Should we be protecting the Western Honey Bee?

Exploring the impact of managing and conserving *Apis mellifera* globally

5400168

Word Count: 3013

Keywords: *Apis mellifera*, conservation, managed honeybee, pollination.

The Honey bee, *Apis mellifera*, receives a lot of positive press, often being portrayed as the most important or only bee to carry our pollination services. Whilst these bees are hugely beneficial for several ecosystem services, are they really the best bees for the job? Several governments believe so, implementing measures to help increase the number managed populations of *A. mellifera*. Some conservationists don't agree, suggesting that wild pollinators are superior pollinators, and that focussing on *A. mellifera* could be detrimental to these wild pollinators. This article argues that *A. mellifera* conservation is necessary at times, however managed populations need to be more heavily monitored and restricted at times in order to provide space and resources for will pollinators to flourish.

The bees

Single bee species management is the norm for meeting pollination needs in agriculture (1) and with 15-30% of food requiring pollination, many farmers rely on the Western Honey bee, *Apis mellifera* (fig 1), to provide pollination services (2), leading it to be the most common of the honey bee species.

Figure 1: The Western Honey Bee, Apis mellifera, from left to right is a queen, drone and worker (3)

A. mellifera has a native range of much of Europe, parts of Western Asia and Africa (4) however the species can be found almost globally (5), with managed populations found in North and South America, Central and western Asia and Australia, as shown in figure 2 (6).

The honey market is thought to be worth 5.92 billion pounds per year globally but the pollination value of *A. mellifera* is far higher at a value of around 120-140 billion pounds (8). Additionally, the number of hives globally has increased by ~45% since the early 1960s, along with honey yield and agricultural production per year as shown in figure 3 (9).
As super-generalist pollinators (see Glossary) (10), it is easy to see how *A. mellifera* has become so widespread, particularly as they are still well suited for adapting regardless of domestication (11). However, within their native range, wild *A. mellifera* is endangered (12) and there have only been small or unsuccessful efforts to conserve the species. On the other hand, maintaining or even further increasing managed populations is a different story, which will be discussed later in this article.

With so much focus on managed *A. mellifera* populations, it is easy to forget about the existence of the other 25,000 species of bee that exists globally, as well as the 200,000 total number of pollinators worldwide. Many of these species are facing population declines, with a large number under threat of extinction. Many of these species are solitary and are often considered less charismatic compared to *A. mellifera*, leading to a lack of public interest in these species. This lack of interest has led to fewer conservation efforts being made for wild pollinators, as discussed later in this article. So, what conservation and management options are available? And how do these differ between *A. mellifera* and wild pollinators?

How did this happen?

The wide spread of this *A. mellifera* is attributed to deliberate introductions thanks to European colonisers, who would transport the species in order to access honey. Introductions occurred as early as 1622 in North America and the 1800's in Australia (13).

How the *A. mellifera* is managed and conserved

As mentioned previously, wild populations of *A. mellifera* are endangered within its native range, however managed populations are common both within and outside of this range. In 2007 there were 72.6 million honey bee colonies globally, an overall increase of between 45-61% from 1961-2010 (7, 14). This increase was

not witnessed everywhere, with some countries experiencing a decrease in the number of managed honey bee colonies (14) as show in figure 4.

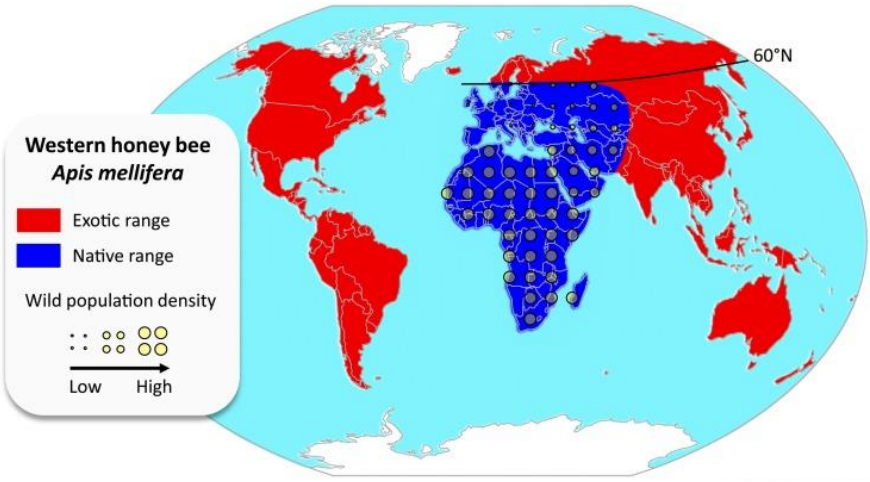

Figure 2: The range of Apis mellifera with red representing its non-native or "exotic" range and blue showing its native range. The circles within A. mellifera represent the wild population density of the insect, showing its small population density in Europe (7)

Because of these local decreases, conservation and increased management efforts have been implemented, even in areas where *A. mellifera* is not native. Often *A. mellifera* health is a priority over other species, for example, in 2016 the Pollinator Health Task force published the Pollinator Partnership Action Plan (15) which outlined guidance for pollinator conservation in America, with its first focus being on *A. mellifera* health. The Agricultural Research Service has five laboratories dedicated to bee research, four of which are dedicated specifically to *A. mellifera* rather than the 4000 native bee species that America is home to (15). This isn't limited to the Obama administrations work. In 2020, the Conservation Reserve Programme planned to manage land with the goal of supporting pollinators, this included by creating a seed mix designed for "pollinator enriched planting" (16), however they focussed solely on the needs of *A. mellifera* (17).

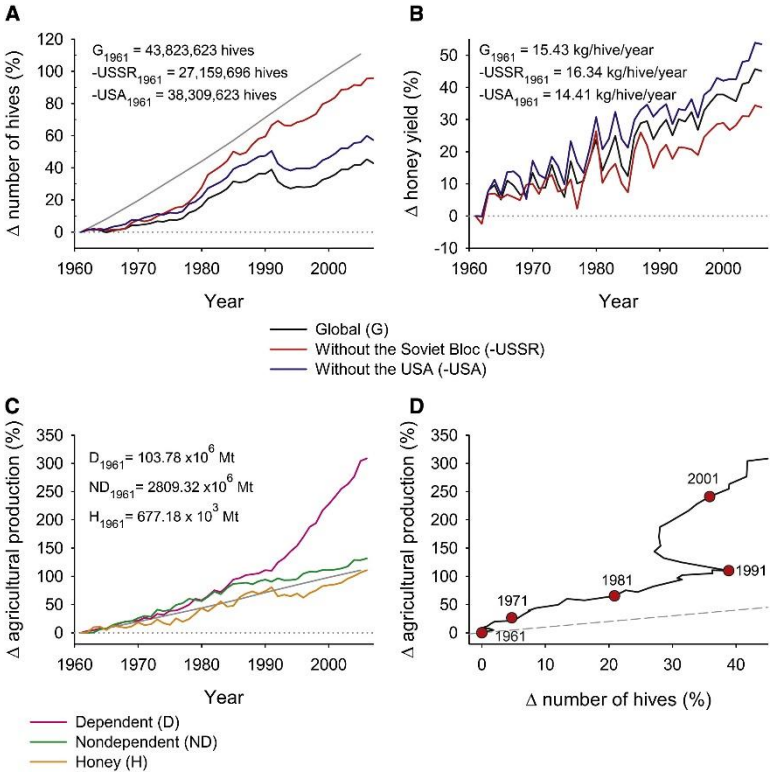

Figure 3: Changes in the number of bee hives, yield of honey and agricultural production globally in regards to A. mellifera between 1961-2007 (9)

In cases like this, the issue isn't that conservation methods focus on *A. mellifera*, especially as *A. mellifera* conservation is essential in some areas, but that these conservation methods disproportionately focus on *A. mellifera* over native species of pollinator (18).

This focus on one species may be due to the public's perception of *A. mellifera*, with much of the media attention being on *A. mellifera* for the last two decades (19) showing *A. mellifera* in a very positive light (20). Even pop culture has perpetuated this idea, with pieces of media like the Bee Movie promoting the idea that the honey bee is the only bee, and that without the species no pollination services will be carried out. Public involvement is essential in bee conservation (19) and as the media

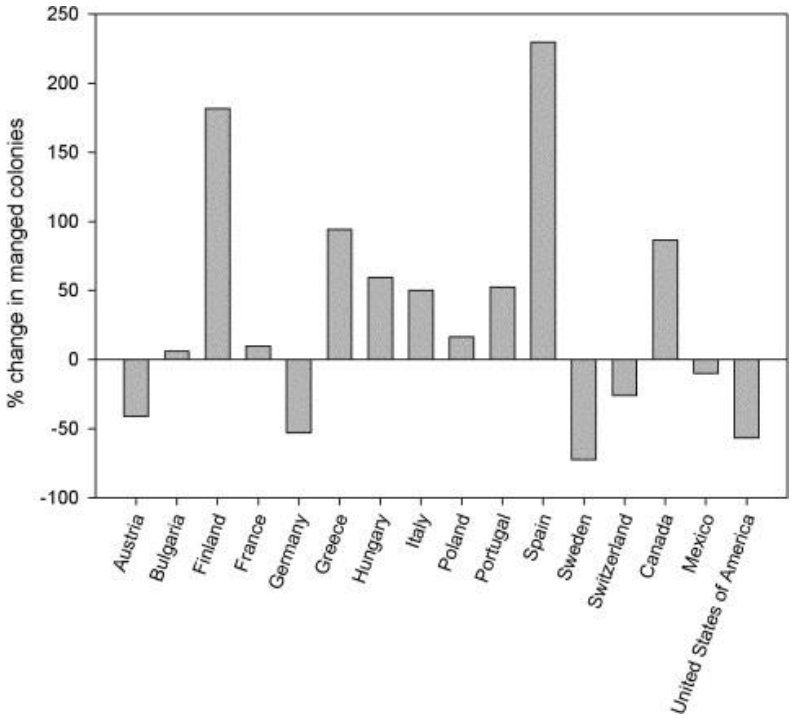

Figure 4: The percentage change in the number of managed A. mellifera colonies in specific countries in Europe and the Americas (14).

often presents *A. mellifera* as the most important or only pollinator (21) other species will often be forgotten. In many cases the public are not fully informed of the presence of other bee species, let alone what their needs are when making areas like their gardens more bee friendly (19) which often leads to spaces being made suitable for non-native/managed *A. mellifera* populations instead of native pollinators (22).

In countries where *A. mellifera* populations haven't decreased, the number of managed *A. mellifera* populations is still being closely monitored. This is to ensure they can meet the demand to produce products like beeswax and honey, or to meet pollination demands. This is particularly important as we rely more heavily on pollinator-dependant crops in a climate where pollinator numbers are generally decreasing (23). It's even suggested that managed *A. mellifera* colonies can and should be placed in a way that ensures fuller *A. mellifera* coverage and ensure the pollination of crops, rather than encouraging native species to pollinate those areas (24).

So, is any of this actually an issue? Should we be focussing so heavily on conserving and managing *A. mellifera*? Or should other native bees and pollinators be the focus?

The benefits of *A. mellifera*

A. mellifera provides a range of ecosystem services, including pollination, production of food and api-products, and cultural services such as recreation. A full breadth of these services can be seen in figure 5. A key service that *A.* mellifera provides is pollination. 87.5% of flowering plants are pollinated by animals (26) and of the 124 main crops produced for human consumption around 70% are reliant on pollinators- with an economic value of 120-140 billion pounds per year (8). Of the insect pollinators involved, *A. mellifera* is thought to be the single most important pollinating species, for several reasons (27).

A. mellifera is a super-generalist bee, meaning it interacts and pollinates many groups of species (10) possibly reducing pollinating deficiency in native plants (28), ensuring pollen does not go to waste (29) and certainly providing essential pollination for modern farming practices such as monocropping (30). *A. melliferas* effectiveness as a pollinator is thought to be the same as, if not better than native species of pollinator for some plant species by some specialists (31, 32, 33). This species' wide distribution also contributes to the bees' effectiveness as a pollinator (27) allowing it access to an increasing number of plant species for it to pollinate.

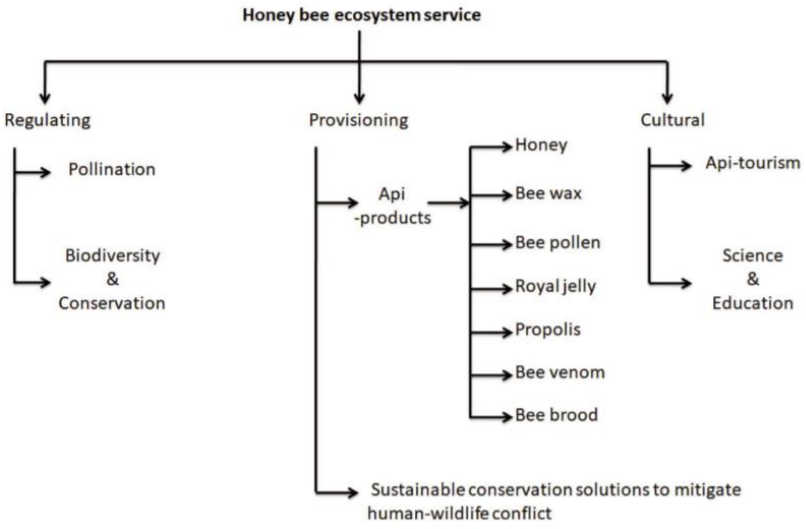

Figure 5: Honey Bee ecosystem services as suggested by Wos, (25), including pollination, api-products such as honey and bee wax and api-tourism.

As well as essential services such as pollination, managed *A. mellifera* populations provide a source of recreation for humans, which can contribute to the increased number of *A. mellifera* in some areas. Api-tourism is also an emerging industry with several benefits, including increased education to the public on bees and their importance and community benefits such as providing jobs, particularly when these sites are run at already established bee farms (25).

Whilst there is potential for native species to fulfil some of these services in areas where *A. mellifera* is non-native, *A. mellifera* is often already there and removing the species would be incredibly difficult. Furthermore, removal of the species could lead to the reduction of seed production by 14% (34). There is an argument to be made that as *A. mellifera* has been found in its non-native range for such a long time and provides such important services that it should not be presented as invasive, which it usually isn't (35) (although you must wonder if it should be considered invasive more often given its impact on native species- which shall be discussed momentarily). Additionally, there is some evidence that by working to change agricultural land use to benefit *A. mellifera*, native bee species will also benefit, making *A. mellifera* conservation beneficial for a range of species (36).

The positives of using *A. mellifera* are indeed vast, so it's easy to see why the negatives of such extensive use of one species are often overlooked. Not only can *A. mellifera* negatively impact native pollinators, but their perception in media can lead to native pollinators being forgotten completely, even though they could be doing a better job. So what specifically are the drawbacks of the current use of *A. mellifera*?

The negative impact of *A. mellifera* on native species

A. mellifera introduction and continued conservation may negatively impact wild and solitary bee species, particularly through the spread of pathogens and increased competition for resources.

Several viruses have been shown to have spillover, such as in another commercially valuable species *Bombus terrestris* where Deformed Wing Virus spillover has occurred (37), or Colony Collapse Disorder in other non-*Apis* hymenopteran species such as solitary bees (38). Ravoet (39) suggested that *A. mellifera* hives often are the source of a range of pathogens, including viruses, fungi, and protists, for solitary bees.

Additionally, bee pollinators are not the only group that *A. mellifera* viruses can be passed on to. Other pollinator and non-pollinator species can also be impacted (38, 40), further

supporting the idea that *A. mellifera* should not be conserved outside of their natural habitat, and that the increasing number of hives could be detrimental to native wildlife.
This doesn't just impact non-apis species, managed/introduced colonies of the *A. mellifera* could potentially impact wild populations of the same species (41, 42) for example through the introduction of *Varroa* mites to European populations. As more managed bees are introduced, the risk of this parasite, and other pathogens, to wild *A. mellifera* populations increases (43), an impact that is often ignored (7).

As *A.* mellifera colony densities increase, the activity of wild pollinators decreases. As mentioned previously, *A. mellifera* are super-generalised pollinators which can lead to increased competition for plants and lead to *A. mellifera* dominating (44, 45). Additionally, as flower abundance increases, the abundance of *A. mellifera* increases faster than the abundance of native species (46). Previously, the argument has been made that without *A. mellifera*, pollen resources may go to waste (29) however even this claim appears to be unsubstantiated, with studies suggesting that oligolectic bees will collect 97-99% of resources available when *A. mellifera* is unavailable (47, 48, 49). Both this and the increased risk of spillover actively oppose the previous statement that by working to change agricultural land use to benefit *A. mellifera*, native bee species will also benefit (36).

Yellow-Faced bees

Ing and Mogren (45) found that *A. mellifera*s outcompeted the endangered Yellow-Faced bee, *Hylaeus anthracinus,* with chemical deterrants being the main contributing factor for this rather than resource depletion. This is particularly noteworthy as *A. mellifera*s are not territorial (50) so would not be deliberately deterring other native bee species from foraging sites.

Our focus on *A. mellifera* in conservation may also have an indirect negative effect on native bee species, such as the inclusion of native bee species in pesticide testing. For example, Iwasa et al. (51) suggested that the use of neonicotinoid insecticides could be safe for use on crops pollinated by *A. mellifera*. These findings were backed up by a 2015 paper that showed that neonicotinoid pesticides had no significant impact on *A. mellifera* under field conditions (52). However, this same paper found that neonicotinoid insecticides "reduced wild bee density, solitary bee nesting, and bumblebee colony growth and reproduction" suggesting that the impact of such pesticides had been underestimated for other bee species (52).

Whilst the negative impact of *A. mellifera* appears damning, it's important to consider other factors that lead to population decline in other non-apis species. For example, for many solitary bee species, factors such as habitat loss and pesticide use are more impactful that the presence of the *A. mellifera* (53), and whilst disease also has a huge impact, *A. mellifera*s are not the sole cause of the spread (53) So what other arguments are there against the conservation of *A. mellifera*?

Native bees do the job better

Whilst the importance of *A. mellifera* is often emphasized for its pollination services, studies have suggested that wild bee pollination in natural, semi natural, and agricultural environments is essential (54, 55) with the importance of *A. mellifera* pollination often being over-estimated (55). In some cases, pollination services increase as wild bee abundance and richness increases, regardless of the abundance of *A. mellifera* (56) and even though seed production is thought to decrease by 14% with the removal of *A. mellifera*, the species accounts for up to 92% of observed floral visits, suggesting that wild pollinators are more efficient pollinators (57). Wild bees have been found to require fewer visits per flower than *A. mellifera* to complete the same pollination services, possibly because some species are specialised pollinators and therefor spend more time on a flower per visit (58).

Supplementing rather than substituting

Garibaldi et al. suggest that wild pollinators are more efficient in general compared to *A. mellifera*. Whilst increased visitation by *A. mellifera* to plant crops does increase fruit set, increased visitation of wild pollinators has a greater impact. This paper suggests that *A. mellifera* should be seen as "supplementing rather than substituting" wild insect pollination (62).

More explicit benefits of using wild pollinators can be seen in crops such as strawberries, where studies have shown that the weight of the fruit itself is higher when grown from flowers visited by wild bees, compared to flowers visited by *A. mellifera* (59).
Additionally, there is evidence that generalised pollinators like *A. mellifera* can aid in the establishment of other invasive plant species (60) and that specialised pollinators may be required by some plant species, as even though generalised pollinators like *A. mellifera* can pollinate these species, their visits are less consistent that specialised species. This can lead to plants competing for pollinators as the abundance of specialists decreases and generalists increase (61).

As the conservation of native bees often requires increasing and improving floral diversity, conserving native species of bee and other pollinator can provide additional ecosystem services, such as providing habitat for other insects and increasing scenic value, possibly bringing walkers and tourism into an area (62). All of this is achieved whilst also providing more resources for managed *A. mellifera* populations, as these groups needs often overlap (62, 36). Conserving native bees may also be essential in the wake of climate change, with the pollination services of *a. mellifera* thought to decrease whilst the same services are thought to increase in wild bee populations in the wake of climate change (63). Wild bees essentially could act as a buffer to the negative impact that climate change may have on *A. mellifera* populations (64).

Conclusion

It can be tempting to see the negative impact that *A. mellifera* have had on native species, or the evidence suggesting that *A. mellifera* are not the best pollinators, and immediately suggest removing *A. mellifera* from non-native areas. However, I don't think that that's a reasonable suggestion. Shifting the focus from introducing/protecting managed *A. mellifera* populations to the conservation of wild *A. mellifera* and other wild species, whilst heavily managing or restricting managed *A. mellifera* seems far more reasonable. If we aren't going to view *A. mellifera* as an invasive species (even though at times it fits the definition of one) because of its usefulness, then we should be doing everything we can to conserve other species, including increasing public interest and increasing actual conservation efforts dedicated to these native populations rather than hoping *A. mellifera* conservation will also benefit other species.
The public's understanding and perception of pollinators is so important when it comes to conservation that it's not surprising that non-apis species don't receive more attention, however it's shocking that more isn't being done to change this given how easy it is to share resources and information now.
Allowing for increased conservation of wild pollinators also provides a sort of "buffer" for ecosystem services such as pollination, particularly if the decrease in honey bee populations continues during the climate crisis. Furthermore, collaboration of honeybees and wild bees has also been shown to increase the yield of some crops like sunflowers and studies in the UK suggest that conservation measures should focus on both wild and managed populations.
The idea of increasing managed *A. mellifera* populations and managing them in such a way that they cover higher areas- rather than working to conserve native bees that could carry

out the same services- quite frankly, seems absurd, particularly now that we understand the impact that these populations can have on the already struggling wild pollinator populations.

Are we conserving the wrong bee? At times yes, but that doesn't mean that *A. mellifera* conservation is inherently bad, but our use of managed *A. mellifera* needs desperate reform for the sake of wild pollinators, non-pollinating insects and food security.

Glossary

Colony Collapse Disorder: A disorder affecting bee colonies that occurs when the majority of the worker bees disappear, either through leaving or death, leaving a queen and plenty of food behind and leading to a colony's death.

Deformed Wing Virus: A virus, often spread by mites, responsible for causing wing and abdominal deformities in bees and other pollinators.

Monocropping: the practice of growing the same crop on the same plot of land every year without crop rotation.

Non-apis: Also known as a *Pollen Bee*, describing any bee outside of the *Apis* bee family.

Spillover: Also known as *pathogen spillover*, occurs when a pathogen from one species moves into another novel species, with such movement possibly resulting in an outbreak.
Super-generalist: a pollinator trait where species obtain floral resources from a very wide range of plant species

References

1. Garibaldi, L.A., Carvalheiro, L.G., Leonhardt, S.D., Aizen, M.A., Blaauw, B.R., Isaacs, R., Kuhlmann, M., Kleijn, D., Klein, A.M., Kremen, C. and Morandin, L., 2014. From research to action: enhancing crop yield through wild pollinators. *Frontiers in Ecology and the Environment*, *12*(8), pp.439-447.

2. Greenleaf, S.S. and Kremen, C., 2006. Wild bees enhance honey bees' pollination of hybrid sunflower. *Proceedings of the National Academy of Sciences*, *103*(37), pp.13890-13895.

3. Ardnt, 2020. Honey Bee (Apis mellifera) queen, drone, and worker, Germany. *Nature Picture Library,* accessed on 11th January 2022 via: https://www.naturepl.com/stock-photo-honey-bee-nature-image00594061.html

4. Beaurepaire, A., Piot, N., Doublet, V., Antunez, K., Campbell, E., Chantawannakul, P., Chejanovsky, N., Gajda, A., Heerman, M., Panziera, D. and Smagghe, G., 2020. Diversity and global distribution of viruses of the western honey bee, Apis mellifera. *Insects*, *11*(4), p.239.

5. Le Conte, Y. and Navajas, M., 2008. Climate change: impact on honey bee populations and diseases. *Revue Scientifique et Technique-Office International des Epizooties*, *27*(2), pp.499-510.

6. Moritz, R.F., Härtel, S. and Neumann, P., 2005. Global invasions of the western honeybee (Apis mellifera) and the consequences for biodiversity. *Ecoscience*, *12*(3), pp.289-301.

7. Requier, F., Garnery, L., Kohl, P.L., Njovu, H.K., Pirk, C.W., Crewe, R.M. and Steffan-Dewenter, I., 2019. The conservation of native honey bees is crucial. *Trends in ecology & evolution*, *34*(9), pp.789-798

8. Gallai, N., Salles, J.M., Settele, J. and Vaissière, B.E., 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological economics*, *68*(3), pp.810-821.

9. Aizen, M.A. and Harder, L.D., 2009. The global stock of domesticated honey bees is growing slower than agricultural demand for pollination. *Current biology*, *19*(11), pp.915-918.

10. Giannini, T.C., Garibaldi, L.A., Acosta, A.L., Silva, J.S., Maia, K.P., Saraiva, A.M., Guimaraes Jr, P.R. and Kleinert, A.M., 2015. Native and non-native supergeneralist bee species have different effects on plant-bee networks. *PloS one*, *10*(9), p.e0137198.

11. Parker, R., Melathopoulos, A.P., White, R., Pernal, S.F., Guarna, M.M. and Foster, L.J., 2010. Ecological adaptation of diverse honey bee (Apis mellifera) populations. *PLoS One*, *5*(6), p.e11096

12. European Commission, 2021. European Red List. *European Commission*, accessed on 1th January 2022 via https://ec.europa.eu/environment/nature/conservation/species/redlist/bees/status.htm

13. Whitfield, C.W., Behura, S.K., Berlocher, S.H., Clark, A.G., Johnston, J.S., Sheppard, W.S., Smith, D.R., Suarez, A.V., Weaver, D. and Tsutsui, N.D., 2006. Thrice out of Africa: ancient and recent expansions of the honey bee, Apis mellifera. *Science*, *314*(5799), pp.642-645.

14. Meixner, M.D., 2010. A historical review of managed honey bee populations in Europe and the United States and the factors that may affect them. *Journal of invertebrate pathology*, *103*, pp.S80-S95.

15. Pollinator Health Task Force., 2016. *Pollinator Partnership Action Plan*. Washington D.C.: Pollinator Health task Force, pp.3-10.

16. McMinn-Sauder, H., Richardson, R., Eaton, T., Smith, M. and Johnson, R., 2020. Flowers in Conservation Reserve Program (CRP) pollinator plantings and the upper Midwest agricultural landscape supporting honey bees. *Insects*, *11*(7), p.405.

17. Iwasaki, J.M. and Hogendoorn, K., 2021. How protection of honey bees can help and hinder bee conservation. *Current Opinion in Insect Science*.

18. Katz, R.D., 2011. Who Speaks For The Bees? Narratives of Pollinator Protection in Public Policy. *Narratives of Pollinator Protection in Public Policy*.

19. Wilson, J.S., Forister, M.L. and Carril, O.M., 2017. Interest exceeds understanding in public support of bee conservation. *Frontiers in Ecology and the Environment*, *15*(8), pp.460-466.

20. Colla, S.R. and MacIvor, J.S., 2017. Questioning public perception, conservation policy, and recovery actions for honeybees in North America. *Conservation Biology*, *31*(5), pp.1202-1204.

21. Smith, T.J. and Saunders, M.E., 2016. Honey bees: the queens of mass media, despite minority rule among insect pollinators. *Insect Conservation and Diversity*, *9*(5), pp.384-390.

22. Memmott, J. and Waser, N.M., 2002. Integration of alien plants into a native flower–pollinator visitation web. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *269*(1508), pp.2395-2399.

23. Aizen, M.A., Garibaldi, L.A., Cunningham, S.A. and Klein, A.M., 2008. Long-term global trends in crop yield and production reveal no current pollination shortage but increasing pollinator dependency. *Current biology*, *18*(20), pp.1572-1575.

24. Cunningham, S.A., Fournier, A., Neave, M.J. and Le Feuvre, D., 2016. Improving spatial arrangement of honeybee colonies to avoid pollination shortfall and depressed fruit set. *Journal of Applied Ecology*, *53*(2), pp.350-359.

25. Wos, B., 2014. Api-tourism in Europe. *Journal of Environmental and Tourism Analyses*, *2*(1), p.66.

26. Ollerton, J., Winfree, R. and Tarrant, S., 2011. How many flowering plants are pollinated by animals?. *Oikos*, *120*(3), pp.321-326.

27. Hung, K.L.J., Kingston, J.M., Albrecht, M., Holway, D.A. and Kohn, J.R., 2018. The worldwide importance of honey bees as pollinators in natural habitats. *Proceedings of the Royal Society B: Biological Sciences*, *285*(1870), p.20172140.

28. Geslin, B., Gauzens, B., Baude, M., Dajoz, I., Fontaine, C., Henry, M., Ropars, L., Rollin, O., Thébault, E. and Vereecken, N.J., 1916. C0205 Massively Introduced Managed Species and Their Consequences for Plant–Pollinator Interactions.

29. Cane, J.H. and Tepedino, V.J., 2017. Gauging the effect of honey bee pollen collection on native bee communities. *Conservation Letters*, *10*(2), pp.205-210

30. Rucker, R.R., Thurman, W.N. and Burgett, M., 2012. Honey bee pollination markets and the internalization of reciprocal benefits. *American Journal of Agricultural Economics*, *94*(4), pp.956-977

31. Freitas, B.M., Paxton, R.J. and Holanda-Neto, J.D., 2002. Identifying pollinators among an array of flower visitors, and the case of inadequate cashew pollination in NE Brazil. *Pollinating bees: the conservation link between agriculture and nature*, pp.229-244.

32. Park, M.G., Raguso, R.A., Losey, J.E. and Danforth, B.N., 2016. Per-visit pollinator performance and regional importance of wild Bombus and Andrena (Melandrena) compared to the managed honey bee in New York apple orchards. *Apidologie*, *47*(2), pp.145-160.

33. Thomson, J.D. and Goodell, K., 2001. Pollen removal and deposition by honeybee and bumblebee visitors to apple and almond flowers. *Journal of Applied ecology*, pp.1032-1044.

34. Nabors, A.J., Cen, H.J., Hung, K.L.J., Kohn, J.R. and Holway, D.A., 2018. The effect of removing numerically dominant, non-native honey bees on seed set of a native plant. *Oecologia*, *186*(1), pp.281-289.

35. Courchamp, F., Fournier, A., Bellard, C., Bertelsmeier, C., Bonnaud, E., Jeschke, J.M. and Russell, J.C., 2017. Invasion biology: specific problems and possible solutions. *Trends in ecology & evolution*, *32*(1), pp.13-22.

36. Evans, E., Smart, M., Cariveau, D. and Spivak, M., 2018. Wild, native bees and managed honey bees benefit from similar agricultural land uses. *Agriculture, Ecosystems & Environment*, *268*, pp.162-170.

37. Gusachenko, O.N., Woodford, L., Balbirnie-Cumming, K., Ryabov, R.E.V. and Evans, D.J., 2020. Deformed Wing Virus spillover from honey bees to bumble bees: A reverse genetic study. *BioRxiv*, pp.2019-12.

38. Singh, R., Levitt, A.L., Rajotte, E.G., Holmes, E.C., Ostiguy, N., Vanengelsdorp, D., Lipkin, W.I., Depamphilis, C.W., Toth, A.L. and Cox-Foster, D.L., 2010. RNA viruses in hymenopteran pollinators: evidence of inter-taxa virus transmission via pollen and potential impact on non-Apis hymenopteran species. *PloS one*, *5*(12), p.e14357.

39. Ravoet, J., De Smet, L., Meeus, I., Smagghe, G., Wenseleers, T. and de Graaf, D.C., 2014. Widespread occurrence of honey bee pathogens in solitary bees. *Journal of Invertebrate Pathology*, *122*, pp.55-58.

40. Levitt, A.L., Singh, R., Cox-Foster, D.L., Rajotte, E., Hoover, K., Ostiguy, N. and Holmes, E.C., 2013. Cross-species transmission of honey bee viruses in associated arthropods. *Virus research*, *176*(1-2), pp.232-240.

41. Fries, I., Imdorf, A. and Rosenkranz, P., 2006. Survival of mite infested (Varroa destructor) honey bee (Apis mellifera) colonies in a Nordic climate. *Apidologie*, *37*(5), pp.564-570.

42. Garibaldi, L.A., Requier, F., Rollin, O. and Andersson, G.K., 2017. Towards an integrated species and habitat management of crop pollination. *Current opinion in insect science*, *21*, pp.105-114.

43. Pirk, C.W., Crewe, R.M. and Moritz, R.F., 2017. Risks and benefits of the biological interface between managed and wild bee pollinators. *Functional Ecology*, *31*(1), pp.47-55.

44. Prendergast, K.S., Dixon, K.W. and Bateman, P.W., 2021. Interactions between the introduced European honey bee and native bees in urban areas varies by year, habitat type and native bee guild. *Biological Journal of the Linnean Society*.

45. Ing, K. and Mogren, C.L., 2020. Evidence of competition between honey bees and Hylaeus anthracinus (Hymenoptera: Colletidae), an endangered Hawaiian yellow-faced bee. *Pacific Science*, *74*(1), pp.75-85.

46. Hung, K.L.J., Kingston, J.M., Lee, A., Holway, D.A. and Kohn, J.R., 2019. Non-native honey bees disproportionately dominate the most abundant floral resources in a biodiversity hotspot. *Proceedings of the Royal Society B*, *286*(1897), p.20182901.

47. Schlindwein, C., Wittmann, D., Martins, C.F., Hamm, A., Siqueira, J.A., Schiffler, D. and Machado, I.C., 2005. Pollination of Campanula rapunculus L.(Campanulaceae): How much pollen flows into pollination and into reproduction of oligolectic pollinators?. *Plant Systematics and Evolution*, *250*(3), pp.147-156.

48. Larsson, M., 2006. *To bee or not to be: critical floral resources of wild-bees* (Doctoral dissertation, Acta Universitatis Upsaliensis).

49. 49. Larsson, M. and Franzén, M., 2007. Critical resource levels of pollen for the declining bee Andrena hattorfiana (Hymenoptera, Andrenidae). *Biological Conservation*, *134*(3), pp.405-414.

50. Roubik, D.W., 1981. Comparative foraging behavior of Apis mellifera and Trigona corvina (Hymenoptera: Apidae) on Baltimora recta (Compositae). *Revista de Biologia Tropical*, *29*(2), pp.177-183.

51. Iwasa, T., Motoyama, N., Ambrose, J.T. and Roe, R.M., 2004. Mechanism for the differential toxicity of neonicotinoid insecticides in the honey bee, Apis mellifera. *Crop protection*, *23*(5), pp.371-378.

52. Rundlöf, M., Andersson, G.K., Bommarco, R., Fries, I., Hederström, V., Herbertsson, L., Jonsson, O., Klatt, B.K., Pedersen, T.R., Yourstone, J. and Smith, H.G., 2015. Seed coating with a neonicotinoid insecticide negatively affects wild bees. Nature, 521(7550), pp.77-80.

53. LeBuhn, G. and Vargas, J., 2021. Pollinator decline: what do we know about the drivers of solitary bee declines?. *Current Opinion in Insect Science*.

54. Garibaldi, L.A., Steffan-Dewenter, I., Kremen, C., Morales, J.M., Bommarco, R., Cunningham, S.A., Carvalheiro, L.G., Chacoff, N.P., Dudenhöffer, J.H., Greenleaf, S.S. and Holzschuh, A., 2011. Stability of pollination services decreases with isolation from natural areas despite honey bee visits. *Ecology letters*, *14*(10), pp.1062-1072.

55. Breeze, T.D., Bailey, A.P., Balcombe, K.G. and Potts, S.G., 2011. Pollination services in the UK: How important are honeybees?. *Agriculture, Ecosystems & Environment*, *142*(3-4), pp.137-143.

56. . Blitzer, E.J., Gibbs, J., Park, M.G. and Danforth, B.N., 2016. Pollination services for apple are dependent on diverse wild bee communities. *Agriculture, Ecosystems & Environment*, *221*, pp.1-7.

57. Geldmann, J. and González-Varo, J.P., 2018. Conserving honey bees does not help wildlife. *Science*, *359*(6374), pp.392-393.

58. Garantonakis, N., Varikou, K., Birouraki, A., Edwards, M., Kalliakaki, V. and Andrinopoulos, F., 2016. Comparing the pollination services of honey bees and wild bees in a watermelon field. *Scientia horticulturae*, *204*, pp.138-144.

59. MacInnis, G. and Forrest, J.R., 2019. Pollination by wild bees yields larger strawberries than pollination by honey bees. *Journal of Applied Ecology*, *56*(4), pp.824-832.

60. Abe, T., Wada, K., Kato, Y., Makino, S.I. and Okochi, I., 2011. Alien pollinator promotes invasive mutualism in an insular pollination system. *Biological Invasions*, *13*(4), pp.957-967.

61. Tepedino, V.J., 1979. The importance of bees and other insect pollinators in maintaining floral species composition. *Great Basin naturalist memoirs*, pp.139-150.

62. Garibaldi, L.A., Steffan-Dewenter, I., Winfree, R., Aizen, M.A., Bommarco, R., Cunningham, S.A., Kremen, C., Carvalheiro, L.G., Harder, L.D., Afik, O. and Bartomeus, I., 2013. Wild pollinators enhance fruit set of crops regardless of honey bee abundance. *science*, *339*(6127), pp.1608-1611.

63. Rader, R., Reilly, J., Bartomeus, I. and Winfree, R., 2013. Native bees buffer the negative impact of climate warming on honey bee pollination of watermelon crops. *Global change biology*, *19*(10), pp.3103-3110.

64. Winfree, R., Williams, N.M., Dushoff, J. and Kremen, C., 2007. Native bees provide insurance against ongoing honey bee losses. *Ecology letters*, *10*(11), pp.1105-1113.