Bee Pollination of Crops: A Natural and Cost-Free Ecological Service

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1 Today's Knowledge About Pollination: Still at a Starting Point?

The principal appreciation of pollination as a key factor for stable and sustainable agricultural crop production, wild plant diversity maintenance, habitat stability and restoration, and thus one of the most important contributions to human life and world economics, is without any doubt higher today and fortunately reached the public awareness, especially if compared to times of Christian Konrad Sprengel (°22 September 1750 – †7 April 1816) the founder of flower-ecology (Sprengel 1793). During his lifetime, he invested a lot of effort into educational work explaining the principles of pollination and raising people's awareness of the importance of pollination. But no one really could appreciate his outstanding work and knowledge at that time. Today, while understanding more and more about the critical role of pollination and pollinators, especially bees, aspects of pollinator declines and landscape changes are shifting increasingly into focus. The public and scientists have realized that the naturally cost-free pollination services like they were available a century ago and not a topic of concern, must today be compensated by providing cost-intensive pollination services in many cases.

At present, there is a long list of publications about pollination research and extension services available worldwide, however it is obvious that many gaps still

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exist in our knowledge on this topic. Thus, it is worthwhile to raise and try to answer the critical questions still open in this field. For example, information about the pollination requirements, insect pollinators and necessary pollinator densities for most crops is still extremely limited in order to provide scientifically proven recommendations for practical use (Allsopp et al. 2008; Delaplane and Mayer 2000; Garratt et al. 2016; Henselek et al. 2018; Schulp et al. 2014). Furthermore, the existing basic scientific findings must finally reach application in agricultural practice, practical solutions and recommendations for the farmers. Most existing recommendations concerning pollination for many crops used in extension service might have some scientific basis, but are mainly deduced only from practical experiences and can be influenced by contrasting interests. In order to highlight this fact one example should help: someone who provides pollination services with his honeybee colonies will appreciate a higher pollinator density (number of bee colonies per hectare) in the field, compared to the farmer who has to pay for this service. However, it will get more complex if someone interferes and asks for a balance and solid pollination services, thus, will hinder “over-pollination”. This illustration might get more complex when an alternative and more attractive crop for the honeybees will bloom nearby during the same time, when the honeybees should fill their duty as pollinators in the target crop the beekeeper/owner has paid for.

Here we will not rewrite and thus duplicate the state of the art details in the field of pollination by bees as many authoritative papers and books are available. For further reading we recommend, for example, the following publications: Free (1993): Insect Pollination of crops; Delaplane and Mayer (2000): Crop pollination by Bees; James and Pitts-Singer (2008): Bee Pollination in Agricultural Ecosystems and Abrol (2012): Pollination Biology – Biodiversity Conservation and Agricultural Production.

On the contrary, we would like to highlight here in this chapter the widespread concerns about pollinator declines and thus the potential loss of pollination services.

2 The Growing Knowledge About the General Importance of Pollinators Is Followed by the Concerns About Pollinator Declines

Today there is no doubt about the general importance of honeybees as providers of pollination (e.g. Gallai et al. 2009; Klatt et al. 2014; Klein et al. 2007; Kremen et al. 2007; Lautenbach et al. 2012; Potts et al. 2016). However, the value of wild pollinators (especially solitary bees and bumblebees) might have been significantly underestimated until now, since the focus was mainly on honeybees. Garibaldi et al. (2013) have shown for many crop systems worldwide that flower visitation by wild insects increases fruit sets significantly and that wild bees (solitary bees and bumblebees) pollinate some crops more efficiently compared to the most common investigated honeybees (Fig. 1). Based on their results, the authors suggested that new practices for integrated management of both honeybees and diverse wild insect assemblages will enhance global crop yields. Recent publications showed that in some cases wild bees (bumblebees and solitary bees) can be more effective than honeybees and significantly improve the fruit set while they apparently change the honeybee flight behaviour and thus boost cross-pollination (Brittain et al. 2013;

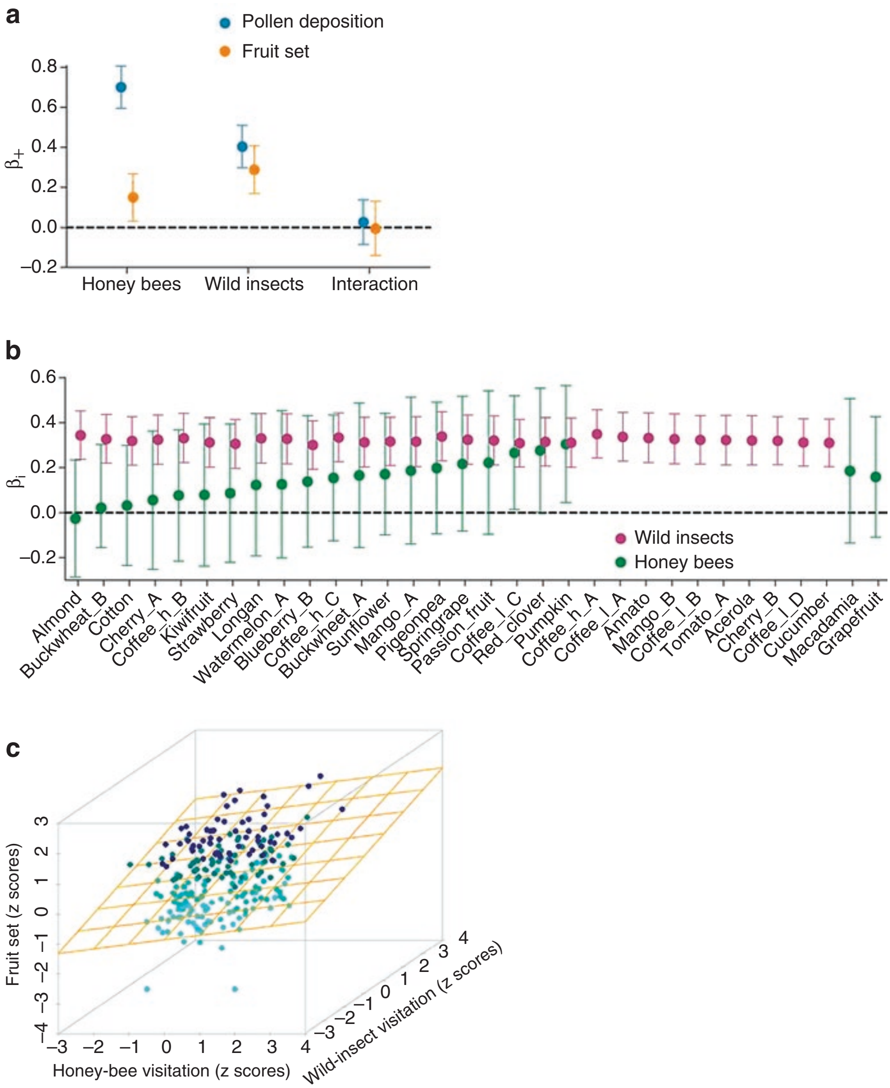

Fig. 1 The visitation of crop flowers by wild bees increases the fruit set in all examined crops (regression coefficient $\beta_i > 0$), whereas honey bee visitation has weaker influence. From Garibaldi et al. (2013)

Garratt et al. 2016; Martins et al. 2015). In orchards with non-*Apis* bees (blue orchard bees, *Osmia lignaria*), the foraging behavior of honeybees changed and the pollination effectiveness of a single honeybee visit was greater than in orchards where non-*Apis* bees were absent, because honeybees switch between planted tree rows due to the presence of the orchard bees. This change led to a greater proportion of fruit set in these orchards (Brittain et al. 2013). Therefore, species interactions can alter the behavior of insects and as a consequence increase the functional quality of the dominant pollinator species, here the honeybees. Garratt et al. (2016) have shown that the proportion of pollination service for apple trees in the UK provided by wild bees (bumblebees and solitary bees) varied from 70–77% while honeybees constantly contributed between 23–28% of pollination services. They also found that the presence of solitary bees in the studied orchards was the most constant and they never totally disappeared while the presence of honeybees and bumblebees depended on the variety of apples and location of the orchard. Therefore the importance of solitary bees as the most reliable pollinator service provider in apple orchards should be highlighted. Moreover, it is known that behavioural differences between honeybees, bumblebees and solitary bees can alter the likelihood of pollen transfer from their bodies to the plant stigma and thus curranty better pollination service. Bumblebees and solitary bees tend to have greater rates of stigmal contact compared to honeybees (Woodcock et al. 2013).

There has been a significant decline in the species richness and abundance of pollinators in recent years in the whole world. The decline is attributed to land-use change and intensification, habitat loss (Fig. 2), habitat fragmentation, increased field size, climate change, pesticide application, introduced alien species, the spread of pests and pathogens, disease switchover and other environmental changes that threaten the biodiversity of insect pollinators and the plants they collect food from. Changes in agricultural practices, the shift to more intensive agriculture, especially since the 1950s, has led to a sharp decline in the area of wildflower-rich habitats, such as hay meadows and pastures where insects can usually find shelter, overwintering and nesting sites, nesting material and food resources, which are all the requisites they need. Decrease in diverse floral resources has led to the decrease in the

Fig. 2 The decline of the brown-banded carder bee *Bombus humilis* Illiger is closely linked to the agricultural intensification and loss of field margins. Today, this bumblebee species is endangered in whole Europe. (Photo: Peeter Veromann)

diversity of wild pollinators. Globally, the reproduction of the majority of flowering plant species (90%) is dependent on animal pollination (Ollerton et al. 2011). Therefore, much concern is about the decline in pollinators, which is followed by the decline in insect-pollinated plants and *vice versa* (Biesmeijer et al. 2006; Garibaldi et al. 2011; González-Varo et al. 2013, Ouvrard and Jacquemart 2018). Today it is also accepted knowledge, that the interactions between insects and plants are highly complex and therefore it is a challenge to predict how these interactions can be affected by changes in pollinator species composition. Moreover, a recent publication suggests that ongoing pollinator declines may have more serious negative implications for plant communities than it is currently assumed. Brosia and Briggs (2014) showed that the loss of a single pollinator species within a pollinator network/community reduces floral fidelity in the remaining pollinators, with significant implications for ecosystem functioning in terms of reduced plant reproduction, even when potentially effective pollinators remained in the system. These findings are based on manipulative field experiments in which a single pollinator species was temporarily removed from study plots in subalpine meadows.

Wild bees have been shown to be efficient crop pollinators around the world and the economic value of this ecosystem service provided is equal with that provided by managed honey bees (Kleijn et al. 2015; Winfree et al. 2007; Potts et al. 2016). Increasing trend to grow mass-flowering crops (e.g. oilseed rape, sunflower etc.) has a positive effect on pollinator densities (Holzschuh et al. 2013; Riedinger et al. 2015) but the effect on different pollinator guilds is unclear. There is evidence that blooming oilseed rape fields promote the abundance of solitary bees (Riedinger et al. 2015) but have an inconsistent impact on bumblebees. However, the growing of mass-flowering cultures is favoring only a small minority of common bee species that prevail in cultural fields and provide most of the crop pollination services (80% of pollination services are provided only by 2% of the wild bee species; see list of dominant bee crop pollinators in the Table 1) (Kleijn et al. 2015). Thus, the methods implemented for conservation of abundant and common wild bee species do not support the biodiversity conservation measure and non-abundant or rare species. What is more, the oligolectic species are still under continuous threat (Fig. 3). In addition, Holzschuh et al. (2016) have raised an important question of whether the increased pollinator densities in mass-flowering crops are caused by their population size increase or if they are simply attracted to huge food resources. So, they found that mass-flowering crops dilute pollinators' abundance because they found a consistent negative correlation between the growth area of mass-flowering crops and pollinator densities in mass-flowering fields across the Europe. Thus, it means that despite of the rapid increase of mass-flowering crops across the Europe, the size of wild pollinator population will not win from this land-use change in general.

Changes in land-use intensity and agricultural practices have also resulted in greater habitat fragmentation, i.e. the spatial detachment of habitat patches which causes reduced and isolated populations that are at an increased risk of inbreeding. Spatial separation affects wild bees on different scales: (i) at large scale (up to hundreds of kilometers), it reduces connectivity of nest sites, isolates bee populations and thus reduces gene-transfer between different populations; and (ii) at small scale,

Table 1 The dominant bee crop pollinators in Europe according to Kleijn et al. (2015). Listed are all species whose abundance formed at least 5% of all specimens of wild bees on crop flowers at least one study

Species	Species	Species
Andrena carantonica	*Bombus hortorum*	*Hylaeus punctulatissimus*
Andrena chrysosceles	*Bombus lapidarius*	*Hylaeus taeniolatus*
Andrena cineraria	*Bombus pascuorum*	*Lasioglossum malachurum*
Andrena decipiens	*Bombus pratorum*	*Lasioglossum pauxillum*
Andrena distinguenda	*Bombus subterraneus*	*Lasioglossum politum*
Andrena dorsata	*Bombus terrestris/lucorum*	*Lasioglossum subhirtum*
Andrena flavipes	*Ceratina cucurbitina*	*Lasioglossum xanthopus*
Andrena haemorrhoa	*Ceratina mandibularis*	*Melitta leporine*
Andrena helvola	*Eucera clypeata*	*Nomada lathburiana*
Andrena labialis	*Halictus resurgens*	*Osmia bicolor*
Andrena lagopus	*Halictus rubicundus*	*Rhophitoides canus*
Andrena nigroaenea	*Halictus scabiosae*	
Andrena nitida	*Halictus simplex*	
Andrena ovatula	*Halictus tetrazonianellus*	
Andrena subopaca		
Anthidium septemspinosum		

Fig. 3 An oligolectic solitary bee *Adrena hattorfiana* (Fabricius) feeding its young on pollen of *Knautia arvensis*. This solitary bee species is threatened in several European countries because of loss of habitats and food plants. (Photo: Peeter Veromann)

at the local habitat patches, it reduces connectivity between foraging and nesting sites that influences food seeking success. Looking at natural habitats it is obvious that the isolated populations are threatened, since the species decline of wild bees will reduce the wild plant diversity very fast followed by instability of the ecosystem itself and its potential for restoration (Potts et al. 2010). However, the impact of fragmentation can differ depending on the habitat preferences of bees. For instance, Williams et al. (2010) have shown that bees nesting below ground are less sensitive to disturbance factors and less influenced by small scale fragmentation than bees that nest above ground. At the same time, the density of bees nesting above ground can be higher in smaller habitat patches (Hinners et al. 2012).

Fragmented landscapes can be redesigned keeping the needs of different pollinators in mind. There are different reasonable measures to connect isolated habitats, for instance, in addition to being food resources, flowering strips inside the fields or in field edges can work as connecting corridors between habitats. For example, pollinator-specific wild flower seed mixes have clearly proven to contribute to wild bees' diversity and abundance (Carvell et al. 2006; Grab et al. 2018; Redpath-Downing et al. 2013; Rundlöf et al. 2018). Woody linear landscape elements like hedgerows, ditches with coppice, lanes with trees etc. can also act as the connecting corridors to reduce isolation between the nesting habitats of wild bees. The importance of hedgerows as a long term set-aside for native bees has been highlighted by several authors e.g. Morandin and Kremen (2013) and Williams et al. (2015), however, this kind of manipulation with agricultural landscape element requires significant input to establish.

The first public and political steps to acknowledge the importance of pollinators and their interactions with plants and to raise awareness were undertaken within the Convention on Biological Diversity (CBD) on the 5th Conference of Parties (in 2000) with the "Sao Paulo Declaration on Pollinators" (International Pollinator Initiative 1999). An action plan (decision VI/5) was developed, and the International Pollinator Initiative was formed under the leadership of the Food and Agriculture Organization (FAO). However, somehow it was unsurprising that someone once asked the principle question: "*Buzziness as usual? Questioning the global pollination crisis*" as Jaboury Ghazoul did in 2005 with a provocative topic concerning the uncertainty about the dynamics of pollinator populations (Ghazoul 2005). Unfortunately, until now there is no adequate answer available concerning this critical question and it will be difficult to answer this in principle, since long-term investigations in this field are lacking totally.

In 2011, key unanswered questions for future research in the field on the greatest knowledge gaps that need to be addressed were postulated by Mayer et al. (2011) in order to inspire new ideas in research on pollination ecology and pollination-related topics. These topics ranged from (1) plant sexual reproduction, (2) pollen and stigma biology, (3) abiotic pollination, (4) evolution of animal-mediated pollination, (5) interactions of plants, pollinators and floral antagonists, (6) pollinator behavior, (7) taxonomy, (8) the breadth and depth of our current understanding of plant-pollinator assemblages, (9) geographical trends in pollinator diversity, (10) drivers of pollinator loss, (11) pollination as an ecosystem service, (12) managing pollination services, (13) conservation and (14) implementation of conservation of plant-pollinator interactions.

The Millennium Ecosystem Assessment (http://www.millenniumassessment.org/), a global initiative launched by the United Nations, demonstrated the vital importance of ecosystem services for human well-being and found that two thirds of them are in decline or threatened. Bees provide direct ecosystem services. The on-going initiative on "The Economics of Ecosystems and Biodiversity" (TEEB, http://www.teebweb.org/) analyses the value of ecosystems and biodiversity to the economy, to society and to individuals. It underlines the urgency of action, as well as the benefits and opportunities that will arise as a result of taking the value of ecosystems and biodiversity into account better in policy decisions.

Thus, today we can conclude, that the focus changed in the last century from principle pollination questions to a more broad view on ecosystems and biodiversity and therefore, to the critical field of economy and society.

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