Pollinator contribution to crop yield

Authors

James Reilly, Ignasi Bartomeus [1], Alfonso Allen-Perkins, Rachael Winfree, Lucas Garibaldi, …

(1) Estación Biológica de Doñana (EBD-CSIC), Avenida Américo Vespucio 26, E-41092 Sevilla, Spain.

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Abstract

Over 75% percent of the world's food crops are dependent on pollinators to at least some degree (IPBES 2017). However, the precise degree of pollinators contribution to crop yield is uncertain because there is a large variability in crop types, pollinator communities, agricultural practices and environmental contexts. Fortunately, since the first case studies reporting a positive effect of pollinators on crop yield, more and more data has accumulated. This allowed us to conduct synthesis summarizing what we know (e.g. Garibaldi et al 2013, Rader et al. 2016, Dainese et al 2019). However, as the question is data hungry and is still not settled, we aim to embrace this uncertainty and periodically report updates as our knowledge increases. This repository uses CropPol v1.1.1, an open database with 93 studies to regress the abundance of wildbees and honeybees on crop yield. The overall estimate of wild bee abundances is 0.064 and that of honeybees is 0.074. This abstract can be enhanced and needs a final sentence about the dynamic nature of this repository.

How to cite this:

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Or the original paper: TBA

Download in PDF:

https://ibartomeus.github.io/CropPollinationModels/Report_CropPolModels.pdf

Source code:

You can find the source code, as well as previous releases of this repositoty at: https://github.com/ibartomeus/CropPollinationModels

Introduction

Over 75% percent of the world's food crops are dependent on pollinators to at least some degree (IPBES 2017). In most crop systems, pollination is provided through a combination of managed honey bees and wild insects, which consist primarily of wild bees, but also flies and other insects (Larson et al. 2001, Rader et al. 2016). Despite not being managed for crop pollination, wild insects often make up a significant fraction of total flower visits and can even be the dominant pollinators in situations where agricultural intensity and/or land use is not extreme (Kremen et al. 2002, Ricketts et al. 2008, Garibaldi et al. 2011, Kennedy et al. 2013, Koh et al. 2016, Reilly et al. 2020).

There is emerging evidence that wild insect visits may increase crop yields per capita more strongly than honey bees (Winfree et al. 2007, Garibaldi et al. 2013, Mallinger and Gratton 2015, Blitzer et al. 2016), and that honey bees alone can be insufficient for eliminating pollination limitation for many crops (Sáez et al. 2022). The mechanism for this is not well understood but could be due to wild bees depositing higher amounts of pollen per visit (Winfree et al. 2007, Park et al. 2016, Eeraerts et al. 2019), or to differences in the behavior of wild bees and the honey bee (Greenleaf and Kremen 2006, Brittain et al. 2013).

Given the potential for different pollinator groups to have different impacts on crop yields, there is a broader debate about whether it is simply the number of individual pollinator visits that matters for yield, or whether pollinator biodiversity (generally measured as the number of pollinator species) is also important. In fact, this question is part of a major debate in ecology about whether the maintenance of ecosystem services (or functions) requires a diverse community of species, or whether most services result from the additive contributions of a few dominant species (Cardinale 2012, Bommarco et al. 2013). Within the pollination literature, pollinator species richness (i.e., the number of pollinator species present) has been shown to be positively associated with crop productivity (Garibaldi et al. 2015, Garibaldi et al. 2016, Dainese et al. 2019), particularly when pollination needs to be provided across many sites or years (e.g., Klein et al. 2003, Winfree et al. 2018, Lemanski et al 2022, other citations). At the same time, a small number of dominant pollinator species do often provide most of the pollination for any particular crop, although the same species may not be dominant across crops, or even within a crop when space and time are considered (Winfree et al. 2015, Kleijn et al. 2015, Genung et al. 2020, Winfree et al 2018 Science, Genung et al 2022).

Here we use a recently published, global compilation of data on crop yield and flower visitation by wild and managed pollinators that roughly doubles the data available for previous analyses (Allen-Perkins et al. 2022) to answer the following three questions:

1) What are the relative contributions of honey bees versus wild insects to crop visitation worldwide?

2) What are the relative contributions of honey bees versus wild insects to crop yield worldwide?

3) Is the total number of flower visits by pollinators sufficient to predict crop yields, or is the diversity of pollinator species also important?

4) Are the relationships between pollinator visits, richness, and yield stable with the number of studies currently available?

Methods

The CropPol database

Our analysis uses the CropPol database (Allen-Perkins et al. 2022) as is basis. CropPol is an open and dynamic (i.e., periodically updated) database of crop pollination studies. The majority of these datasets provided data on both insect visitation rates and crop yields or related measurements and were used in the analyses conducted for this paper. Within each study, the most basic unit of observation at which pollinator visit counts and the resulting yield can be paired was the site-year ("site" is typically a field or part of a field). Some sites were sampled for multiple years, but single-year sites were also common. In our analyses, we allowed multiple years of data to be part of the same study as long as the collection methods did not change. We only included studies with at least three site-years. As expected, studies from Europe and North America were somewhat overrepresented in our sample, together totaling almost two thirds of the datasets. It is also likely that even within regions there are biases in the landscapes where studies were located and in which crops were selected. This limits our ability to infer patterns on a global scale, but currently represents the best available data.

A strength of the dynamic database is that it will allow continuous updates to our analysis as the number of available studies grows.

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# we can add a map, but I don't want to load more packages if not necesary.
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Data processing

Across the all datasets, the number of pollinators visiting flowers was measured in two different ways: either by observing the number of insects visiting flowers per unit time (a true visit rate), or by netting insects visiting flowers and summing the number of specimens collected. In the context of crop pollination studies, the latter data type is commonly referred to as "net data", and might be more accurately described as visitor abundance on flowers than as a true visit rate. In this analysis, we used the two interchangeably as "number of visits". If both types of measurements were available for a given dataset, preference was given to true visit rates; any potential variation in mean or variance that might result from the different collection methods across studies should be mitigated because we converted all values to z-scores for the analysis. All datasets categorized visit rates or visitor abundances into the following pollinator groups: honey bee, bumble bees, other wild bees, non-bee Hymenoptera, Syrphids, Bombyliids, other flies, beetles, Lepidoptera, and other insects, although not every study recorded every group. For our main analysis, we chose to combine the visits by all pollinators other than the honey bee into a "wild insects" group. Thus we compared two main groups, honey bee (HB) and wild insects (WI), consistent with previous analyses (e.g. Garibaldi et al. 2013). We did not drop studies that found or reported only bees as visitors, on the assumption that researchers for the most part did not neglect sampling insect groups that were important for the pollination of their crop. We did however drop 10 studies that specifically focused on wild insect visitation and did not record honey bee visits at all, because these studies would misattribute to wild insects the yield due to honey bees. We did not need to do a similar filtering step for wild insects because wild insects were recorded in all studies in the final set.

Crop yield is defined as the amount of agricultural production harvested per unit of harvested area. In our datasets, often this was simply kg per unit area, but sometimes was more specific to the crop, e.g., kg per plant, fruit per branch, fruit/seed set, etc. (Table S1). When more than one production variable was provided, we used the variable listed by the data providers as "yield" in the online database as opposed to the alternative "yield2." We did not include any studies that only estimated pollen deposition (visits multiplied by pollen per visit) because this not a direct measurement of the effect of pollinator visitation. As above for insect visitation rates, we performed analyses on z-scores to mitigate differences in scale between metrics.

Statistical analysis

We analyzed the relative importance of the honey bee and wild insect visits to crop yields by using a single model. The full model included the effects of honey bee visits, wild insect visits, and their interaction. All models included both random intercepts and slopes for the predictor variable study. We chose to fit random slopes in addition to random intercepts because it is reasonable to assume that the slope of the relationship between visits and yield could vary across crop studies for any number of reasons that might differ across crops such as degree of pollinator dependence (Klein et al. 2007), bloom phenology, or management practices. In all models, visits by each insect group and the outcome variable (yield) were transformed to z-scores prior to running to model, so the slopes of the fixed effect estimates from the model were interpreted as effect sizes for comparison. Details on alternative models can be found in Reilly et al 2023...

To determine whether crop yields increased in the presence of more wild insect species or whether it was simply the total number of insect visits to flowers that was important, we analyzed a new set of models that contained pollinator species richness in addition to flower visitation rate by honey bees and wild insects... [I will probably show only a single model including both richness and abundance].

Results

1) What are the relative contributions of honey bees versus wild insects to crop visitation worldwide?

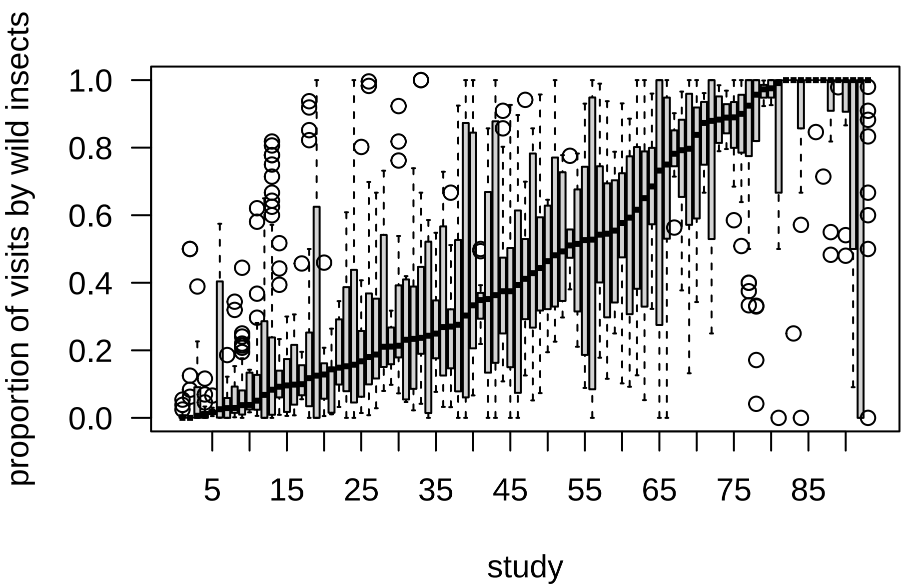
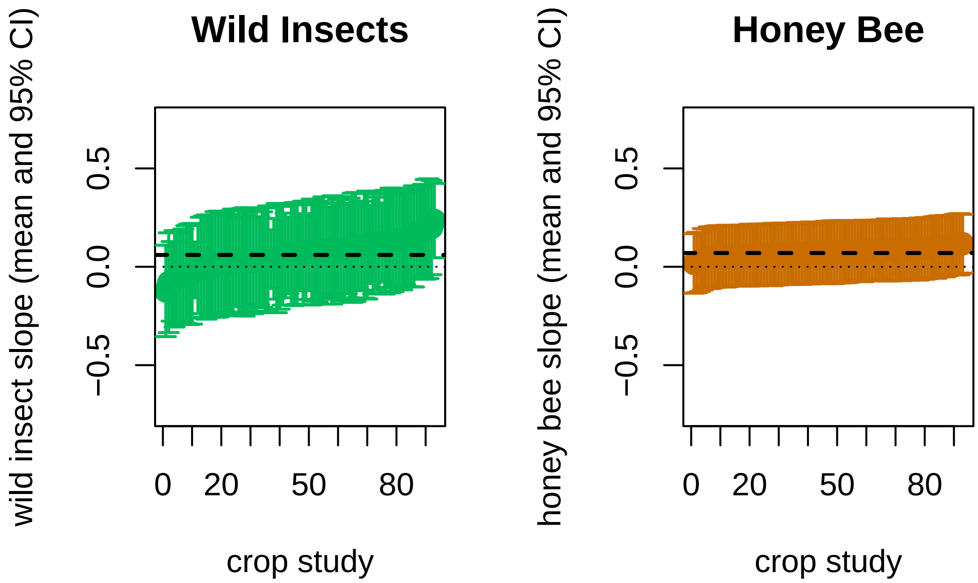


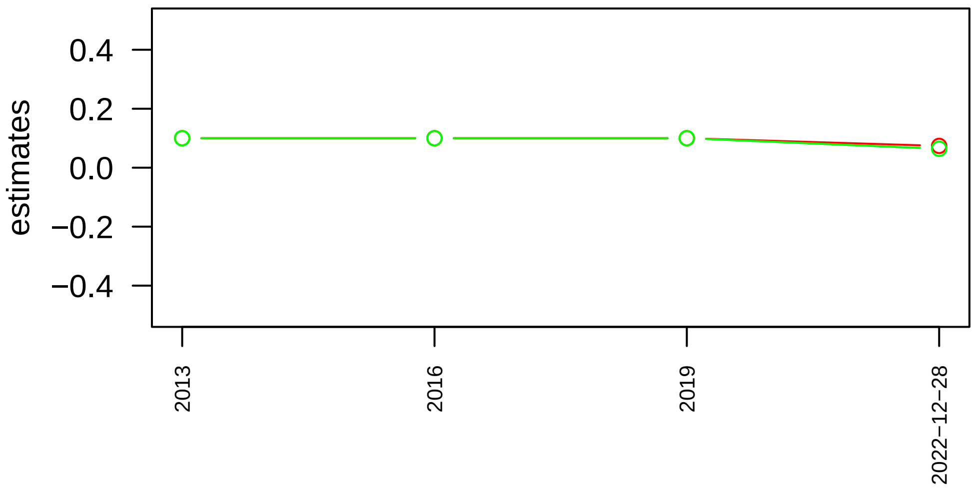
Fig 1: This figure shows...

2) What are the relative contributions of honey bees versus wild insects to crop yield worldwide?



3) Is the total number of flower visits by pollinators sufficient to predict crop yields, or is the diversity of pollinator species also important?

4) How the relationships between pollinator visits, richness, and yield changed with the number of studies available?



What next?

As all models are open, models will be updated regularly and new models can be added into the report. If you want to contribute to the modelling efforts, let us know in an issue or directly make a pull request.

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