How far is world agricultural production likely to be threatened by pollinator declines?

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Recent studies have shown declines in insect pollinators in North America and Europe. Animal pollinators, and particularly the honeybee, provide an essential ecosystem service in facilitating the reproduction of a large number of agricultural crops (Aizen et al. 2009) and improving yields for even more. Pollination provided for a total of 9.5% of the economic value of global food production in 2005 (Gallai et al. 2008). Thus, the question is raised whether, and if so to what extent, the decline in animal pollinators, which has so far been observed on a regional scale, poses a threat to global agricultural production. Although this is a concern for various agricultural sectors, such as e.g. the production of biofuels, this essay will focus on the implications of pollinator declines for the production of crops that are directly used as a food source by humans.

This essay will start off by demonstrating the importance of the service that animal pollinators, especially bees, provide. Following that, it will move on to discuss recent reported pollinator declines. In order to assess the potential threat to world agricultural production that might arise as a result of pollinator decline, the essay will then look at the relative importance of pollinator-dependent crops in world agricultural production, compared to non-pollinator-dependent crops. Consequently, a number of potentially threatening issues are discussed, such as the extent to which global agriculture depends on pollinator-dependent crops and the implications this has for yield stability; the strong reliance on pollinator "monocultures" (Winfree 2008), and the further problems that might arise due to climate change. The essay will conclude with the claim that world agricultural production is very likely to be threatened by pollinator declines, even though there remains a lot of uncertainty about its exact effects.

Animal pollination is necessary for the reproduction of most flowering plants (Willmer, 2011: 3). The service pollinators provide is therefore essential for both the functioning of natural ecosystems, and the production of a wide range of human food crops (Allsopp et al., 2008). According to data from 200 countries, approximately 75% of crop species identified as globally significant (FAO, 2005 as cited in Klein et al., 2007) rely, to different extents, on pollination, mostly by insects, although various other animals such as birds and bats also provide this ecosystem service. Among insect pollinators, bees are the most important (Willmer, 2011: 4; Klein et al., 2007) as they can pollinate the large majority of crops. Pollination by one of the most commonly used species, *Apis mellifera* (the European honeybee), is able to increase productivity of 96% of animal-pollinated crops (Klein et al., 2007; Winfree, 2010), and is widely used as a managed pollinator. It is, however, not always the most effective pollinator (Kremen et al., 2002) since unmanaged native species can contribute considerably to the pollination of many crops (Goulson, 2003). The importance of both managed and wild bees to agriculture has been emphasised by many scholars (e.g. Kluser and Peduzzi, 2007), although their relative contribution to global agricultural production has not clearly been detected (Potts et al., 2010). In addition to being crucial for the reproduction of pollinator-dependent crops, pollinators can also enhance the quality and quantity of seeds and fruits of self-fertile crops (e.g. Klein et al., 2003, Eilers et al., 2011). A case study on factors important for successful pollination of lowland coffee (*Coffea canephora*), a self-sterile crop, by Klein et al. (2003a) showed that a high diversity of pollinating bees can lead to a significantly higher fruit set. Similar data exist for the example of highland coffee (*Coffea arabica*) in Indonesia, which is a self-fertilizing crop (Klein et al., 2003b). Overall, pollination is an ecosystem service that is invaluable to agriculture.

In recent decades, however, insect pollinators have been frequently reported to be in decline. Pollinators are under a lot of pressure. Paradoxically, many of the pressures on pollinators can be directly attributed to industrial agricultural practices. Potts et al. (2010) mention land-use change and resultant habitat loss and fragmentation, pesticide use and environmental pollution, decline in resource diversity, the introduction of alien species, the spread of pathogens and climate change (Potts et al., 2010: 348) as potential drivers of pollinator decline. These factors have led to regional declines in insect pollinators, mainly in Europe and the USA, where feral and managed honey bees have declined by 25% in recent decades (Allen-Wardell et al., 1998). VanEngelsdorp et al. (2008) investigated the honey bee colony declines due to Colony Collapse Disorder (CCD) in the winter of 2007-2008, reporting a total loss of 35.8% of colonies. Another study by Biesmeijer et al. (2006) reports that bee diversity has fallen significantly in Britain and the Netherlands since 1980, which was accompanied by a decline in wild plant communities. In this case, it is not clear what the exact causal relations between these two observed declines are, but they might be relations of positive feedback. In economic terms, “proof” of the growing decline in pollinators, and hence in hives supply, is the increase in money spent by farmers to rent honey bees (Winfree, 2006).

While there are plenty of reported regional declines in insect pollinators, there has been debate about whether this amounts to an “impending ‘global pollinator crisis’” (Ghazoul, 2005: 367). According to Nabhan (1996), and Matheson et al. (1996) (as cited in Allen-Wardell et al., 1998: 10) a high number of pollinators might be under threat of extinction worldwide and data exists for global bumble bee decline (mentioned in Winfree, 2010: 171). On the other hand, Ghazoul (2005) emphasises that research pointing towards pollinator decline is based on data on particular regions and pollinators: honeybees in the USA and bumblebees and butterflies in Europe, arguing that a minority of important food crops is dependent on pollinators.

Given the importance of pollinators demonstrated above, and the evidence for a decline in pollinators, at least on a regional scale, it is important to estimate the importance of pollinator-dependent crops in world agricultural production. This is done by considering global production volumes of non-dependent crops compared to dependent ones and investigating the importance of pollinator dependent crops in providing for human dietary needs.

Regarding production quantity, most of the crops grown for the provision of human food are not pollinator-dependent (Allsopp et al., 2008; Willmer, 2011). Instead, their reproduction is facilitated by abiotic pollination, self-pollination or vegetative propagation (Eilers et al., 2011). For example, staple crops such as rice, wheat, maize, oats and sorghum are wind pollinated (Willmer, 2011: 605) and therefore not in danger of being affected by pollinator declines. Klein et al. (2007) define 115 “principal world crops” (as cited in Willmer, 2011: 606), of which those 28 crops that are not dependent on animal pollinators account for 60% of global agricultural production. It has also been stated that most crops reliant on animal pollination are “minority or specialist foods” (Richards, 2001: 170) without global importance and that hardly any staple crops are dependent on animal pollination (Richards 2001, Ghazoul 2005).

However, the importance of pollinator-dependent crops must not be underestimated. Examining the variety of crops used for food production, the majority are to some degree pollinator-dependent, reaching from pollination as essential for reproduction to cases in which pollination increases yield and yield quality but is not necessarily required (see Klein et al., 2007). About one third of what humans eat depends directly or indirectly on pollinators

(Kearns et al. as cited in Ghazoul, 2005: 387; Kluser and Peduzzi, 2007: 354). Although production volumes of the 115 principal world crops amount to only 35% of total crop production, the number of crops dependent (to different degrees) on animal pollination is 87 out of 115 (Willmer, 2011: 606).

Klein et al. (2007) examined the proportion of global crops used directly for human food that depend on animal pollination for fruit and seed production to different degrees. They found that 20% of world crop production accounts for crops with increased production of fruit and vegetables when animal-pollinated, and approximately 15% accounts for crops whose seed production increases with pollination (Klein et al., 2007: 306). They also identified the level of dependence of those plants on pollinators and provide evidence for "increased production with pollinators in 92 out of 108 selected crops" (*ibid*.: 307). Animal pollination was essential for 13 crops, and dependence was high for 30 crops, modest for 27 crops, and little for 21 crops (Klein et al., 2007).

It is also important to consider the nutritional quality of pollinator dependent crops: Eilers et al. (2011) analysed the nutritional composition of more than 150 of the leading global crops, using data on animal pollinator dependency by Klein et al. (2007). Eilers et al. (2011) found that pollinator-dependent crops hold most of the lipids, vitamins and minerals that are necessary to prevent nutritional deficiency. For example, 98% of the available vitamin C is present in pollinator-dependent plants, and 58% of calcium comes from plants that have an increased yield due to animal pollination. While there are some nutrients present in non-dependent crops, these are mostly lost during processing.

Overall, pollinator-dependent crops make up a considerable proportion of world agricultural production, and are of paramount importance for human nutritional needs. It is in this context that the effect of pollinator declines on global agricultural production has to be evaluated.

Given the importance of pollinator-dependent crops illustrated above, pollinator declines could pose various risks and threats to world agricultural production. One of these issues relates to the growing percentage of pollinator-dependent crops grown globally and a resulting threat to the stability of crop yields. Garibaldi et al (2011) suggest that yield improvement over the last decades was lower the more dependent the respective crop is on pollinators. They found that variation in pollination is responsible for "half of the yield stability of dependent crops" (Garibaldi et al., 2011: 5911). Likewise, Aizen et al. (2009), examining data for from 1961 to 2006 to investigate trends in global cultivated areas, found that the overall area that accommodates pollinator-dependent crops has constantly been growing, outpacing the growth in honeybee colonies (Garibaldi, 2011). These trends point in the direction of a rise in the "extent of agricultural reliance on animal pollination" (Steffan-Dewenter et al., 2005: 651), and an increase of yield instability with the growing production of pollinator-dependent crops on a global scale and posing a considerable risk for agricultural production in the face of pollinator declines.

Another threat is posed by the increasing reliance of agricultural production on single pollinator species. Wild pollinators are sufficient to pollinate agricultural crops when their needs for habitats are met (Kremen et al., 2002). More than 40% of the major animal pollinated crops have been said to rely on wild pollinators (Power, 2010). They do, however, tend to decline in areas of large scale intensive agricultural production and monocultures (Ricketts et al., 2008, as cited in Winfree, 2008: R968), in which case they do not suffice to pollinate crops. The European honey bee, in contrast, can conveniently be managed to pollinate agricultural crops (Winfree, 2008), and can increase yield in 96% of animal-pollinated crops (Klein et al., 2007; Winfree 2010). Honeybees are responsible for around 80% of pollination in the USA (USDA as cited in Willmer, 2011: 606). This "virtual monoculture" (Winfree, 2008: R9688) of generalist pollinators poses various threats on agriculture, which are exacerbated by the low genetic variety that results from the limited number of breeding facilities that produce queens (Johnson, 2007 as cited in Winfree, 2008: R968). Such threats include the potential competition with, and further reduction of, native pollinators (see Potts et al., 2010) and the susceptibility to parasites and pathogens (Winfree, 2008; 2010). Bees are generally more prone to extinction than other taxa (Steffan-Dewenter et al., 2005). The yet unexplained Colony Collapse Disorder (e.g. Kluser and Peduzzi, 2007, VanEngelsdorp 2008), can lead to the relatively sudden death of large numbers of whole honeybee colonies, which poses severe risk on cultivated areas that are relying on them as main pollinators. All these factors make the reliance on honeybees as main pollinators in many cultivated areas of the world uncertain.

Finally, the role climate change is particularly salient to the issue of pollinator decline. Changing temperatures might lead to a mismatch in the temporal and spatial occurrence of pollinators and flowers (Potts et al., 2010; Winfree, 2010), for example when flowering time shifts due to warmer weather. It could also result in lasting mismatches between pollinator and plant that have been evolved together, if one adapts to a new climate faster than the other and changes behaviour (Winfree 2010). Although evidence remains fairly limited, some declines in pollinators as a result of climate change have been reported (as mentioned in Potts et al., 2010: 351), and, given that extreme weather conditions and disturbances due to global climate change are projected to occur with increasing frequency in the next decades, this trend is likely to increase.

This essay has shown the significance of animal pollinators for world agricultural production and looked at a selection of threats that might arise from pollinator declines. Although most of the declines have been reported on a regional scale, the findings of Aizen et al. (2008) suggest that pollinator limitation might be on the verge of becoming a global issue (Winfree, 2008). Serious threats are likely to be posed on agricultural production in the form of yield instability and a slowdown in yield growth for pollinator-dependent crops. The reliance on monocultures with a single species of pollinators bears immense risk. In addition, climate change poses a threat of yet unknown significance in the future. Therefore, pollinator declines are very likely to have negative effects on world agricultural production, threatening human food supply. "[I]f the area of pollinator-dependent crops is increasing and the supply of pollinators decreasing, we will encounter pollination-driven declines in food production eventually" (Winfree, 2008: R968). Research by Aizen et al. (2009) suggests that in case of complete pollinator absence, total agricultural production is expected to decline by 3-8%, "with smaller impacts on agricultural production diversity" (Aizen et al., 2009: 1579), which means that current demands for animal-pollinated food crops could not be met any more. Furthermore, pollinator declines also impact on biodiversity in natural ecosystems, which can lead to feedback effects on cultivated areas. All these issues "act simultaneously and could act synergistically" (Potts et al., 2010: 351). They are also inherently uncertain and long-term empirical data is lacking (Winfree, 2010). Hence, the implications of further pollinator declines, or even absence, for world agricultural production cannot be reliably forecast due to the complexity of ecosystems and the interactions between their inhabitants, which might add further threats to agriculture.

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