Notes on Methodology

INCORPORATING MEASURES OF DATA QUALITY INTO PLANT-POLLINATOR DATABASES

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Abstract—The development of large databases of plant-pollinator relationships poses both great opportunities and a particular problem for scientists and practitioners interested in these interactions. A major issue is that it is rare for measures of data quality to be included, in the sense of stating the evidence by which animal X has been determined to be a pollinator of plant Y. Adding such information to databases is vital if we are to fully understand the plant-pollinator relationships that they describe and address information gaps. We present some examples of data quality schemas that have been used in the past and then adopted by the Pollinators of Apocynaceae Database and the Database of Pollinator Interactions (DoPI), and how the forthcoming USDA-NRCS PLANTS database has tackled this question. In addition, we discuss the use of controlled vocabularies developed by the Brazilian Network of Plant-Pollinator Interactions (REBIPP), allied to a vocabulary based on the Darwin Core standard. It is our hope that the pollination ecology community will see the importance of these or other evaluations of data quality and adopt them accordingly.

Keywords—Agriculture, bees, flowers, insects, pollination, species interactions

INTRODUCTION

The study of pollinators and their interactions with plants has entered a new phase in which historical and contemporary information is being merged into openly accessible databases that provide an important resource for understanding plant-pollinator interactions and how they may change in the future due to human influences. The earliest online, open access database of plant-pollinator interactions, as far as we are aware, dates to 1995 (see Ollerton 2025a) but since then the diversity and size of such databases has increased dramatically. Examples include:

- Rede Brasileira de Interações Planta-Polinizador (the Brazilian Network on Plant-Pollinator Interactions – Salim et al. 2022a; REBIPP 2024)
- Database of Pollinator Interactions for Britain (Balfour et al. 2022; DoPI 2024)
- Global Biotic Interactions, an open source/open service/open data facility that covers all types of ecological interactions (GLOBI 2024; Poelen et al. 2014)
- Interaction Web Database that likewise covers more than just pollinators and plants (Vázquez et al. 2003; IWDB 2023)
- Mangal which is also focused on more than simply plant-pollinator interactions (Vissault et al. 2020)

- CropPol which is a global database focused on crop pollination (Allen-Perkins et al. 2021)
- Web of Life which provides access to different types of ecological interaction networks, including pollination networks (Fortuna et al. 2014)
- EuPPollNet: A European Database of Plant-Pollinator Networks (Lanuza et al. 2025)

In addition, the Global Biodiversity Information Facility (GBIF) has been publishing species occurrence data for decades, and many datasets include biotic interactions (Salim et al. 2022b). Historically, however, GBIF has not prioritized the interpretation and indexing of biotic interactions. This is not due to a lack of data or properly standardized ways of documenting such data. In fact, there have been recent efforts to address this issue (Salim et al. 2022a), including the reformulation of the GBIF data model in order to capture more representative biodiversity data, for example biotic interactions such as plant-pollinator and flower visitation (GBIF 2024).

There is some overlap between these (and other) databases in terms of the species that are included and the source(s) of the information about those species. They also vary in their approach to a fundamental question in pollination ecology: are the observed visitors to flowers confirmed pollinators?

POLLINATORS VERSUS FLOWER VISITORS

Distinguishing between flower visitors and actual pollinators of a given plant is critical because the range of pollen vectors in a community is typically a subset of the diversity of floral interactors. To demonstrate this, consider the example presented by Ollerton (2021, pp.59-64), using a data set of more than 50 species of insects visiting the flowers of nine species of asclepiad (Apocynaceae subfamily Asclepiadoideae) in South Africa (Ollerton et al. 2003). Removing the non-pollinators from the data set resulted in a list of effective pollinators containing fewer than 25% of the insect visitors. This is likely to be a conservatively low number, and an equivalent analysis for plants with highly generalised pollination systems such as many Apiaceae probably, Asteraceae or Caprifoliaceae would likely result in a much higher ratio of flower visitors to pollinators (see Ollerton et al. 2024 for instance). Nevertheless, it demonstrates the point that flower visitation, though an important interaction from the visitor's perspective, providing food, shelter or other resources, is not synonymous with pollination.

With this in mind, we turn to a recent development in plant-pollinator databases that is trying to address these concerns.

THE 'PLANTS' DATABASE

The United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) national plant data team is currently compiling a database of plant-pollinator interactions within PLANTS (Plant List of Attributes, Names, Taxonomy, and Symbols; https://plants.usda.gov) as a resource for conservationists and planners in the implementation of U.S. Farm Bill conservation programs (Agriculture Improvement Act of 2018, Public Law 115-334 (2018)). The PLANTS website is one of the most widely utilized U.S. websites and the leading source of standardized taxonomic floristic information for U.S. federal agencies, universities, and the public. The compilation of plant-pollinator interaction data in PLANTS addresses the departmental wide need to provide a centralized framework and access to current and historic plant and pollinator distribution records to inform the development of suitable habitat for pollinators and ongoing research including how climate change is impacting plants and the pollinators that depend on them. Given the importance of pollinators to U.S. agricultural production and ecosystem services, it is hoped to include as much information as possible about the effectiveness of different pollinators for particular plant species. However, there are two main hurdles to overcome.

The first hurdle is a lack of data. It is estimated that the pollination ecology of no more than 10% of the world's flowering plants has been studied in any sort of detail (Ollerton 2021, 2024). Of these, perhaps 10% have been researched in enough depth to be able to state that animal X is an effective pollinator of species Y. The second issue is defining exactly what it means to be an effective pollinator.

THE ‘COX-KNOX POSTULATES’

Simply observing an animal visiting a flower is not sufficient to conclude that this animal is a pollinator, i.e., has deposited pollen in adequate amounts and of sufficient quality to start the process that results in the production of seeds. The procedure for deciding if an animal is an effective pollen vector of a given plant was formalised by Cox & Knox (1988) and is referred to as the ‘Cox–Knox postulates’, in an analogy to ‘Koch’s postulates’ in medicine. According to Cox & Knox (1988), in order to determine whether an animal is a pollinator, the following requirements must be met:

- The animal picks up pollen on its body
- The animal transports that pollen to another flower
- There is a transfer of pollen from the animal to the stigma
- This deposited pollen results in the production of one or more seeds

Ideally, these observations should take place in the field rather than in a laboratory, glasshouse, or garden. However, these requirements depict pollination as a dynamic process composed of multiple inter-related events (Gómez et al. 2023), as opposed to a single flower visitation event, and subsequently, imposes challenges for inferring pollination from what is observed in the field (i.e. snapshots of the whole process as discrete events).

When it comes to the interactions between flower visitors and flowers, we can consider pollinator effectiveness to be made up of two components, that are a referred to as the ‘quantity’ and ‘quality’ aspects of the interactions (Herrera 1987, 1989). Quantity refers to the number of visits made by a particular type of flower visitor. This reflects the local population size of that animal and the choices it makes in relation to preferences for nectar, pollen, flower type, and so on. Quality is how much pollen is deposited on a stigma after a flower visit. Multiplying these two components gives us a measure of pollinator effectiveness, showing that rare flower visitors that deposit a lot of pollen per visit can be considered just as effective as common visitors that deposit very little.

None of the above needs to be technically demanding but assessing the role of insects and vertebrates as pollinators is time-consuming, and is likely to be possible for only a fraction of the 352,000 or so flowering plants. It’s also difficult to attract funding and interest, unless the plant is especially rare or charismatic. The result of such basic pollination studies, however, is a data set that is detailed, rigorous and important from the point of view of understanding the pollination requirements of a particular plant. Unfortunately, unless it is especially novel, such findings are highly unlikely to be published in high-impact, international journals where ‘big picture’ research is prioritized. For these reasons we suspect that graduate students and postdoctoral researchers are often dissuaded by their supervisors from carrying out this kind of research, even though basic information of this nature is fundamental to the large databases underlying our ‘big picture’ ecological worldview.

MEASURES OF DATA QUALITY

An approach that has been adopted by some large databases is to be upfront about the uncertainties associated with the flower visitors/pollinators of plant species and assign alpha-numerical codes that reflect the certainty of effective pollination for each interaction, from no information to strong evidence of pollination. In Table 1 we demonstrate how this approach, pioneered by Adams & Lawson (1993), has subsequently been developed by other workers.

One consequence of this classification is that it reveals the paucity of data that confirms effective pollinators of flowers. As an example, consider the Pollinators of Apocynaceae Database (PoAD), currently one of the largest compilations devoted to a single flowering plant family (Ollerton et al. 2019). PoAD includes data for over 12% of the more than 5,350 species within the dogbane and milkweed family (Apocynaceae). Of the 4,325 plant-flower visitor interactions in PoAD that can definitively be assigned to Code 1, 2, 3, or 4 in Table 1, just 9% are Code 1 (identity of the pollinator proven) while 4% are Code 4 (i.e. definitely *not* a pollinator). The remaining interactions comprise just over 41% Code 2 (identity of the pollinator inferred from pollen on their bodies) and almost 46% Code 3 (identity of the pollinator inferred from circumstantial evidence, such as legitimate flower visits).

This is quite typical: most published data on flowers and 'pollinators' have not actually assessed pollination at all, it has been inferred from other evidence. This is a significant research gap in the field of pollination ecology and it limits, for example, some of the conclusions that can be drawn from studies of 'plant-pollinator' networks (King et al. 2013). Indeed, the Apocynaceae is arguably better represented at Code 2 than other plant families as most species in the family disperse their pollen as coherent masses (pollinia) that attach to the flower visitor, making inference of their pollinating role more straightforward. The only other family that does this is the orchids (Orchidaceae) which, with an estimated 28,000 species, is an order of magnitude more diverse than the Apocynaceae. In those taxa that disperse their pollen as more-or-less free grains or tetrads, the use of traditional microscopy and, increasingly, e-DNA approaches can also be effective at categorising flower visitors into Code 2.

Another approach that can be adopted is to focus on the flowers and to categorise them into broad pollination systems based on an understanding of flower phenotype, e.g. colour, shape, size, rewards, and odour, together with knowledge of the flower visitors. An example of this is presented in Ollerton (2021, pp.91-92). Observations of the African rainforest climber *Dictyophleba lucida* (Apocynaceae) revealed that its white flowers begin to open as night falls. At the same time it produces nectar and a strong, sweet odour that attracts hawkmoths which were observed to visit the flowers. Although experiments to demonstrate pollinator effectiveness were not carried out, we can be fairly confident that this plant falls into the 'moth pollination system' category. Note that this approach is distinct from that of just using the information about the flowers themselves, i.e., the 'pollination syndrome', though these two terms (syndrome/system) are sometimes used synonymously.

CONTROLLED VOCABULARIES

An ongoing question is how to incorporate evidence of pollination data quality into controlled vocabularies that are usable in plant-pollinator databases such as that of USDA PLANTS. As part of the Agricultural Biodiversity Case Study (Work Package 10) within the WorldFAIR project (Drucker 2024a,b), the authors held a series of online meetings to discuss this issue. The Darwin Core (DwC) standard (Wieczorek et al. 2012) term which typifies the recording of biotic interactions such as animal pollination is dwc:eventType (see: http://rs.tdwg.org/dwc/terms/eventType). The term dwc:eventType was added to the DwC standard in June 2023, and it is not yet fully adopted by data providers. In addition, although controlled vocabularies for this domain exist, such as those provided by iNaturalist, Arctos and Field Museum, and the Open Biological and Biomedical Ontologies (OBO), they are not consistently used by researchers.

Members of the Brazilian Network of Plant-Pollinator Interactions (REBIPP) have developed a data model allied to a vocabulary based on the Darwin Core standard (Salim et al. 2022a; see https://ppi.rebipp.org.br/terms/). Terms related to pollinator effectiveness are presented in Appendix 1. Additionally, the terms dwc:individualCount, dwc:organismQuantity and dwc:organism QuantityType from the DwC standard can be used to document flower visitation frequencies. This represents a standardised way of incorporating information about pollinator effectiveness into databases and is adherent to the FAIR principles for data (Findable, Accessible, Interoperable and Reusable - Wilkinson et al. 2016), and specifically to the sub-principle 'I2. (meta)data use vocabularies that follow FAIR principles'. Considering semantic interoperability, the more commonly used this vocabulary is, the more humans and machines will interpret relevant terms in a coherent way, facilitating data interpretation and improving communication. The Agricultural Biodiversity Case Study of the WorldFAIR project (Trekels et al. 2023; Drucker 2024a,b) worked with diverse groups as pilot projects that tested the data model and or the PPI vocabulary proposed by Salim et al. (2022) and developed a 'cookbook' to guide users interested in how to use them based on the lessons learned by pilots (Salim et al. in prep).

Table 1: The development and use of coding systems to indicate the effectiveness as pollinators of flower visitors in large databases. Rather than using codes, the USDA-NRCS PLANTS database uses 'Observed Pollinator Effectiveness' categories. Their position in the table broadly reflects how they map against the codes in the first column – see 'Notes' below the table.

Code	Adams & Lawson (1993)	Ollerton & Liede (1997) & ASCLEPOL	Ollerton et al. (2019) & Pollinators of Apocynaceae Database	Balfour et al. (2022) & Database of Pollinator Interactions (DoPI)	USDA-NRCS PLANTS database
0	Not Tracked-	Not Tracked	The plant is an obligate selfer	Not Tracked	Tracked by self-incompatibility category
1	'Confirmed' pollinator. The minimum criteria for pollinator status include observation of uptake of pollinia from the anther by the vector, travel to a flower of the same species with deposition of the pollinia on the stigma	Identity of the pollinator proven. Insects with pollinia attached observed to bring about insertion of these pollinia into the guide rails of a flower of the same species, under natural conditions	Identity of the pollinator proven – visitors with pollinia/pollen attached and observed to bring about pollination of a flower under natural conditions	Pollination confirmed, visitors with pollen attached and observed to produce pollination of a flower (e.g., transferring pollen to stigmas and/or leading to seed set)	'Confirmed to be pollinated by' - the flower visitor was observed transferring pollen grains onto the stigma of a plant, or the pollinator visit was followed to document successful seed set.
2	'Probable' pollinator. One or more of the minimum criteria are not met. In most reports of probable pollinators, pollinia are taken up on a number of occasions… but further visiting of flowers is not reported, or visits occur without later deposition of pollinia on a stigma	Identity of the pollinator inferred. Insects observed with pollinia attached, under natural conditions	Identity of the pollinator inferred – visitors observed with pollinia/pollen attached, under natural conditions	Pollination inferred, visitors observed with pollen attached (but not confirmed to transfer pollen to stigmas)	'Inferred to be pollinated by' - the outcome of pollen transfer or seed set is not clearly determined. The flower visitors were observed touching the reproductive parts of flowers, but not transferring pollen and where pollen was collected on their bodies but not observed to be transferred to plant reproductive parts.
3(2)	Not Tracked	Not Tracked	The code '3(2)' indicates that although the data do not quite reach the standards of evidence required to assign them to code 2, additional evidence (e.g. details of floral phenotype) strongly supports the case for the visitors being pollinators	Not Tracked	Categories 2 & 3 are combined into inferred pollinator

Table 1 continued

Code	Adams & Lawson (1993)	Ollerton & Liede (1997) & ASCLEPOL	Ollerton et al. (2019) & Pollinators of Apocynaceae Database	Balfour et al. (2022) & Database of Pollinator Interactions (DoPI)	USDA-NRCS PLANTS database
3	'Suggested' pollinator. Little evidence is provided in the report to support the pollinator role. Most reports of this type describe visitation to flowers or presence of insects on inflorescences or floral parts, with or without pollen from an unidentified source. Suggested pollinator status is also used for reports which state that 'pollination was observed' but provide no details	Identity of the pollinator inferred from circumstantial evidence. Insects observed to visit flowers, but not to pick up pollinia, under natural conditions	Identity of the pollinator inferred from circumstantial evidence, e.g., visitors observed on flowers, but evidence of picking up pollinia/pollen is missing, under natural conditions	Pollination inferred from circumstantial evidence (e.g., visitors observed on flowers, but evidence of picking up pollen is missing)	Categories 2 & 3 are combined into inferred pollinator
4	Not Tracked	Not Tracked	The flower visitor is a nectar or pollen thief, a herbivore, a predator, or a parasite of insects in the flowers	No pollination, the flower-visitor is a nectar or pollen robber, a herbivore, a predator, or a parasite of insects in the flowers	'Non-pollinator' - flower visitors are not associated with the transfer of pollen between plant species and do not affect pollination. Their body size and/or shape and interactions do not lead to pollen transfer (e.g. nectar robbers, small beetles eating pollen but not reaching the stigma)
-	No similar category	No similar category (though completeness of the sampling in relation to the size of the family noted in the text of the paper)	No similar category (though completeness of the sampling in relation to the size of the family noted in the text of the paper)	No similar category	'Not assessed' - pollination was neither inferred nor assessed
A	Not Tracked	Not Tracked	Where pollination or visitation was observed outside of the plant's natural range, the letter A was appended to the number code (e.g. 2A)	Not Tracked	Native status of the plant according to the PLANTS database distribution information

Table 1 continued

Code	Adams & Lawson (1993)	Ollerton & Liede (1997) & ASCLEPOL	Ollerton et al. (2019) & Pollinators of Apocynaceae Database	Balfour et al. (2022) & Database of Pollinator Interactions (DoPI)	USDA-NRCS PLANTS database
B	Not Tracked	Where pollination had been observed under non-natural conditions, e.g. plants and/or pollinators outside of their natural range, this was noted and a coding 'B' appended to the record	Where pollination or visitation was observed outside of the animal's natural range, the letter B was appended to the number code (e.g. 2B)	Not Tracked	Native status of the pollinator according to ITIS and NatureServe distribution information

Notes: The text is copied verbatim from the original sources. Deleted text (…) in Adams & Lawson relates to their criteria that the insect and the plant should be accurately identified, which is taken for granted in the remaining studies. Adams & Lawson (1993) focused just on orchids (Orchidaceae) whilst Ollerton & Liede (1997) dealt with asclepiads (the former family Asclepiadaceae, now subsumed into Apocynaceae). Both of these groups present pollen as more-or-less coherent masses, hence the use of the term 'pollinia'. Alpha numerical codes will not be utilized in the USDA NRCS PLANTS database to denote observed pollinator effectiveness, instead, four categories will be utilized: Confirmed to be pollinated by; Inferred to be pollinated by (combining Code 2 and Code 3 into one category); Non-pollinator; Not assessed.

Final comments

At the present time, recent estimates suggest that we have data on the pollinators of no more than 10% of the estimated 352,000 flowering plant species (Ollerton 2021, 2024). The data that we do have is of variable quality, as the Apocynaceae example above demonstrates. As our knowledge and understanding of the relationships between plants and pollinators grows, and datasets become increasingly FAIR, it is ever-more important to standardize the associated vocabulary. Projects such as the Agricultural Biodiversity Case Study within WorldFAIR were just the beginning of this process and we anticipate that future work will result in a more coherent set of guidelines for researchers. At the same time, as well as being FAIR, it is vital that we approach the construction of plant-pollinator interaction databases with an open and honest (FAIROH?) assessment of the limitations of data quality. This not only gives us a firmer basis for understanding and conserving plant-pollinator interactions, it will also highlight their importance for agriculture and for sustaining the natural world. National and regional funding programmes are a vital part of this. For example, the European Union's Pollinators Initiative is the basis for a recent series of projects examining pollination ecology, pollinator conservation, and crop production across the continent. The most recent of these – project 'Butterfly' – includes a work package that aims to use GLoBI to integrate DoPI, CropPoll, EuPPollNet and other data sources into an online European Atlas of Plant-Pollinator Associations called EuroAPPA (see Ollerton 2025b). At this stage the intention is to adopt the DoPI approach to assessing data quality, as outlined in Table 1. Ultimately, it does not matter which approach to incorporating measures of data quality into plant-pollinator databases is used by researchers, as long as the method is made transparent to allow comparisons as our knowledge on pollination ecology grows.

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Author contribution

All authors contributed equally to the conception and writing of this paper.

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No potential conflict of interest was reported by the authors. Author Jeff Ollerton is an Associate Editor of the Journal of Pollination Ecology. Thus, the peer-review process for this article was handled independently by another member of the editorial board.

Data availability statement

Data used to write this article are available from the original published sources, as cited.

Appendices

Additional supporting information may be found in the online version of this article:

Appendix 1: Plant-pollinator vocabulary relevant to the quality of observations in large databases.

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