Pollinator contribution to crop yield

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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 synthesize 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 v2.1.0, an open database with 93 studies to regress the abundance and richness of wildbees and honeybees on crop yield. Currently, the overall estimate of wild bee abundances is 0.078 and that of honeybees is 0.085. Pollinator richness has an estimate of 0.036. By providing a dynamic assessment of how our knowledge changes as more data is available, we ensure updated answers to key questions in ecology.

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

Source code:

You can find the source code, as well as previous releases of this repository 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) How the relationships between pollinator visits, richness, and yield has changed as the number of studies available grows?

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 over-represented in our sample. 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.

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. 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 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.

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. 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

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 run a model that contains pollinator species richness in addition to flower visitation rate by honey bees and wild insects.

We analyzed the full model that contained pollinator species richness in addition to flower visitation rate by honey bees and wild insects, as well as the interaction between wild insects and honeybees, wild insects and richness and honeybees and richness (Model R18 in Reilly et al. 2023). 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.

Results

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

We observe a large variation in the relative contribution of honey bee visitation rates and other wild insects within and across crops. While some crops are solely visited by wild insects in some areas, others are mainly visited by honeybees.

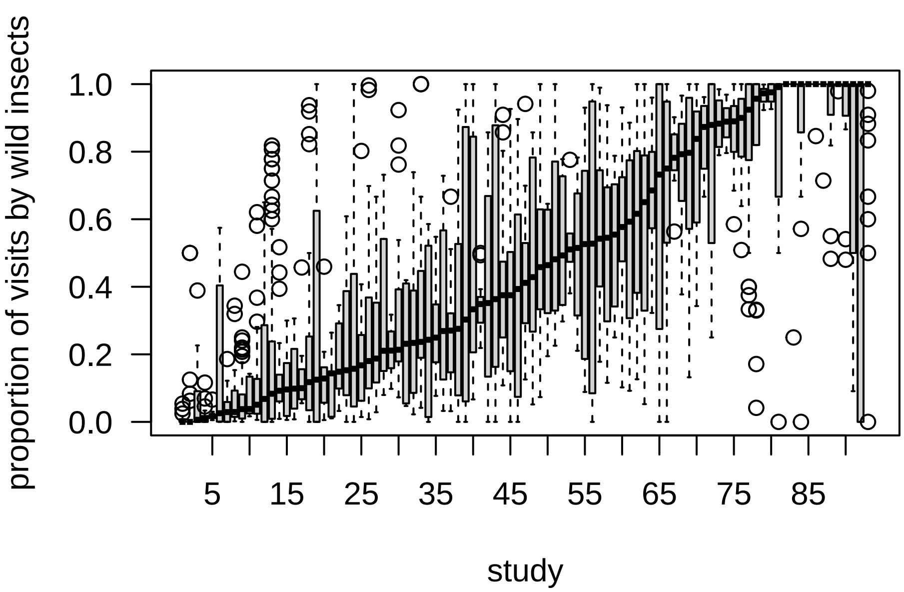

Fig 1: This figure shows the proportion of total visits provided by wild insects (vs. honey bee) for each pollination study. In these boxplots, the bold center line is the median, the hollow boxes cover the interquartile range (IQR), and the whiskers extend to the most extreme points

within 1.5*IQR from the median. If any points are more extreme than this, they are plotted as gray circles.

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

Similarly, we observe a large variation on the effect of pollinator richness, wild and honeybee visitation rates on crop yields, with an overall small, but positive effect size.

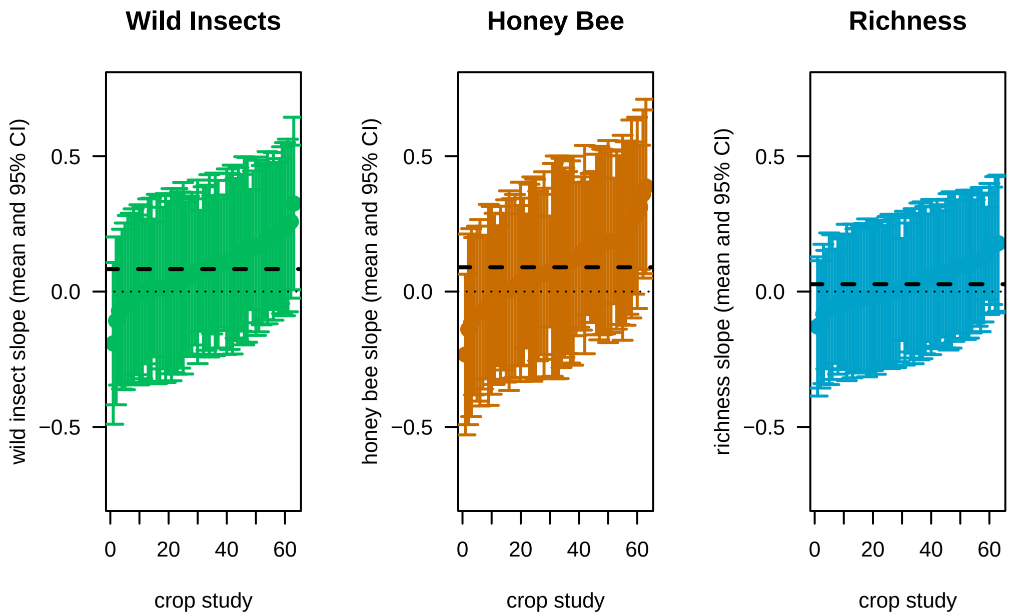

Fig 2: This figure shows the estimated means and 95% CIs for the effect of wild insects, honey bee, and species richness on crop yield for each pollination study. The dashed black line is the overall mean across all studies. Means were calculated using the random effect estimates from the full model.

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

The mean wild insects estimate is 0.083, and the honeybee mean estimate is 0.09. Overall, species richness has a shallower positive effect on yield (pollinator richness estimate is 0.027)

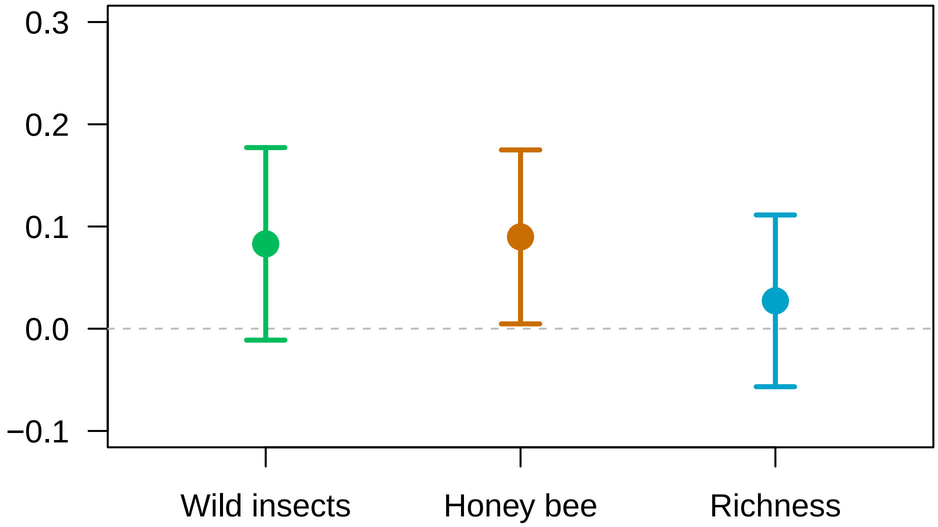

Fig 3: This figure shows the current overall mean estimate (and 95% CIs) for the effect of wild insects, honey bees, and richness on crop yield. Estimates based on the CropPol database are generated using the full model as described in the methods.

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

Since the first synthesis papers, we found that the effect size tend to decrease as more studies are added to the analysis.

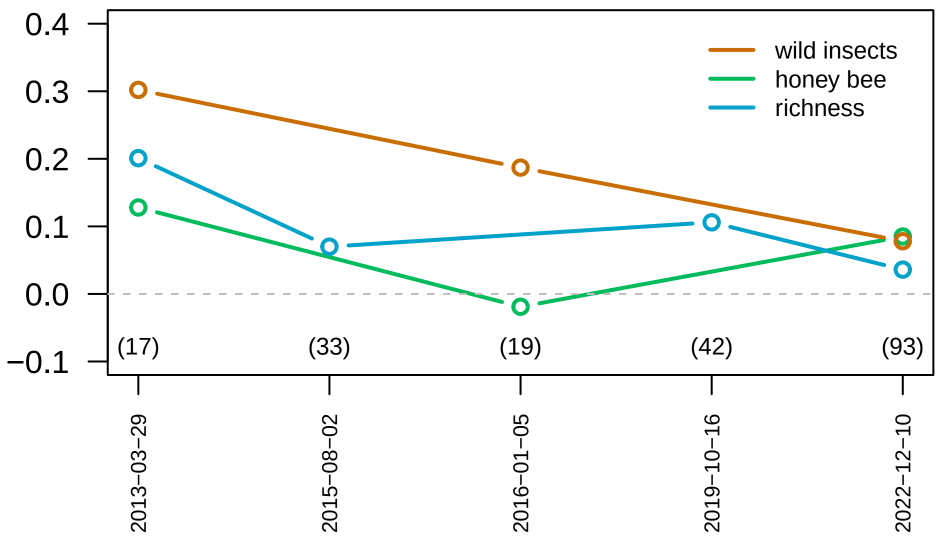

Fig 4: This figure shows the history of the estimated effects of wild insects, honey bees, and richness on crop yield over time. Literature estimates are drawn from Garibaldi et al. 2013, Garibaldi et al. 2015, Rader et al. 2016, and Dainesse et al. 2019. Estimates based on the CropPol database (year > 2022) are generated using the full model as described in methods. Sample size is indicated between brackets below each time period.

What next?

Models will be updated regularly and as all scripts are open, enhanced models or new models answering new questions can be added into the report in the future. 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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