InsectChange: Comment

Laurence Gaume[1*], Marion Desquilbet[2]

[1] AMAP, University of Montpellier, CNRS, CIRAD, INRAE, IRD, Montpellier, France

[2] Toulouse School of Economics, INRAE, University of Toulouse Capitole, Toulouse, France

*Corresponding author

Correspondence: laurence.gaume@cirad.fr

ABSTRACT

The InsectChange database (van Klink et al. 2021) underlying the meta-analysis by van Klink et al. (2020a) compiles worldwide time series of abundance and biomass of invertebrates reported as insects and arachnids, as well as ecological data likely to influence their change. Based on a comprehensive review of the original publications and datasets, we highlight numerous issues in this database, such as errors in insect counts, sampling biases, inclusion of non-insects driving assemblage trends, omission of internal drivers investigated in the original studies and inaccurate assessment of local cropland cover. We argue that in its current state this database does not allow to study the temporal trends of insects and arachnids or their drivers. Our in-depth analysis therefore calls for major changes and extreme vigilance in its use. It precisely details each problem identified and makes numerous suggestions in the supplementary information, which can be used as a basis for improvement.

Keywords: Insects, Terrestrial invertebrates, Freshwater invertebrates, Insect abundance change, Insect decline, Time-series analysis, Methodological biases, Cropland cover assessment, Land cover analysis

Introduction

Today experts agree that biodiversity is shrinking in the face of global changes characterizing the Anthropocene era (IPBES, 2019). However, as regards insects, which provide invaluable ecosystem services, the extent to which declines vary among insect groups and regions is still the subject of intensive investigation, trend assessment being hampered by lack of data and analytical weaknesses (Didham et al., 2020; Duchenne et al., 2022). There is also no consensus on the main drivers of insect changes, including land use (urbanization/agriculture), climate change, pesticides, other pollution types and invasive species, mostly because these drivers are not easily disentangled or may act in synergy (Wagner et al., 2021; Outhwaite et al., 2022).

While many authors have warned on insect extinctions worldwide (Cardoso et al. 2020), van Klink et al. (2020a) added to the debate by estimating a smaller decline in the abundance of terrestrial insects than reported by these authors and an increase in freshwater insects. They found that cropland was not involved in terrestrial insect decline and proposed improved water quality to be a driver of the freshwater insect increase. Yet their meta-analysis raised different comments regarding (1) their data selection and methodology (Desquilbet et al., 2020), which led to some corrections (van Klink et al., 2020b); (2) the limitations of abundance and biomass as sole indicators of insect trends, masking the possible replacement of sensitive species with stress-tolerant ones (Jähnig et al., 2021); and (3) the heterogeneity in temporal coverage with a lack of old baselines (Duchenne et al., 2022).

In the first place however, the sensitive issue of insect trends and drivers requires the utmost rigor in databases intended to serve as references. The InsectChange database (van Klink et al., 2021) underlying the analysis by van Klink et al. (2020b) includes time series of abundance and biomass of invertebrates reported as insects and arachnids in terrestrial and freshwater realms worldwide, together with ecological data likely to influence their trends. We carried out a comprehensive and in-depth analysis of the relevance and accuracy of the InsectChange datasets by systematically going back to the original publications. Our analysis highlights numerous limitations in the constitution of this database, the accumulation of which is prone to bias any assessment of insect change and drivers of change. Our supplementary information provides a detailed description of each problem identified and makes numerous suggestions for improvement.

1. The different issues in the InsectChange database

Invertebrate taxa included in InsectChange are insects and arachnids according to the title and abstract, but also entognaths (arthropods comprising springtails, diplurans and proturans), as indicated only in the keywords and appendices. We find that 17 types of problems pertaining to errors (240), inconsistencies (39), methodological issues (166) and information gaps (81) affect 154 of the 165 datasets totalizing 526 occurrences (Figure 1a), with more problem types per study in the freshwater realm (3.4 ± 1.5, n=62) than in the terrestrial realm (2.6 ± 1.7, n=103; Figure 1b, Appendix S1, *Problems.xlsx*). These multiple problems and the consequences they may have on the assessment of insect trends are detailed in Appendix 1.

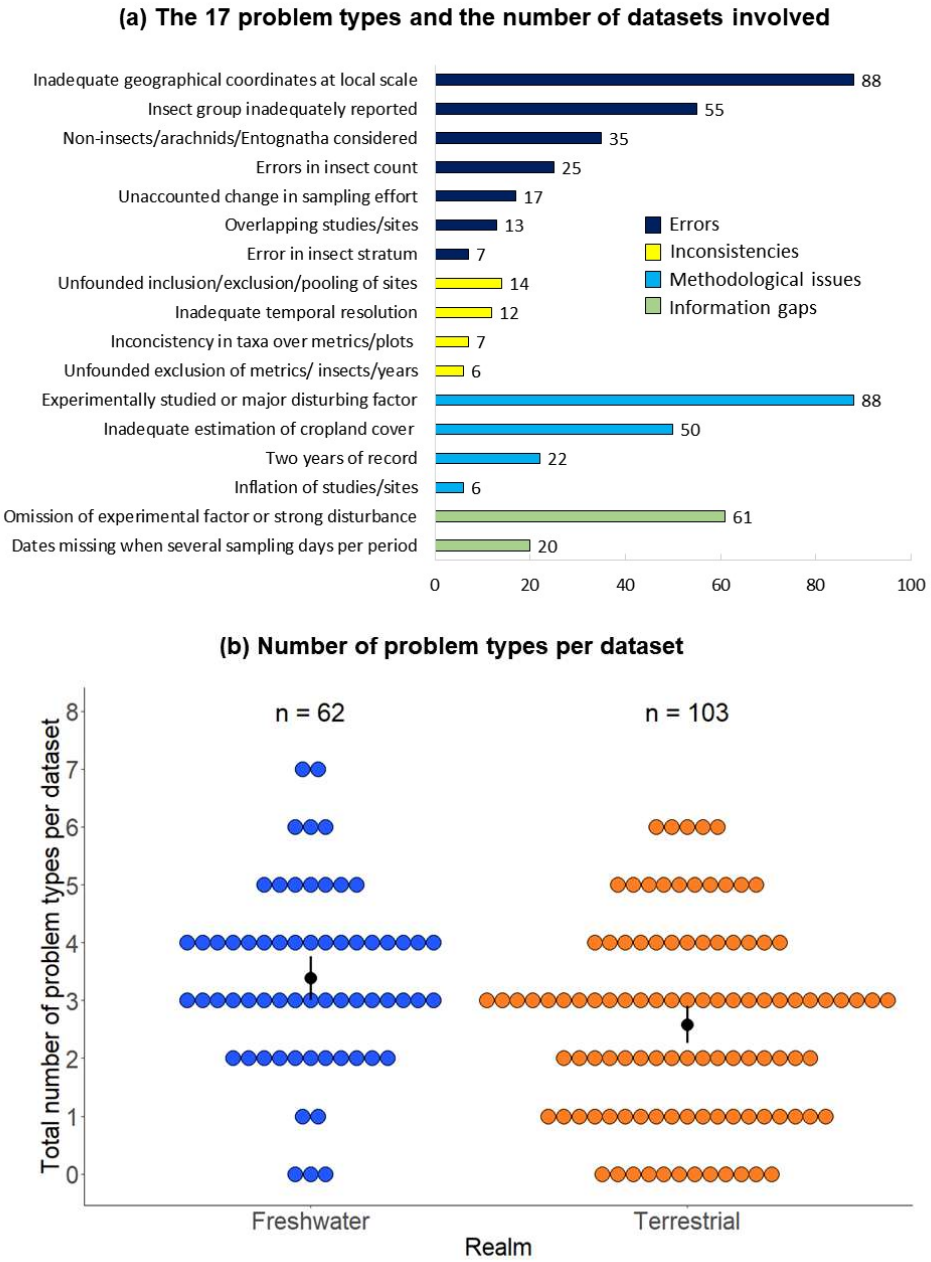

Figure 1 - Problems encountered in the InsectChange database (*Problems.xlsx*). (a) The 17 types of problems and numbers of datasets involved. *Cropland cover assessment only for terrestrial studies. (b) Number of problem types per freshwater and terrestrial dataset (except those related to cropland cover assessed only for terrestrial studies) and associated means (± SE). Each dot refers to a study. Thus, the occurrence of *i* dots on the line *y* corresponding to *y* problem types indicates that there are *i* studies with *y* problem types.

Among the errors, 35 datasets considered taxa other than insects, arachnids or entognaths (hereafter collectively referred to as "insects" for brevity), most often including the entire invertebrate assemblage instead of insects only, sometimes biasing the trends to the point of reversal (Figure 2a). The composition of

the invertebrate group selected from the source datasets was misreported in 55 datasets, often because the authors of InsectChange neglected to specify that they had selected only certain taxa from the original community (e.g. Figure 2b). Insect numbers were misreported from source studies in 25 datasets because of misinterpretation, calculation errors, inversion of numbers, or species counted twice (e.g. Figures 2c and 2d). Variation in sampling effort was not accounted for in 17 datasets (e.g. Figure 2e). Some datasets or plots had overlapping data for all or part of the time period (13 datasets, e.g. Figure 2f). Finally, the geographic coordinates of the included plots were erroneous or not precise enough in 88 datasets, given the matching with external databases at a local scale.

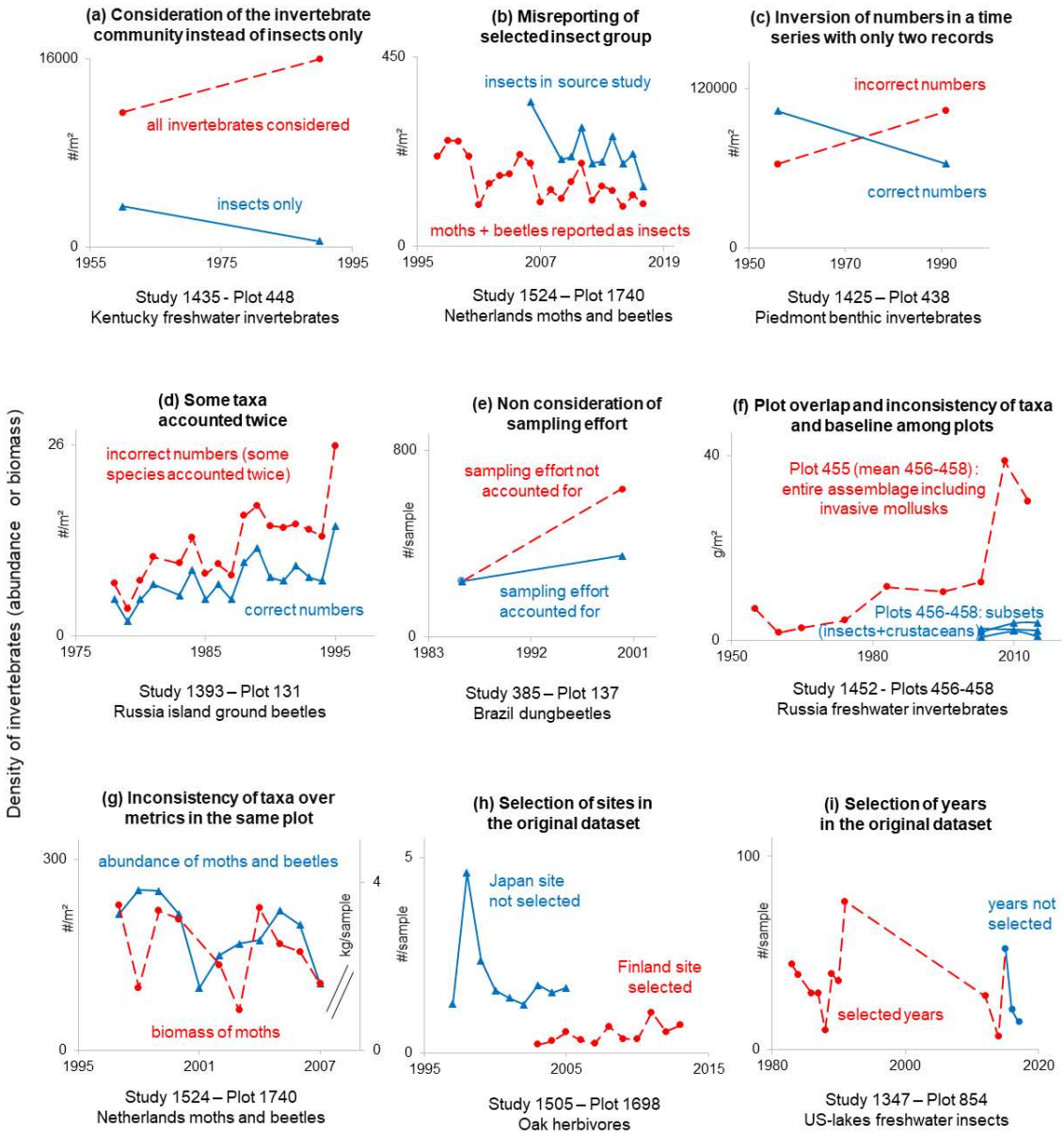

Figure 2 - Errors and inconsistencies in data selection biasing insect change assessment (Appendix S1, *Problems.xlsx*, *Fig2and4.xlsx*). Examples of errors (a-e), inconsistencies regarding taxa over plots or metrics (f, g), inconsistencies regarding data selection (h, i).

There were also a number of inconsistencies and information gaps. There were inconsistencies of taxa (7 datasets) between plots of a same dataset (e.g. Figure 2e) or between metrics (abundance or biomass) in a same plot (e.g. Figure 2g), but users cannot identify them because the insect group is not indicated at the plot or metric level. Unfounded inclusion, exclusion (e.g. Figure 2h) or pooling of original sites concerned 14 datasets. There were unfounded exclusions of data regarding a metric, some insect groups or time records (6 datasets, Figure 2i). A total of 12 datasets had temporal resolutions that did not match the resolutions of the original datasets or the ones stated in the metadata (Appendix S1, *Problems.xlsx*). Moreover, dates were not indicated when there were successive samplings per period, which may lead users to consider samples as interchangeable replicates, when they are time-dependent (20 datasets).

Regarding methodological issues, the inclusion of studies with experimental conditions or major disturbances and the estimation of the local cropland cover are the focus of sections 3 and 4. In addition, 22 datasets had only two years of data, while non-monotonic dynamics of insect populations call for more records. The number of datasets and/or sites was unduly inflated in 6 datasets compared to the original studies, leading to their overweighting: e.g. site inflation from splitting some sites of original datasets into several plots only a few meters apart.

2. Focus on the problematic inclusion of clams, snails, worms, shrimps in freshwater data

In the freshwater realm, 80% (19 out of 24) of the biomass and 40% (21 out of 54) of the abundance datasets included invertebrates other than insects. They were related to 28 distinct datasets, 24 of which involved the entire freshwater invertebrate assemblage (Figure 3, Appendix S2: Table S1). The great majority of these 24 datasets included worms, mollusks and crustaceans, with notably Oligochaeta, Hirudinea, Turbellaria and Amphipoda, often indicative of poor water quality (Enns et al., 2023) (Appendix S2: Table S2). The inclusion of these datasets is not consistent with the purpose of the database, because the dynamics of insects cannot be inferred from those of entire invertebrate assemblages. This is illustrated by Figure 3a showing that insect and invertebrate assemblages can have contrasted trajectories (top), and that proliferating invasive mollusks can drive the trend of the invertebrate assemblage (bottom) (see also *FreshwaterNonInsects.xlsx*).

Beyond these examples, we calculated that on average insects made up 48.5% ± 32.2% of the entire assemblage in the 13 datasets (48 plots) with information on all or part of the time records (Figure 3b, *FreshwaterNonInsects.xlsx*). The insect share in the assemblage was also highly variable over time (Appendix S2: Figure S1) with a coefficient of variation averaging 34.8% ± 22.5% in the 8 datasets (42 plots) where information was available for more than one time record. Therefore, considering non-insects in the assemblage can considerably alter the inferred 'insect' trend. Out of the 53 plots of 15 datasets with reported or inferred information on invertebrates driving the trend of the entire assemblage, non-insects (invasive mollusks, opportunistic oligochaetes and/or amphipods…) were found to drive the assemblage trend in half of the plots (25), affecting two-thirds of the datasets (10) (*FreshwaterNonInsects.xlsx*).

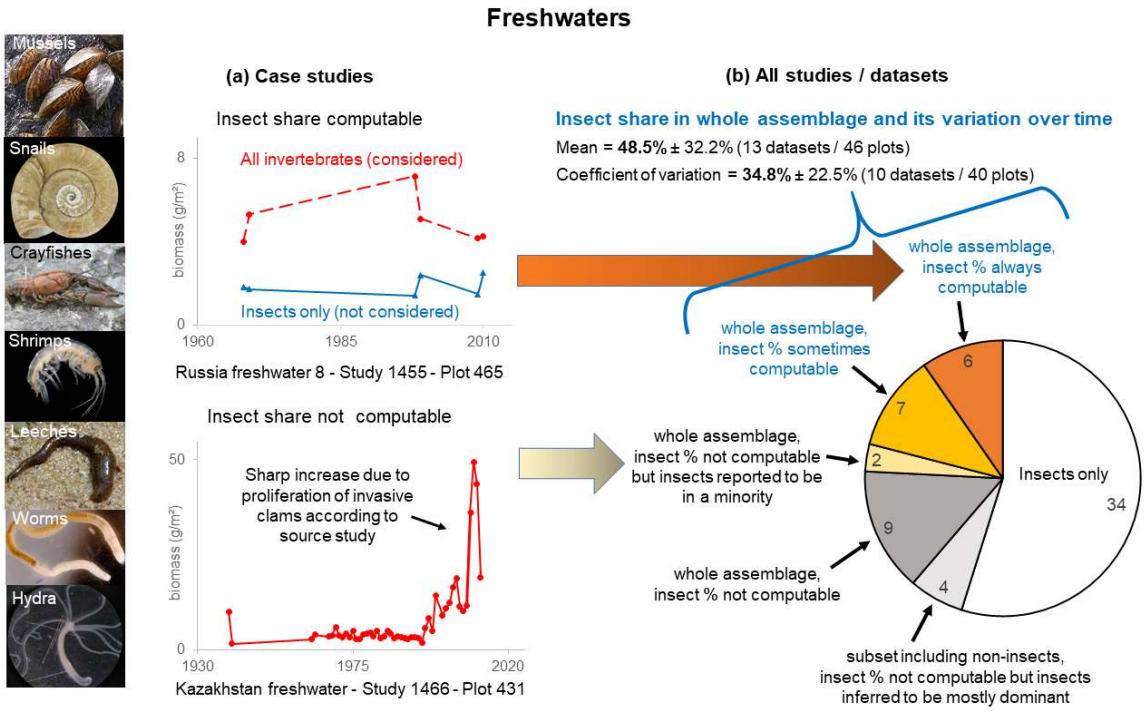

Figure 3 - Freshwater time-series including non-insects while the insect share was often low and variable over time (Appendix S2, *FreshwaterNonInsects.xlsx*). (a) Case studies 1455 and 1466 (Appendix S1) illustrating (top) contrasted trajectories of the entire assemblage and insects only, and (bottom) invasive non-insects driving the trend. (b) The 62 freshwater datasets, 28 including non-insects (24 the entire assemblage). The insect share, extracted from 13 of these, averaged 48.5% with a ~35% coefficient of variation. Photograph credits detailed in Appendix S2: Table S3.

3. Inclusion of experimental or disturbed situations with internal drivers of insect change

A major limitation of the InsectChange database is that users are inclined to erroneously attribute insect changes to the ecological drivers included in InsectChange after extraction from external databases, when they more directly reflect habitat changes caused by internal drivers investigated in the original studies, which, in most cases, are not indicated in InsectChange. Indeed, 88 datasets were extracted from controlled or natural experiments or from strongly disturbed contexts, but the factors originally investigated or the major disturbances were not mentioned in 69% of these 88 datasets (Appendix S3, *Problems.xlsx*). Among these 88 datasets, 14 controlled experiments tested the effect of one or several treatments in different plots (Figure 4a) and 53 natural experiments (Diamond, 1983) investigated the effect of a natural disturbance by comparing insect abundance in more or less disturbed plots (Figure 4b) or before and after the disturbance in a plot (Figure 4c). In these experimental datasets, only control plots, only experimental plots or both types of plots were inconsistently included in InsectChange. In 21 observational datasets of the 88, a strong disturbance affected insect trends (Figure 4d).

Among these 88 datasets, the factor could be positive, such as cessation of harmful activities, remediation measures (Figure 4e), active restoration or creation of new habitats such as ponds (Figure 4f), reservoirs or nesting sites, favoring insect recovery or colonization. The studied factor could also be negative, such as a severe drought, fire or pesticide application, creating deleterious conditions for insects at the beginning,

middle or end of the observation period, followed by recovery, this timing strongly influencing insect trends (Appendix S3). An increase in invertebrate abundance or biomass after a negative factor of pollution was paradoxically expected in 6 freshwater studies (Figure 4g, Appendix S3) because only or mostly stress-tolerant chironomids were considered or proliferating non-insects were included such as oligochaetes, opportunists in eutrophicated waters (Rosa et al., 2014), or invasive amphipods.

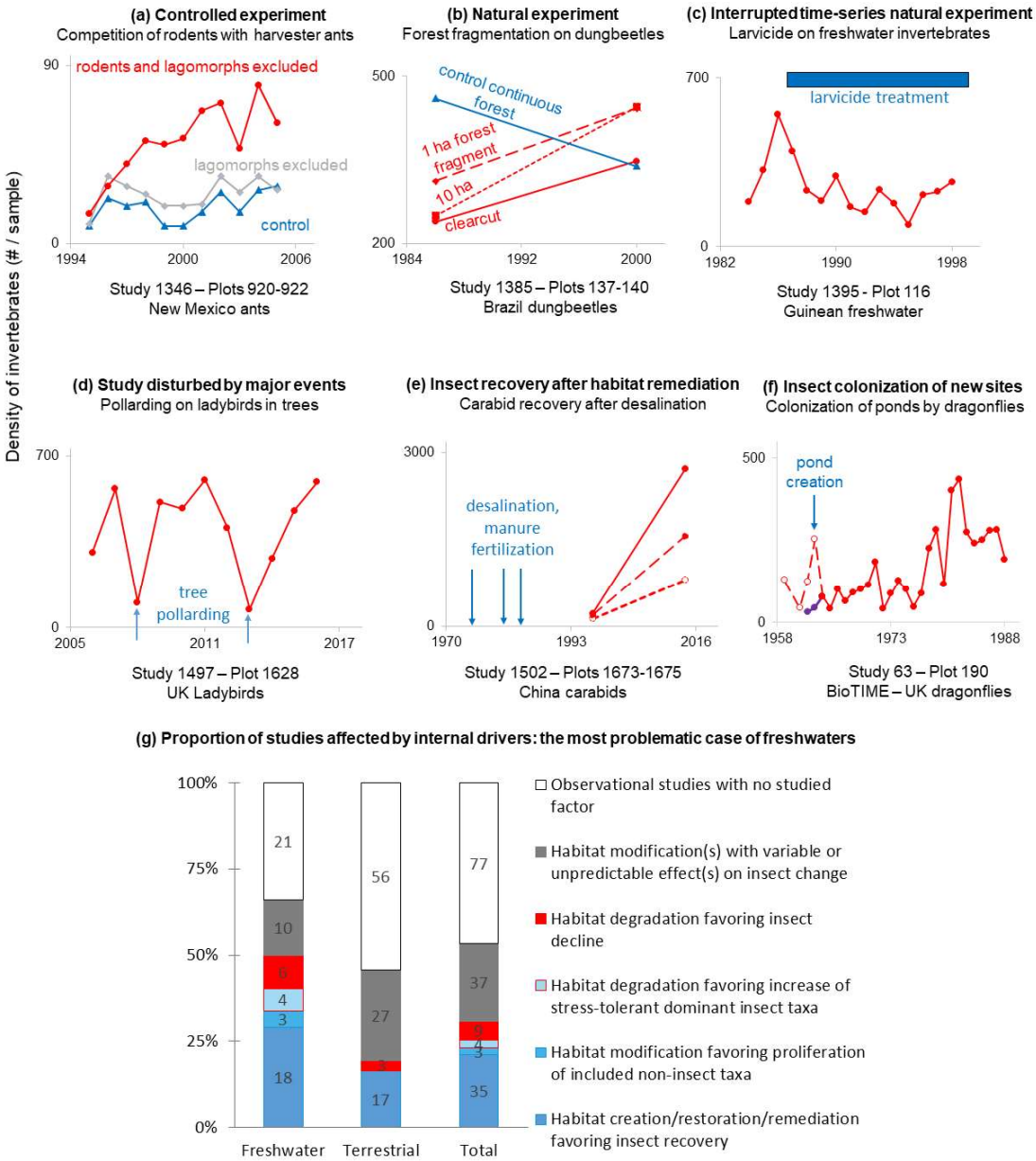

Figure 4 - Inclusion of studies with specific internal drivers (Appendix S3, *Fig2and4.xlsx*). Examples of (a-c) controlled or natural experiments and (d-f) studies with major disturbances; in (f), dashed and purple curves respectively represent erroneous and actual data. (g) Comparison of the proportions of studies affected by internal factors between freshwater and terrestrial realms showing the particularly problematic case of freshwaters in terms of studies affected by factors and frequency of situations favoring insect increase. Blue: insect increase favored, Red: insect decrease favored.

Two-thirds (41 of 62) of the freshwater datasets were affected by internal drivers, a proportion significantly higher than that (one half: 47 of 103) of the terrestrial datasets (χ^2 = 5.7, P=0.02, Figure 4g left and middle, Appendix S3). Of these two thirds, internal drivers were found to create situations favoring insect increase in 61% of cases (25 freshwater datasets in blue on Figure 4g left). Considering all freshwater and terrestrial datasets impacted by specific drivers (Figure 4g, right), there were 5 times more situations favoring an increase in insects (42 datasets in blue) than those favoring a decline in insects (9 datasets in red).

This analysis raises the question of whether the data included in InsectChange are representative of the habitat conditions and associated insect trends worldwide, particularly in freshwaters. In controlled experiments, it seems prudent to consider only control sites. Care should be taken regarding the representativeness of the situations investigated in natural experiments and of the overall studies in terms of sites without, under or post-disturbance (Cardinale et al., 2018). In any case, using insect abundance or biomass time series matched with external databases for the search of potential drivers, without knowledge of the factors originally investigated in the source studies, exposes users to the risk of misinterpreting trend drivers.

4. Methodological issues resulting in a strong overestimation of the local cropland cover

Last, we found a strong overestimation of local cropland, a possible driver included in InsectChange by matching study plots to land covers provided in the European Space Agency Climate Change Initiative (ESA CCI) database (ESA, 2017) via the geographic coordinates (GC) that were either provided in the source studies or inferred by the authors of InsectChange. We found that the assessment of local cropland cover was inadequate for almost half (468 of 982) of the terrestrial plots, with a very uneven distribution of errors (Figure 5a, Appendix S4, *CroplandCover.xlsx*).

Most plots assessed as having no surrounding crops were well assessed (451 of 486), while most plots assessed as having surrounding crops suffered from an overestimation of the crop cover (350 of 496), with two thirds (233) in fact having no surrounding crops. We observed a similar picture when considering only plots with distinct GC (508) (Figure 5a). Because of this strong bias, we argue that InsectChange cannot provide a reliable analysis of the impact of local cropland cover on insect change and could incorrectly dismiss the impact of crops on insect decline.

The main reason for these errors was an inaccurate assessment of the local cropland cover from the interpretation of satellite images in the ESA-CCI database (Appendix S4), notably due to its limitation that grasslands may inaccurately be coded as croplands (Peng et al., 2017; Liu et al., 2018) and its imprecise representation of land cover when used at a local scale composed of nine 300 m × 300 m squares with a rough cropland cover assigned to each of them (Figure 5b). Second, the GC were inadequate for estimating land cover at this scale for 228 of the 982 plots, mainly (212 plots) because the considered plots aggregated data from sampling points often several kilometers apart under the unique GC of their barycenter or of only one of these points.

Concerning freshwaters, the GC provided were inadequate for 108 of the 585 plots matched with ESA-CCI information and should be used with caution. We did not check local cropland cover estimates, as water quality at sampling points may be more dependent on upstream land use (Allan, 2004; Desquilbet et al., 2020). For both terrestrial and freshwater datasets, a quality check on the accuracy of estimates provided for other possible drivers of insect change is strongly recommended, notably local-scale drivers (urban cover and climate change) similarly affected by the inadequacy of GC.

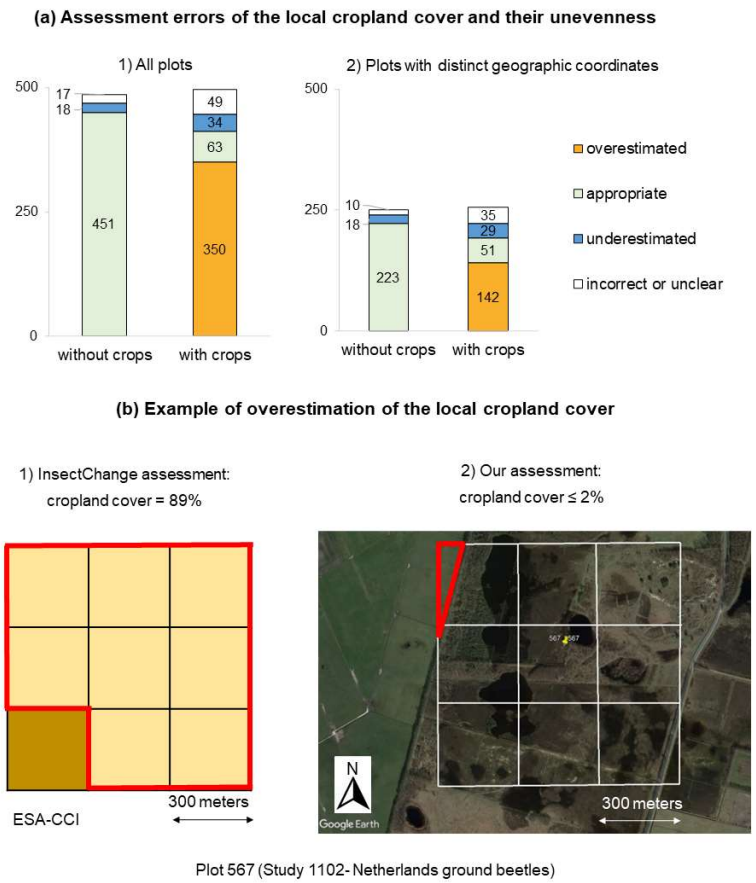

Figure 5 - Overestimation of local cropland cover (Appendix S4, *CroplandCover.xlsx*). (a) Assessment errors of plot cropland cover and their unevenness. (b) Example of overestimation of the local cropland cover (Study 1102, Plot 567) outlined in red; 1) InsectChange assessment: cropland cover = (8×100%)/9 = 89% based on ESA-CCI; 2) our assessment: cropland cover ≤ 2% based on Google Earth and information from the source study.

Conclusion

The numerous problems underlying InsectChange call for corrections and an extreme vigilance in its use. They fully undermine the results obtained so far from this database, in the first place those of van Klink et al. (2020a), widely covered by the media, which cast unsubstantiated doubt on insect decline (Kimbrough, 2020; McGrath, 2020). We argue that InsectChange, in its current state, does not allow for the study of insect trends worldwide or their drivers, and is particularly unsuitable for the analysis of agriculture influence on insects, or for the study of changes in freshwater insect assemblages. Our detailed appendices are designed to facilitate data consolidation. More generally, this careful review underlines the need for relevant matching with external databases. It illustrates the value of contacting dataset owners to ensure their appropriate use. It calls for vigilance to avoid transferring errors across databases, as occurred for 11 datasets incorporated from the Global Population Dynamics Database (Prendergast et al., 2010) and/or Biotime (Dornelas et al., 2018) into InsectChange (Appendix S1). Finally, our in-depth analysis highlights the attention that needs to be paid to the data and its meaning to ensure that large databases built from individual datasets participate in a cumulative knowledge process.

1 # Appendices

2 **Appendix 1** – Description of the types of problems and their possible impact on insect trend analysis

Problem category	Problem type	Definition	Consequences and risks
Errors	Inadequate geographical coordinates for study at local scale	The geographical coordinates provided in columns "Latitude" and "Longitude" of the table *PlotData.csv* of InsectChange are inexact or not precise enough for the matching with ESA-CCI land cover estimates (column "frcCrop900m" of the table *Plotdata.csv* providing the ESA-CCI land cover estimate for a 300 × 300 m cell and the eight surrounding cells).	- Misestimation of land cover, temperature and precipitation at the local scale - Erroneous analysis of drivers of insect change at the local scale
	Insect group inadequately reported	The insect or invertebrate group reported in the column "InvertebrateGroup" of the table *DataSource.csv* and/or in the column "GroupInData" of the table *SampleData.csv* of InsectChange does not correspond to or is wider than the group of insects (or invertebrates) that were actually extracted from the source studies.	- Misidentification of insect group - Erroneous analysis of changes of specific groups of insects or invertebrates
	Non-insects / arachnids / entognaths considered	The group of invertebrates included in InsectChange includes taxa (most frequently macro-invertebrates) that are not insects, arachnids or entognaths.	- Abundance and even more biomass numbers affected - Misanalysis of change of taxa interpreted as insects, which depends on the weight of non-insect invertebrates included and the variation of this weight over time.
	Errors in insect count	The abundance and/or biomass numbers reported in the column "Numbers" of the table *InsectAbundanceBiomass.csv* of InsectChange do not correspond to the actual abundance and/or biomass numbers in the source study.	Erroneous analysis of insect change
	Unaccounted change in sampling effort	A change in sampling effort over the study time in the source study was not considered and corrected when reporting the abundance and/or biomass numbers of the source study in the column "Numbers" of the table *InsectAbundanceBiomass.csv* of InsectChange.	- Slope of insect dynamics affected - Erroneous analysis of insect change
	Overlapping studies/plots	Different studies include the same plots, or a plot in a given study is actually a pooling of other plots in the same study, resulting in overlaps in insect data (the exact same insects are counted twice, in different studies or different plots of a same study).	- Overweighting of some insect populations in the global analysis - Erroneous analysis of insect change
	Error in insect stratum	The stratum reported in the column "Stratum" of the table *SampleData.csv* of InsectChange is erroneous.	Erroneous analysis of insect change conducted at the stratum level
Inconsistencies	Unfounded inclusion/exclusion/pooling of plots	Some plots were inconsistently either included, or excluded, or pooled.	Included plots not representative of sites in source studies
	Inadequate temporal resolution	The methodology detailed p. 17 of the file MetadataS1 of InsectChange, describing that the temporal resolution was as fine as possible between the week and the year (except in six datasets where plots were sampled between six and eight times in any month) was not respected.	Erroneous analysis of insect change
	Inconsistency in taxa over plots/metrics	The table *SampleData.csv* of InsectChange provides information at the study but not the plot level. It does not allow to know whether insect groups differ between plots. For studies including both abundance and biomass in the table *InsectAbundanceBiomass.csv*, the table *SampleData.csv* only indicates the insect groups for abundance data and does not allow to know which insect groups are included in the biomass data.	Biased analysis of insect change
	Unfounded exclusion of metrics/ insects/years	A metric (abundance or biomass), some insect groups or some years present in the source study were not included in InsectChange.	- Data not representative of the source data - Biased analysis of insect change

3 **Appendix 1** – Description of the types of problems and their possible impact on insect trend analysis (continued)

Methodological issues	Experimentally studied or major disturbing factor	Study corresponding to our definition of a controlled experiment, a natural experiment or a study with a major disturbance (see Appendix S3).	Biased analysis of insect change
	Inadequate estimation of cropland cover	The estimation of the local cropland cover provided in the column "frcCrop900m" of the table *PlotData.csv* of InsectChange is inadequate.	Erroneous analysis of the impact of land use on insect change at the local scale
	Two years of record	While the times series covers a period of at least 9 years, there are data for only two years (the first and last years of the series, column "Year" of the table *InsectAbundanceBiomass.csv* of InsectChange).	Given the non-monotonic dynamics of insect populations, possible misinterpretation of insect trend
	Inflation of studies/plots	Some time series were included in different studies instead of different plots of a same study, and/or split between several plots instead of being grouped together in a single plot, inconsistently with the methodology used for other time series.	Overweighting of some time series in the statistical analyses
Information gaps	Omission of experimental factor or strong disturbance	Study corresponding to our definition of a controlled experiment, a natural experiment or a study with a major disturbance (see Appendix S3), in which the factor or disturbance was not mentioned in column "DetailsPlots" or "ExperimentalTreatment" of the table *PlotData.csv* of InsectChange.	- Misinterpretation of insect trends without reference to the drivers investigated in the source studies - Risk of erroneously attributing insect changes to drivers extracted from external databases, when they more directly reflect habitat changes caused by internal drivers investigated in the original studies w
	Dates missing when several sampling days per period	InsectChange provides several samplings in a given period (column "Period" of the table *InsectAbundanceBiomass.csv* of InsectChange) but does not allow to know their chronology because it does not report the sampling date.	- Consideration of the different samples as interchangeable replicates when they are time dependent - Erroneous analysis of insect change

4

Acknowledgments

We thank Sonja Jähnig for helpful discussions, Gaëlle Viennois for double-checking the land cover analysis, Dirk Maes and Hans van Dyck for their help in analyzing biased data on Belgian lepidopterans (study 70), Sylvain Chabé-Ferret for insights on the analysis of controlled and natural experiments, other co-authors of Desquilbet et al. (2020), Marianne Elias, Marilyne Laurans, Doyle McKey and Denis Bourguet for helpful comments on earlier drafts.

Conflict of interest disclosure

We declare that we comply with the PCI rule of having no financial conflicts of interest in relation to the content of the article.

Funding

This work was publicly funded by the French National Research Agency (ANR-17-EURE-0010 to MD, ANR-16-IDEX-0006 to LG, *Investissements d'avenir* program).

Author contributions

Marion Desquilbet and Laurence Gaume contributed equally to this work.

Supplementary information availability

Supplementary information is available online on bioRxiv and will be permanently archived in the Figshare repository if the paper is accepted for publication (https://doi.org/10.6084/m9.figshare.23458877). It comprises five appendices (Appendix S1, Appendix S2, Appendix S3, Appendix, S4 and Appendix S5) and four datasheets (*Problems.xlsx, FreshwaterNonInsects.xlsx, CroplandCover.xlsx* and *Fig2and4.xlsx*).

- Appendix S1 and *Problems.xlsx* respectively detail and record the problems encountered in InsectChange.
- Appendix S2 summarizes the inclusions of freshwater non-insects in the InsectChange assemblages, while *FreshwaterNonInsects*.xlsx details the calculation of their parts in the assemblages and the problematic consequences on the inferred 'insect' trends.
- Appendix S3 focuses on studies analyzing the effect of internal drivers and highlights the driver-induced situations that favor an increase or decrease in insects.
- Appendix S4 shows the assessment of the adequacy of geographic coordinates and local cropland cover, which are detailed in *CroplandCover.xlsx*.
- Appendix S5 details the errors transferred from other databases to InsectChange.
- *Fig2and4.xlsx* provides information supporting Figures 2 and 4 of this comment.

References

Allan JD (2004) Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annual Review of Ecology, Evolution, and Systematics,* **35**, 257-284. https://doi.org/10.1146/annurev.ecolsys.35.120202.110122

Cardinale BJ, Gonzalez A, Allington GRH, Loreau M (2018) Is local biodiversity declining or not? A summary of the debate over analysis of species richness time trends. *Biological Conservation,* **219**, 175-183. https://doi.org/https://doi.org/10.1016/j.biocon.2017.12.021

Cardoso P, Barton PS, Birkhofer K, Chichorro F, Deacon C, Fartmann T, Fukushima CS, Gaigher R, Habel JC, Hallmann CA, Hill MJ, Hochkirch A, Kwak ML, Mammola S, Ari Noriega J, Orfinger AB, Pedraza F, Pryke JS, Roque FO, Settele J, Simaika JP, Stork NE, Suhling F, Vorster C, Samways MJ (2020) Scientists' warning to humanity on insect extinctions. *Biological Conservation,* **242**, 108426. https://doi.org/https://doi.org/10.1016/j.biocon.2020.108426

Desquilbet M, Gaume L, Grippa M, Céréghino R, Humbert JF, Bonmatin JM, Cornillon PA, Maes D, Van Dyck H, Goulson D (2020) Comment on "Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances". *Science,* **370**. https://doi.org/10.1126/science.abd8947

Diamond JM (1983) Ecology: Laboratory, field and natural experiments. *Nature,* **304**, 586-587. https://doi.org/10.1038/304586a0

Didham RK, Basset Y, Collins CM, Leather SR, Littlewood NA, Menz MHM, Müller J, Packer L, Saunders ME, Schönrogge K, Stewart AJA, Yanoviak SP, Hassall C (2020) Interpreting insect declines: seven challenges and a way forward. *Insect Conservation and Diversity,* **13**, 103-114. https://doi.org/https://doi.org/10.1111/icad.12408

Dornelas M, Antão LH, Moyes F, Bates AE, Magurran AE, Adam D, Akhmetzhanova AAet al. (2018) BioTIME: A database of biodiversity time series for the Anthropocene. *Global Ecology and Biogeography,* **27**, 760-786. https://doi.org/https://doi.org/10.1111/geb.12729

Duchenne F, Porcher E, Mihoub J-B, Loïs G, Fontaine C (2022) Controversy over the decline of arthropods: a matter of temporal baseline? *Peer Community Journal,* **2**. https://doi.org/10.24072/pcjournal.131

Enns D, Cunze S, Baker NJ, Oehlmann J, Jourdan J (2023) Flushing away the future: The effects of wastewater treatment plants on aquatic invertebrates. *Water Research,* **243**, 120388. https://doi.org/https://doi.org/10.1016/j.watres.2023.120388

ESA. (2017). *Land Cover CCI Product User Guide Version 2.0*

Hallmann CA, Sorg M, Jongejans E, Siepel H, Hofland N, Schwan H, Stenmans W, Müller A, Sumser H, Hörren T, Goulson D, de Kroon H (2017) More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PloS ONE,* **12**, e0185809. https://doi.org/10.1371/journal.pone.0185809

Hallmann CA, 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. https://doi.org/10.1111/icad.12377

IPBES. (2019). *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.*

Jähnig SC, Baranov V, Altermatt F, Cranston P, Friedrichs-Manthey M, Geist J, He F, Heino J, Hering D, Hölker F, Jourdan J, Kalinkat G, Kiesel J, Leese F, Maasri A, Monaghan MT, Schäfer RB, Tockner K, Tonkin JD, Domisch S (2021) Revisiting global trends in freshwater insect biodiversity. *WIREs Water,* **8**, e1506. https://doi.org/https://doi.org/10.1002/wat2.1506

Kimbrough L. (2020). Insects decline on land, far better in water, study finds. *Mongabay, news & inspiration from nature's frontline*. Retrieved from https://news.mongabay.com/2020/05/insects-decline-on-land-fare-better-in-water-study-finds/

Liu X, Yu L, Li W, Peng D, Zhong L, Li L, Xin Q, Lu H, Yu C, Gong P (2018) Comparison of country-level cropland areas between ESA-CCI land cover maps and FAOSTAT data. *International Journal of Remote Sensing,* **39**, 6631-6645. https://doi.org/10.1080/01431161.2018.1465613

McGrath M. (2020, 2020/04/23). Nature crisis: 'Insect apocalypse' more complicated than thought. *BBC News*. Retrieved from https://www.bbc.com/news/science-environment-52399373

Outhwaite CL, McCann P, Newbold T (2022) Agriculture and climate change are reshaping insect biodiversity worldwide. *Nature,* **605**, 97-102. https://doi.org/10.1038/s41586-022-04644-x

Peng S, Ciais P, Maignan F, Li W, Chang J, Wang T, Yue C (2017) Sensitivity of land use change emission estimates to historical land use and land cover mapping. *Global Biogeochemical Cycles,* **31**, 626-643. https://doi.org/https://doi.org/10.1002/2015GB005360

Prendergast J, Bazeley-White E, Smith O, Lawton J, Inchausti P, Kidd D, Knight S. (2010). The Global Population Dynamics Database. Knowledge Network for Biocomplexity (Publication no. 10.5063/F1BZ63Z8.).

Rosa BJ, Rodrigues LF, de Oliveira GS, da Gama Alves R (2014) Chironomidae and Oligochaeta for water quality evaluation in an urban river in southeastern Brazil. *Environ Monit Assess,* **186**, 7771-7779. https://doi.org/10.1007/s10661-014-3965-5

van Klink R, Bowler DE, Comay O, Driessen MM, Ernest SKM, Gentile A, Gilbert F, Gongalsky KB, Owen J, Pe'er G, Pe'er I, Resh VH, Rochlin I, Schuch S, Swengel AB, Swengel SR, Valone TJ, Vermeulen R, Wepprich T, Wiedmann JL, Chase JM (2021) InsectChange: a global database of temporal changes in insect and arachnid assemblages. *Ecology,* **102**, e03354. https://doi.org/https://doi.org/10.1002/ecy.3354

van Klink R, Bowler DE, Gongalsky KB, Swengel AB, Gentile A, Chase JM (2020a) Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances. *Science,* **368**, 417-420. https://doi.org/10.1126/science.aax9931

van Klink R, Bowler DE, Gongalsky KB, Swengel AB, Gentile A, Chase JM (2020b) Erratum for the Report "Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances" by R. Van Klink, D. E. Bowler, K. B. Gongalsky, A. B. Swengel, A. Gentile, J. M. Chase. *Science,* **370**, eabf1915. https://doi.org/10.1126/science.abf1915

Wagner DL, Grames EM, Forister ML, Berenbaum MR, Stopak D (2021) Insect decline in the Anthropocene: Death by a thousand cuts. *Proceedings of the National Academy of Sciences,* **118**, e2023989118. https://doi.org/doi:10.1073/pnas.2023989118