reduction compared to the least intensive urban sites), and pasture (75% abundance reduction) areas.  We further show that on cropland, the strongly negative response to intensity is restricted to tropical areas, and that the direction and magnitude of response differs among taxonomic groups.  **Intro**  The reliance of global crop production on animal pollinators makes pollinator biodiversity research highly relevant to policy makers. More than 75% of globally important food crops are at least partially reliant on animal pollination, including fruits, vegetables, coffee, cocoa and almonds20.  Much of the Earth’s terrestrial surface is subject to anthropogenic use. More than 75% of the terrestrial world exhibits direct evidence of historical or current transformation24, with just over 50% (~67 million km²) currently used by humans25. This area is comprised of ~44% for agriculture and forestry, and ~7% for infrastructure including urban areas25.  Temperate non-tropical regions have a longer history of agricultural activity, which may have acted to filter more sensitive species55, meaning more recent shifts towards intensive agriculture may have a smaller effect.  Functional specialisation tends to be higher in tropical pollination systems.  We test for global differences in responses among land-use types, taxonomic groups, geographic regions, and biodiversity metrics. We do so using two global compilations of data: 1) The PREDICTS database, a global compilation of site-level ecological survey data across different land uses and land-use intensities62; and 2) a new database of animal species judged to be pollinators (see Millard et al.19 and Methods).  **Results**  Increasing land-use intensity from minimal to intense use was associated with a significant change in pollinator biodiversity.  Relative to the primary vegetation minimal use baseline, for both natural and anthropogenic land-use types, biodiversity was often higher at low intensity.  Effects of land-use intensity were strongest in urban areas, with a 43% reduction for species richness and 62% for total abundance, between minimal and intense use.  Land-use intensity had a divergent effect on cropland pollinator biodiversity between the non-tropical and tropical geographical zones (Fig. 3). In the non-tropical zone, species richness and total abundance did not differ significantly among cropland intensity classes, and were significantly higher in minimal-intensity cropland compared to the primary-vegetation baseline. In contrast, in the tropical zone, species richness and total abundance decreased between primary vegetation and high intensity cropland by 44 and 49%, respectively.  Both Hymenoptera and Lepidoptera showed a strong negative response to increasing fertiliser application rate for both species richness and total abundance. Dipteran richness and abundance, on the other hand, increased markedly by 760% and 374% respectively. Coleopteran response to total fertiliser application rate was insignificant for all of species richness, total abundance, and Simpson diversity.  **Discussion**  Our results are consistent with previous analyses showing reductions in overall pollinator biodiversity at high land-use intensity63, and increases at low-intermediate intensity64.  We also highlight that strong negative responses to land-use intensity within croplands are largely restricted to the tropics, with no apparent effect (and even increases at low intensity) in non-tropical cropland. This is an important result, given the dominance of animal pollinated plants in tropical environments66, and that rapid agricultural expansion is predicted to occur in the near future67.  Differences in response to intensity between tropical and non-tropical areas are likely driven by the interacting effects of historical land-use and climate sensitivity, which differ between the temperate and tropical zones.  We may overlook extinction-debt effects - delayed species extinctions expected as a consequence of ecosystem perturbation.  Further research is required to better resolve the way in which these threats interact at the global level.  **Methods**  The PREDICTS database is structured such that each site is nested at a series of levels (Supplementary Fig. 14), allowing one to account for variation owing to study methodology.  We then calculated site-level species richness (the number of uniquely named species sampled at a site), Chao1- estimated species richness (the number of species at a site controlled for abundance94), total abundance (the sum of all species sampled abundances at a site), and the Simpson diversity index (the reciprocal of the sum of squared proportional abundances for all species sampled at a site).  We built generalised linear mixed-effects models with a Poisson error distribution for species richness and Chao1-estimated species richness94, and linear mixed-effects models for Simpson diversity and total abundance.  We included a random intercept of study identity to account for variation in sampling methods, sampling effort and broad geographical differences among studies, and a random intercept of spatial block within study to account for the spatial structuring of sites.  We focused on cropland in our remaining analyses, given the importance of animal pollination to crop production. We built 3 models for all potential pollinating species, modelling each of three biodiversity metrics (species richness, total abundance, and Simpson diversity) in cropland as a function of land-use intensity (minimal, low, high), geographical zone (temperate/tropical), and their interaction. | 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. |

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