Removing non-crop flowers within orchards promotes the decline of pollinators, not their conservation: A comment on McDougall et al. (2021)

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Conflicts of Interest

The authors declare no conflict of interest.

Abstract:

1. Abundant and diverse floral resources are needed for the preservation of pollinator populations and the services they provide to human societies. However, pollinators are negatively affected by several agricultural practices, among which pesticide use and 'weed' removal stand out.

2. McDougall *et al.* (2021) published a paper titled "Managing orchard groundcover to reduce pollinator foraging post-bloom", where they propose removing the within-field flowering ground vegetation after the mass flowering period of the crop ends, to reduce pesticide exposure.

3. They consider this is a bee conservation strategy, after observing it reduces the abundance and diversity of pollinators within the crop. However, despite assuming this implied a realization of an expected reduction in pesticide exposure, this was not quantified.

4. Here, we give three main arguments against the proposal of the authors, i.e. the need for providing accessible, sufficient, safe and seasonally-spread feeding resources to crop pollinators, the potential role of diverse floral resources in their pesticide tolerance, and the urgent need to reduce pesticide use and impact in agriculture.

Keywords:

Pesticides; pollination service; wild flower strips; hedgerows; sustainable agriculture.

Introduction:

Reducing the exposure of pollinators to pesticides is an important issue aimed at preserving biodiversity and ecosystem functioning in agroecosystems (Gill *et al*., 2012; Goulson *et al*., 2015). In order to prevent this and other related issues like human exposure to dangerous agrochemicals (Vanbergen *et al*., 2020; Castiello *et al*., 2023), the main principles for improving the sustainability of agriculture include fostering the development of existing natural processes, as well as the internal cycling of nutrients and energy. This can be done, for example, by reducing the use of herbicides and insecticides, increasing the biodiversity within crop fields, and avoiding bare soil with permanent vegetation cover (Horrigan *et al*., 2002; Brodt *et al*., 2011; Kremen *et al*., 2012; Garibaldi *et al*., 2017; Kleijn *et al*., 2019). In a recent paper by McDougall *et al*. (2021) published in the journal "Pest Management Science" entitled "Managing orchard groundcover to reduce pollinator foraging post-bloom", the authors propose removing flowering ground herbs once the mass flowering period of the crop ends as a bee conservation strategy. With a multiyear field-experimental approach, they conclude this practice reduces the abundance and diversity of pollinators within the crop during the post-bloom stage, thus reducing their exposure to pesticides. Nevertheless, though this reduced pesticide exposure is expected, it was not quantified, limiting the understanding about the effectiveness of this management to really protect pollinators from insecticides and fungicides. We instead advocate for providing feeding resources to farm-associated pollinators and other beneficial fauna through the promotion of flowering herb cover within crop fields (Requier *et al*., 2015), as well as reducing herbicide and pesticide use (EC 2022; Goulson *et al*., 2015). In the following paragraphs, we give arguments against the proposal of McDougall *et al*. (2021):

Removing flowering ground cover reduces the feeding habitat for pollinators. Habitat loss is among the main drivers of pollinator decline in agricultural landscapes, which is mainly mediated by the reduction of floral and nesting resources associated with intensive agriculture (Potts *et al*., 2010; González-Varo *et al*., 2013; Parreño *et al*., 2021). The strategy proposed by McDougall *et al*. (2021) entails the removal of ground cover through the application of herbicide after the mass flowering of crops, therefore shortening the availability of nectar and pollen to the broad range of pollinators distributed within crop fields. McDougall *et al*. (2021) defend this management practice as a conservation tool by assuming a relocation of pollinators from orchards to surrounding nominally pesticide-free seminatural areas after removal of ground cover. Yet, in our opinion this assumption has several flaws:

- **Limited home-ranges for most solitary bee species:** The authors argue that "*Many important pollinators have relatively long foraging ranges, such as honey bees, which can forage several kilometers from their hives*", therefore pollinators can track floral resources in surrounding seminatural areas. However, evidence shows that, apart from the *Apis* genus and some bumblebees, most bee species exhibit typical foraging ranges below 1-km from nesting areas (Greenleaf *et al*., 2007; Zurbuchen *et al*., 2010a, 2010b; Hofmann *et al*., 2020). Moreover, individual farmers may not be able or allowed to manage vegetation outside their establishments to preserve or promote flowering vegetation at the landscape-scale (possibly excepting, e.g., large farms that encompass landscape-scales on their own). Therefore, we expect that in many contexts this proposed mitigation measure cannot be applied in the same fashion, nor is it as feasible, as the promotion of within-field ground cover flowering vegetation.
- **Orchard boundaries likely offer significantly less area than orchard access rows:** Besides landscape-scale enhancements, McDougall *et al*. (2021) suggest the use of

flowering vegetation surrounding the orchards (e.g. hedgerows) as a mitigating measure to compensate for the negative effects of their proposed strategy. However, despite the great potential of surrounding vegetation to support pollinators (e.g. through perennial species) and the importance of combining multiple types of semi-natural habitats (Maurer *et al*., 2022), access rows between crop-rows offer a much larger area for flowering vegetation, especially in intensive perennial orchards. For example, in a square-shaped apple orchard with typical 20 crop rows per hectare, the ratio between hallways to edges is *c.* 5:1 in a one hectare field, *and* it grows to *c.* 40:1 in a 16 hectare field (considering typical five-meter-wide access rows and field edges). As found recently in apple orchards (von Königslöw *et al*., 2022; Bishop *et al*., 2023), it is not clear that hedgerows alone, or associated with more distant surrounding vegetation, would be able to support the number and diversity of potential crop-flower visitors feeding from the ground cover vegetation within-field. Furthermore, in terms of ecosystem service provision, although floral enhancements in the edges have been found beneficial for pollinators there, a meta-analysis observed inconsistent effects within crop fields in terms of yield (Zamorano *et al*., 2020), therefore the removal of ground-covering flowers could have an economic impact.

- **Pesticides everywhere:** In spite of being proposed as a mitigating measure, flowering plants around the orchard can also be a path of pesticide exposure to pollinators, since pesticide drift into field edges and beyond is very common (Otto *et al*., 2009). Moreover, the authors suggest that the elimination of flowering ground cover and the continued use of pesticides should be applied at a larger scale in order to see stronger effects (i.e. fewer pollinators within crops); this could result in irreversible losses of landscape-scale biodiversity and ecosystem services, as many of the fleeing pollinators would probably not be able to find suitable habitat.

- **Long-term matters: removing flowering ground cover can have long-lasting effects on pollinator communities and crop yield.** Management actions applied after crop blooming can impact the pollinator community of the following years, both before, during and after crop bloom (Schellhorn *et al.*, 2015 and references therein). For example, Blaaw & Isaacs (2014) reported that blueberry fields with added wildflower plantings only showed effects on pollinators after three years. However, McDougall *et al*. (2021) focused the sampling effort as well as the interpretation of their results only in the period after crop bloom (across three years), not acknowledging that pollinator populations depend on the whole growing season to maintain or increase their abundance (Timberlake *et al*., 2019). Therefore, practices decreasing the availability of food during a large part of the year could negatively impact their numbers in the following seasons (Westphal *et al*., 2003; Nicholls & Altieri 2013). Available nectar and pollen sources should be maintained as long as possible throughout the growing season, especially before the bloom of early flowering temperate crops, with little time between pollinator emergence and crop bloom (Campbell *et al*., 2017). Considering the great importance that diverse communities of pollinators can have to crop pollination, as highlighted by McDougall *et al*. (2021) for their own study system, eliminating a large portion of pollinator food resources could negatively impact their contribution to crop yields.

Diverse food sources could mitigate the effects of pesticides. The negative effects of the exposure to a fungicide in several metrics of *Bombus terrestris* colony performance under a mono-floral diet were not detected when offered a mix of flower species, showing that besides the direct positive effect on fitness, diverse floral resources increase bumblebee fungicide tolerance (Wintermantel *et al*., 2022). A similar result was found for *Bombus vosnesenskii* colonies, with the negative effects of exposure to common pesticides on reproduction being ameliorated in sites with flower plantings (Rundlöf *et al*., 2022). Further, studies on *Osmia lignaria* showed additive effects of food resource stress and insecticide exposure on behavior (Stuligross *et al*., 2023), reproduction and survival (Stuligross & Williams 2020). These findings suggest that an augmented pesticide tolerance of pollinators achieved by access to diverse floral resources is another important reason to increase flower abundance and diversity within crop fields; this means that pesticides and more flowers is better than pesticides and less flowers. However, if the remaining landscape offers enough food resources, *some* individuals (or colonies) nesting at pesticide-safe distances from the crop, and belonging to highly mobile species, could be benefited by not having wild flowers to visit within an orchard treated with pesticides after crop bloom. But even in this scenario, other individuals from the same species, as well as from other less mobile species, could attempt to nest inside the orchard, and suffer the impacts of pesticides in a flower-poor environment. Therefore, the potential for a net benefit of removing non-crop flowering plants is not clear.

Compliance with regulations should occur through reductions in insecticide and herbicide use, and via improvements in their safety to non-target organisms. McDougall *et al*.

(2021) suggest that compliance with US-EPA regulations (*"minimize exposure of this product to bees and other pollinators when they are foraging on pollinator attractive plants around the application site"*) would be facilitated to farmers by reducing the abundance and diversity of pollinators in their crop fields via eliminating flowering ground cover. In the introduction, the authors state: *"There is growing recognition that IPM tactics should be combined with pollinator management strategies (...) and thus if this technique can meet both objectives it would be a potentially valuable tool in the repertoire of crop managers"*. However, the objective of crop managers is generally to maintain or increase crop productivity and profit (hopefully in a sustainable manner), not to reduce pesticide exposure *per se*. We fear that the practice proposed by the authors could be used by practitioners as a justification for more simplified agriculture with high pesticide and herbicide use, and less diversity (both of plants and animals). Abundant and diverse flower resources are needed for preserving and improving the health of pollinator communities in agroecosystems and enhancing yields of pollinator-dependent crops (Garibaldi *et al*., 2014). A possible short-term benefit to producers might be an increase in compliance with legal restrictions (e.g. US-EPA). However, in this case the compliance would occur as a result of the elimination (by displacement and/or death) of pollinators from local orchards, which is not a desirable outcome from a conservation nor a productivity perspective. Furthermore, although habitat loss and decreasing plant diversity are the most significant indirect effects of herbicides impacting on pollinator species, there is growing evidence showing that herbicides have harmful direct impacts on the health of pollinators (Blot *et al*., 2019; Battisti *et al*., 2021; Motta *et al*., 2018, 2022). The idea of using pollinator-harmful compounds to conserve them seems contradictory, and against the principles of

"Integrated Pest and Pollinator Management (IPPM)" strategies.

Conclusions

The main cause of pollinator decline is intensive agriculture (IPBES 2016; Vanbergen *et al*., 2020; Dicks *et al*., 2021), dominated by monocultures and pesticide use, which generates landscapes with low plant diversity (Goulson *et al*., 2008; Potts *et al*., 2010, 2016; Ollerton *et al*., 2014). The opportunities to increase plant diversity in agroecosystems both temporally and spatially must be seized (Mandelik *et al*., 2012). One opportunity is the promotion of ground cover flowering plants in access rows between perennial crop rows, which can provide food resources for diverse pollinators and other beneficial fauna (García and Minarro 2014; Karamaouna *et al*., 2019; Peris-Felipo *et al*., 2021). Reducing herbicide and insecticide use is a key complementary strategy to that of diversifying ground cover vegetation in the path to *i*) preserve and recover pollinator populations in croplands, and *ii*) to promote a more sustainable form of agriculture as a whole (EC 2022; Goulson *et al*., 2015).

More productivity of pollinator dependent crops is generally associated with higher pollinator abundance and diversity within crop fields (Garibaldi *et al*., 2016; Reilly *et al*., 2020; Garratt *et al*., 2023). As McDougall *et al*. (2021) found, the elimination of ground flowering plants and the use of pesticides removes pollinators from crop fields. No benefit to biodiversity and ecosystem function is thus expected if a reduction in pesticide exposure is achieved via a reduction in plant diversity at orchard scale. Rather, upscaling these practices could trigger negative impacts at large spatio-temporal scales on the diversity of pollinators, and of many other important fauna, ultimately affecting important ecosystem services such as crop pollination.

References

Battisti L., Potrich M., Sampaio A.R., de Castilhos Ghisi N., Costa-Maia F.M., Abati R., …, Sofia S.H. (2021) Is glyphosate toxic to bees? A meta-analytical review. Sci Total Environ, 767, 145397. https://doi.org/10.1016/j.scitotenv.2021.145397

Bishop G.A., Fijen T.P., Desposato B.N., Scheper J. & Kleijn D. (2023) Hedgerows have contrasting effects on pollinators and natural enemies and limited spillover effects on apple production. Agric Ecosyst Environ, 346, 108364. https://doi.org/10.1016/j.agee.2023.108364

Blaauw B.R. & Isaacs R. (2014) Flower plantings increase wild bee abundance and the pollination services provided to a pollination-dependent crop. J Appl Ecol, 51(4), 890-898. https://doi.org/10.1111/1365-2664.12257

Blot N., Veillat L., Rouzé R. & Delatte H. (2019) Glyphosate, but not its metabolite AMPA, alters the honeybee gut microbiota. PloS one, 14(4), e0215466. https://doi.org/10.1371/journal.pone.0215466

Brodt S., Six J., Feenstra G., Ingels C. & Campbell D (2011) Sustainable agriculture. Nat Educ Knowl, 3(1).

Campbell A.J., Wilby A., Sutton P. & Wäckers F.L. (2017) Do sown flower strips boost wild pollinator abundance and pollination services in a spring-flowering crop? A case study from UK cider apple orchards. Agric Ecosyst Environ, 239, 20-29. https://doi.org/10.1016/j.agee.2017.01.005

Castiello F., Suárez B., Beneito A., Lopez-Espinosa M.J., Santa-Marina L., Lertxundi A., …, Freire C. (2023) Childhood exposure to non-persistent pesticides and pubertal development in Spanish girls and boys: Evidence from the INMA (Environment and Childhood) cohort. Environ Pollut, 316, 120571. https://doi.org/10.1016/j.envpol.2022.120571

Dicks L.V., Breeze T.D., Ngo H.T., Senapathi D., An J., Aizen M.A., …, Potts S.G. (2021) A global-scale expert assessment of drivers and risks associated with pollinator decline. Nat Ecol Evol, 5(10), 1453-1461. https://doi.org/10.1038/s41559-021-01534-9

EC European Commission (2022) Farm to Fork strategy. <https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en>

García R.R. & Minarro M. (2014) Role of floral resources in the conservation of pollinator communities in cider-apple orchards. Agric Ecosyst Environ, 183, 118-126. https://doi.org/10.1016/j.agee.2013.10.017

Garibaldi L.A., Carvalheiro L.G., Leonhardt S.D., Aizen M.A., Blaauw B.R., Isaacs R., ..., Winfree R. (2014) From research to action: enhancing crop yield through wild pollinators. Front Ecol Environ, 12(8), 439-447. https://doi.org/10.1890/130330

Garibaldi L.A., Carvalheiro L.G., Vaissière B.E., Gemmill-Herren B., Hipólito J., Freitas B.M., ..., Zhang H. (2016) Mutually beneficial pollinator diversity and crop yield outcomes in small and large farms. Science, 351(6271), 388-391. https://doi.org/10.1126/science.aac7287

Garibaldi L.A., Gemmill-Herren B., D'Annolfo R., Graeub B.E., Cunningham S.A. & Breeze T.D. (2017) Farming approaches for greater biodiversity, livelihoods, and food security. Trends Ecol Evol, 32(1), 68-80. https://doi.org/10.1016/j.tree.2016.10.001

Garratt M.P., O'Connor R.S., Carvell C., Fountain M.T., Breeze T.D., Pywell R., ..., Potts S.G. (2023) Addressing pollination deficits in orchard crops through habitat management for wild pollinators. Ecol Appl, 33(1), e2743. https://doi.org/10.1002/eap.2743

Gill R.J., Ramos-Rodriguez O. & Raine N.E. (2012) Combined pesticide exposure severely affects individual-and colony-level traits in bees. Nature, 491(7422), 105-108. https://doi.org/10.1038/nature11585

González-Varo J.P., Biesmeijer J.C., Bommarco R., Potts S.G., Schweiger O., Smith H.G., ..., Vilà M. (2013) Combined effects of global change pressures on animal-mediated pollination. Trends Ecol Evol, 28(9), 524-530. https://doi.org/10.1016/j.tree.2013.05.008

Goulson D., Lye G. & Darvill B. (2008) The decline and conservation of bumblebees. Annu Rev Entomol, 53, 191-208. https://doi.org/10.1146/annurev.ento.53.103106.093454

Goulson D., Nicholls E., Botías C. & Rotheray E.L. (2015) Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science, 347(6229), 1255957. https://doi.org/10.1126/science.1255957

Greenleaf S.S., Williams N.M., Winfree R. & Kremen C. (2007) Bee foraging ranges and their relationship to body size. Oecologia, 153(3), 589-596. https://doi.org/10.1007/s00442-007-0752-9

Horrigan L., Lawrence R.S. & Walker P. (2002) How sustainable agriculture can address the environmental and human health harms of industrial agriculture. Environ Health Perspect, 110(5), 445-456. https://doi.org/10.1289/ehp.02110445

Hofmann M.M., Fleischmann A. & Renner S.S. (2020) Foraging distances in six species of solitary bees with body lengths of 6 to 15 mm, inferred from individual tagging, suggest

150 m-rule-of-thumb for flower strip distances. J Hymenopt Res, 77, 105. https://doi.org/10.3897/jhr.77.51182

IPBES 2016. The assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. Potts SG *et al.*, eds. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. <https://nora.nerc.ac.uk/id/eprint/519227>

Karamaouna F., Kati V., Volakakis N., Varikou K., Garantonakis N., Economou L., ..., Edwards M. (2019) Ground cover management with mixtures of flowering plants to enhance insect pollinators and natural enemies of pests in olive groves. Agric Ecosyst Environ, 274, 76-89. https://doi.org/10.1016/j.agee.2019.01.004

Kleijn D., Bommarco R., Fijen T.P., Garibaldi L.A., Potts S.G. & Van Der Putten W.H. (2019) Ecological intensification: bridging the gap between science and practice. Trends Ecol Evol, 34(2), 154-166. https://doi.org/10.1016/j.tree.2018.11.002

Kremen C., Iles A. & Bacon C. (2012) Diversified farming systems: an agroecological, systems-based alternative to modern industrial agriculture. Ecol Soc, 17(4). http://dx.doi.org/10.5751/ES-05103-170444

Mandelik Y., Winfree R., Neeson T. & Kremen C (2012) Complementary habitat use by wild bees in agro-natural landscapes. Ecol Appl, 22(5), 1535-1546. https://doi.org/10.1890/11-1299.1

Maurer C., Sutter L., Martínez-Núñez C., Pellissier L. & Albrecht M. (2022) Different types of semi-natural habitat are required to sustain diverse wild bee communities across agricultural landscapes. J Appl Ecol, 59(10), 2604-2615. https://doi.org/10.1111/1365-2664.14260

McDougall R., DiPaola A., Blaauw B. & Nielsen A.L. (2021) Managing orchard groundcover to reduce pollinator foraging post-bloom. Pest Manag Sci, 77(7), 3554-3560. https://doi.org/10.1002/ps.6409

Motta E.V., Powell J.E. & Moran N.A. (2022) Glyphosate induces immune dysregulation in honey bees. Anim Microbiome, 4(1), 1-14. https://doi.org/10.1186/s42523-022-00165-0

Motta E.V., Raymann K. & Moran N.A. (2018) Glyphosate perturbs the gut microbiota of honey bees. Proc Natl Acad Sci USA, 115(41), 10305-10310. https://doi.org/10.1073/pnas.1803880115

Nicholls C.I. & Altieri M.A. (2013) Plant biodiversity enhances bees and other insect pollinators in agroecosystems. A review. Agron Sustain Dev, 33(2), 257-274. https://doi.org/10.1007/s13593-012-0092-y

Ollerton J., Erenler H., Edwards M. & Crockett R. (2014) Extinctions of aculeate pollinators in Britain and the role of large-scale agricultural changes. Science, 346(6215), 1360-1362. https://doi.org/10.1126/science.1257259

Otto S., Lazzaro L., Finizio A. & Zanin G. (2009) Estimating ecotoxicological effects of pesticide drift on nontarget arthropods in field hedgerows. Environ Toxicol Chem, 28(4), 853-863. https://doi.org/10.1897/08-260R.1

Parreño M.A., Alaux C., Brunet J.L., Buydens L., Filipiak M., Henry M., ..., Leonhardt S.D. (2021) Critical links between biodiversity and health in wild bee conservation. Trends Ecol Evol. https://doi.org/10.1016/j.tree.2021.11.013

Peris-Felipo F.J., Santa F., Aguado O., Falcó-Garí J.V., Iborra A., Schade M., ..., Miranda-Barroso L. (2021) Enhancement of the diversity of pollinators and beneficial insects in intensively managed vineyards. Insects, 12(8), 740. https://doi.org/10.3390/insects12080740

Potts S.G., Biesmeijer J.C., Kremen C., Neumann P., Schweiger O. & Kunin W.E. (2010) Global pollinator declines: trends, impacts and drivers. Trends Ecol Evol, 25(6), 345-353. https://doi.org/10.1016/j.tree.2010.01.007

Potts S.G., Imperatriz-Fonseca V., Ngo H.T., Aizen M.A., Biesmeijer J.C., Breeze T.D., ..., Vanbergen A.J. (2016) Safeguarding pollinators and their values to human well-being. Nature, 540(7632), 220-229. https://doi.org/10.1038/nature20588

Reilly J.R., Artz D.R., Biddinger D., Bobiwash K., Boyle N.K., Brittain C., ..., Winfree R. (2020) Crop production in the USA is frequently limited by a lack of pollinators. Proc Royal Soc B, 287(1931), 20200922. https://doi.org/10.1098/rspb.2020.0922

Requier F., Odoux J.F., Tamic T., Moreau N., Henry M., Decourtye A. & Bretagnolle V (2015) Honey bee diet in intensive farmland habitats reveals an unexpectedly high flower richness and a major role of weeds. Ecol Appl, 25(4), 881-890. https://doi.org/10.1890/14-1011.1

Rundlöf M., Stuligross C., Lindh A., Malfi R.L., Burns K., Mola J.M., …, Williams N.M. (2022) Flower plantings support wild bee reproduction and may also mitigate pesticide exposure effects. J Appl Ecol, 59(8), 2117-2127. https://doi.org/10.1111/1365-2664.14223

Schellhorn N.A., Gagic V. & Bommarco R. (2015) Time will tell: resource continuity bolsters ecosystem services. Trends Ecol Evol, 30(9), 524-530. https://doi.org/10.1016/j.tree.2015.06.007

Stuligross C. & Williams N.M. (2020) Pesticide and resource stressors additively impair wild bee reproduction. Proc Royal Soc B, 287(1935), 20201390. https://doi.org/10.1098/rspb.2020.1390

Stuligross C., Melone G.G., Wang L. & Williams N.M. (2023) Sublethal behavioral impacts of resource limitation and insecticide exposure reinforce negative fitness outcomes for a solitary bee. Sci Total Environ, 161392. https://doi.org/10.1016/j.scitotenv.2023.161392

Timberlake T.P., Vaughan I.P. & Memmott J. (2019) Phenology of farmland floral resources reveals seasonal gaps in nectar availability for bumblebees. J Appl Ecol, 56(7), 1585-1596. https://doi.org/10.1111/1365-2664.13403

Vanbergen A.J., Aizen M.A., Cordeau S., Garibaldi L.A., Garratt M.P., Kovács-Hostyánszki A., ..., Young J.C. (2020) Transformation of agricultural landscapes in the Anthropocene: Nature's contributions to people, agriculture and food security. Adv Ecol Res, 63 (pp. 193-253). Academic Press. https://doi.org/10.1016/bs.aecr.2020.08.002

von Königslöw V., Fornoff F. & Klein A.M. (2022) Pollinator enhancement in agriculture: Comparing sown flower strips, hedges and sown hedge herb layers in apple orchards. Biodivers Conserv, 31(2), 433-451. https://doi.org/10.1007/s10531-021-02338-w

Westphal C., Steffan-Dewenter I. & Tscharntke T. (2003) Mass flowering crops enhance pollinator densities at a landscape scale. Ecol Lett, 6(11), 961-965. https://doi.org/10.1046/j.1461-0248.2003.00523.x

Wintermantel D., Pereira-Peixoto M.H., Warth N., Melcher K., Faller M., Feurer J., …, Klein A.M. (2022) Flowering resources modulate the sensitivity of bumblebees to a common fungicide. Sci Total Environ, 829, 154450.

Zamorano J., Bartomeus I., Grez A.A. & Garibaldi L.A. (2020) Field margin floral enhancements increase pollinator diversity at the field edge but show no consistent spillover into the crop field: a meta-analysis. Insect Conserv Divers, 13(6), 519-531. https://doi.org/10.1111/icad.12454

Zurbuchen A., Cheesman S., Klaiber J., Müller A., Hein S. & Dorn S. (2010) Long foraging distances impose high costs on offspring production in solitary bees. J Anim Ecol, 79(3), 674-681. https://doi.org/10.1111/j.1365-2656.2010.01675.x

Zurbuchen A., Landert L., Klaiber J., Müller A., Hein S. & Dorn S. (2010) Maximum foraging ranges in solitary bees: only few individuals have the capability to cover long foraging distances. Biol Conserv, 143(3), 669-676. https://doi.org/10.1016/j.biocon.2009.12.003