

Pollinator decline and its effects on ecosystem stability and crop production

Dr. Vinod kumar Mishra*

Assistant Professor, Zoology, Government Thakur Ranmat Singh College, Rewa, Madhya
Pradesh, India

drvinodmishra813@gmail.com

Abstract: Pollinator decline has emerged as one of the most consequential biodiversity crises of the contemporary era, with implications that extend from the structural integrity of natural ecosystems to the economic security of global agriculture. This paper examines the documented evidence of pollinator decline, analyzes its principal drivers, and critically assesses its dual impact on ecosystem stability and crop production. Drawing on ecological network theory, bioeconomic modeling, and empirical field studies, the paper argues that pollinator decline operates through two interlocking pathways: a destabilization of plant–pollinator mutualistic networks that erodes the resilience of natural ecosystems, and a direct constraint on crop yields that disproportionately threatens food security in nutrient-poor and import-dependent regions. The analysis further interrogates the limitations of current mitigation strategies, including agri-environmental schemes, and highlights persistent gaps between conservation policy and agricultural practice. The paper concludes that addressing pollinator decline requires not merely isolated conservation interventions but a fundamental reconciliation of agricultural intensification with ecological function.

Keywords: Pollinator, intensification, ecological, conservation policy, structural integrity

1. INTRODUCTION

The relationship between flowering plants and their animal pollinators represents one of the most ecologically and economically significant mutualisms in the natural world. Over the past two decades, a substantial and growing body of evidence has documented declines in both the abundance and diversity of pollinating insects across multiple continents, taxonomic groups, and habitat types. Long-term monitoring using standardized trapping protocols across more than five dozen nature protection areas in Germany recorded a seasonal decline of seventy-six percent, and a mid-summer decline of eighty-two percent, in total flying insect biomass over a twenty-seven-year period, with the decline apparent regardless of habitat type (Hallmann et al., 2017). Such findings, corroborated by subsequent studies across Western Europe, have elevated pollinator decline from a specialized concern within conservation entomology to a matter of broad scientific and public alarm (Powney et al., 2019; Seibold et al., 2019, as cited in Duchenne et al., 2021).

The significance of this decline cannot be adequately understood through a single lens. Pollinators are not merely one component among many in the natural world; they are a keystone functional group whose activity underlies the reproduction of the majority of the world's flowering plant species and a substantial share of global food production. More than eighty-seven percent of flowering plant species depend on animal pollination for reproduction, and eighty-seven of the leading global food crops rely on pollinators, a dependency that corresponds to roughly thirty-five percent of global crop production volume by weight (Ollerton, Winfree, & Tarrant, 2011; Klein et al., 2007, as cited in Kleftodimos et al., 2024). Pollinator decline therefore sits at the intersection of two distinct but interdependent concerns: the stability of the ecological networks that sustain wild biodiversity, and the productive capacity of the agricultural systems that sustain human food security. This paper analyzes both dimensions in turn, before considering the adequacy of current responses and the structural challenges that limit their effectiveness.

The analytical approach taken here treats pollinator decline not as an isolated environmental event but as a systems-level phenomenon, in which multiple interacting stressors compound to drive nonlinear and sometimes irreversible outcomes. This framing matters because it shifts the policy question away from addressing any single driver in isolation and toward understanding how interventions targeting one stressor may be undermined or amplified by the presence of others. The sections that follow examine the principal drivers of decline, the mechanisms by which decline destabilizes ecosystems, the corresponding effects on crop production and food security, and the strengths and limitations of current mitigation strategies.

2. DOCUMENTING THE DECLINE: SCALE AND EVIDENCE

The evidence base for pollinator decline is drawn from multiple independent lines of inquiry, each with distinct strengths and limitations, and a critical reading of this evidence reveals both clear consensus and meaningful uncertainty. Long-term abundance data for individual species and taxonomic groups have been complemented in recent years by biomass-based monitoring, which captures changes in total insect mass rather than relying solely on the presence or absence of particular taxa; this distinction matters because biomass is often considered more ecologically meaningful for assessing functional impacts on pollination and food webs than species counts alone (Hallmann et al., 2017). The convergence of biomass decline data from Germany with independent species-abundance data from the United Kingdom and elsewhere

in Western Europe lends considerable weight to the conclusion that the decline is real, broad-based, and not an artifact of any single methodology (Powney et al., 2019; Seibold et al., 2019, as cited in Duchenne et al., 2021).

Nonetheless, important sources of uncertainty remain, and an honest analytical treatment of the literature must acknowledge them rather than treat the decline narrative as monolithic. Research on the role of climate change in driving pollinator decline across the Northern Hemisphere has noted that there is currently no scientific consensus on which drivers are most important, and that while climate change is expected to contribute to future biodiversity loss, current warming trends have in some cases been associated with positive effects on pollinator assemblages at higher latitudes, complicating any simple narrative of uniform climate-driven decline (Duchenne et al., 2021). This regional and taxonomic heterogeneity suggests that global pronouncements about pollinator decline, while broadly accurate in direction, may obscure substantial variation in magnitude and even sign across geographies, a nuance with direct implications for how mitigation resources ought to be targeted.

3. DRIVERS OF POLLINATOR DECLINE: AN ANALYTICAL SYNTHESIS

The drivers of pollinator decline are numerous, and a purely additive view of these drivers—treating each as an independent contributor to a single aggregate decline—understates the analytical complexity of the problem. The most comprehensive global risk assessment to date, an international expert panel convened to construct the first planetary risk index for pollinator decline, ranked habitat destruction as the foremost global cause of pollinator loss, followed by land management practices such as livestock grazing, fertilizer application, and crop monoculture, with widespread pesticide use ranking third and climate change fourth, although the panel noted that data constraints limit confidence in the climate ranking (University of Cambridge, 2024). This ranking is analytically significant because it reframes the popular narrative, which often foregrounds pesticides or climate change, by foregrounding instead the structural transformation of agricultural land use itself as the primary driver.

A more detailed review of these drivers identifies habitat loss and fragmentation, agrochemical exposure, pathogen transmission, the spread of alien and invasive species, and climate change as the principal forces at work, while explicitly emphasizing that the interactions between these drivers may be as consequential as any single driver in isolation (Potts et al., 2010). This emphasis on interaction effects represents a critical analytical point: stressors that might be

individually sublethal can combine synergistically to produce outcomes far more severe than the sum of their parts. Pesticide exposure, for instance, can impair a pollinator's immune function in ways that increase its susceptibility to pathogens that it might otherwise tolerate, while habitat fragmentation can simultaneously reduce the floral resources available to buffer against nutritional stress and increase the physiological cost of foraging across degraded landscapes. A subsequent review has explicitly confirmed that synergistic interactions between stressors such as habitat loss, pesticide use, pathogens, pollution, and climate change can intensify negative impacts on pollinators and accelerate the pace of species loss beyond what any single-driver model would predict (Goulson et al., 2015; Janousek et al., 2023; Williams & Hemberger, 2023, as cited in Tong et al., 2024).

A further and increasingly recognized driver—one that complicates straightforward conservation narratives—is the negative effect that managed honeybee populations can themselves exert on wild bee species, primarily through resource competition for limited floral resources (Tong et al., 2024). This finding carries an important analytical implication: conservation strategies that focus narrowly on supporting domesticated pollinator populations, such as commercial beekeeping, may not only fail to protect wild pollinator diversity but could in some contexts actively undermine it, particularly in landscapes where floral resources are already limited by agricultural intensification. This tension between managed and wild pollinator conservation has not been fully resolved in the literature and represents a genuine point of ongoing scientific and policy debate rather than a settled matter.

4. ECOSYSTEM STABILITY: NETWORK THEORY AND THE MECHANICS OF DECLINE

The effects of pollinator decline on ecosystem stability are best understood through the lens of ecological network theory, which models plant–pollinator interactions not as isolated pairwise relationships but as complex webs of mutual dependency. Plant–pollinator networks are frequently structured in a nested topology, in which specialist species interact with a subset of the partners used by generalist species; this nested structure is theoretically linked to greater community stability, because if a specialist pollinator is lost, a functionally equivalent generalist may be able to assume its ecological role, a phenomenon described as the insurance hypothesis (Bascompte, Jordano, Melián, & Olesen, 2003; Bastolla et al., 2009, as cited in research on biodiversity-productivity relationships). Empirical work testing this hypothesis

has found that the degree of nestedness in a network is a significant predictor of reduced temporal variability in measures of primary productivity, lending support to the idea that network structure itself functions as a buffer against the loss of individual species.

This buffering capacity, however, is neither unlimited nor guaranteed, and a closer analytical examination reveals important boundary conditions on network resilience. Modeling work combining theoretical frameworks with empirical plant–pollinator networks from around the world has demonstrated that increasing disturbance-induced mortality can drive plant–pollinator systems through critical transitions into an undesired low-abundance state, a dynamic amplified by positive feedback loops between declining plant rewards and declining pollinator visitation (research on ecosystem complexity and resilience in plant-pollinator systems, 2021). Crucially, this same research found that network complexity—measured as connectance or species richness—enhances the capacity of plant–pollinator communities to withstand external disturbance, which implies that the very biodiversity loss driving pollinator decline may simultaneously erode the structural property that would otherwise buffer ecosystems against that decline. This creates a potentially self-reinforcing spiral: as diversity declines, network complexity falls, and the system's capacity to absorb further shocks deteriorates, increasing the likelihood of an abrupt rather than gradual transition to a degraded ecological state.

The cascading consequences of pollinator loss extend beyond the pollinators themselves to the plant communities they service, through a process known as coextinction. Simulation studies modeling the removal of pollinator species from real-world interaction networks have found that while plant phylogenetic diversity often declines faster than would be expected under random species loss, plant functional diversity—the variety of ecological strategies and traits represented in a plant community—proves comparatively more robust to coextinction cascades, declining more slowly than chance alone would predict (research on plant-pollinator coextinctions, 2013). This is an analytically important and somewhat counterintuitive finding: it suggests that pollinator decline may erode the evolutionary history embedded within a plant community more rapidly than it erodes that community's functional capacity to maintain ecosystem processes such as nutrient cycling and productivity, at least in the earlier stages of decline. This divergence between phylogenetic and functional consequences highlights the importance of distinguishing between different dimensions of biodiversity loss rather than treating "ecosystem stability" as a single undifferentiated outcome variable, since a community

could appear functionally resilient by certain measures while having already lost irreplaceable evolutionary diversity.

Further complicating the stability picture, research on the propensity for extinction cascades in plant–pollinator networks has shown that the species most critical to overall community persistence—those with the highest connectance, often termed keystone species—are frequently also the species most vulnerable to coextinction, since their central position in the network exposes them to a wider range of partner losses (Vanbergen et al., 2017). This finding represents a troubling structural irony: the very network properties that confer resilience under normal conditions may concentrate risk in precisely the nodes whose loss would be most destabilizing, meaning that network-based resilience can mask a fragility that only becomes apparent once a critical threshold of disturbance is crossed. Taken together, the network-theoretic literature suggests that ecosystem stability in the face of pollinator decline is neither uniformly robust nor uniformly fragile, but contingent on network structure, the identity of the species lost, and the cumulative intensity of the stressors at play—a far more nuanced picture than simple narratives of either resilience or collapse would suggest.

5. EFFECTS ON CROP PRODUCTION: YIELD GAPS AND ECONOMIC CONSEQUENCES

The implications of pollinator decline for agricultural production are both more immediately measurable and, in important respects, more severe than is commonly appreciated. A comprehensive global assessment analyzing nearly two hundred thousand plant–pollinator interactions and over two thousand yield measurements across thirty-two crop species found that twenty-eight to sixty-one percent of crop systems worldwide are currently limited by insufficient pollinator visitation, a phenomenon termed pollinator limitation, with blueberry, coffee, and apple identified as the crops most frequently affected (Turo et al., 2024). The same study found that increasing pollinator densities could close sixty-three percent of the yield gap currently observed in these systems, indicating that a substantial share of global agricultural productivity is being left unrealized not because of limitations in soil, water, or genetics, but specifically because of insufficient pollination service (Turo et al., 2024). This finding is analytically significant because it demonstrates that pollinator decline is not merely a future risk to be modeled hypothetically; it is already actively constraining realized crop yields at a global scale.

The economic magnitude of these effects becomes clearer when modeled through bioeconomic frameworks that simulate the consequences of further pollinator decline or collapse. A revised global bioeconomic model simulating a worldwide pollinator collapse projected that crop prices would rise by approximately thirty percent, producing a global welfare loss of 729 billion dollars, equivalent to roughly 0.9 percent of global gross domestic product and 15.6 percent of the global value of agricultural production used for human food (research on degraded pollination ecosystem services, 2023). The same modeling exercise found that global availability of Vitamin A would fall by approximately eight percent under such a scenario, illustrating that the consequences of pollinator decline extend beyond aggregate caloric supply into the micronutrient composition of global diets, with corresponding implications for public health that are easily overlooked in analyses focused solely on tonnage or market value (research on degraded pollination ecosystem services, 2023).

A regional analysis modeling a hypothetical collapse of wild pollinators in Europe by 2030 projected an eight percent reduction in European crop yields, a contraction in net agricultural exports, and a partial—but only partial—mitigation of these effects through land-use expansion and international trade adjustments, with the model estimating a global annual welfare decline of thirty-four billion euros even after accounting for these market adjustments (research on the economic and food security repercussions of wild pollinator collapse in Europe, 2025). This finding carries an important analytical nuance: market mechanisms such as trade and cropland expansion can absorb some of the shock of pollinator decline, but they do so unevenly, with European Union member states that have resisted stronger biodiversity protection policies projected to bear disproportionately higher costs, and with the burden of price increases falling primarily on consumers rather than producers, who may in fact benefit from higher prices for the crops they are still able to bring to market (research on the economic and food security repercussions of wild pollinator collapse in Europe, 2025).

The distributional consequences of pollinator decline are not evenly shared across the global economy, and this asymmetry constitutes one of the most important findings in the recent literature. Research focused specifically on low-income countries found that pollinator declines have already reduced global production of fruit, vegetables, and nuts by three to five percent, contributing to an estimated 427,000 excess deaths annually due to reduced consumption of nutrient-dense foods, with researchers focusing their economic analysis on Nepal, Honduras, and Nigeria finding annual economic losses in agricultural crop value of

thirty-one percent, seventeen percent, and twelve percent respectively (research published in Environmental Health Perspectives, cited in Beyond Pesticides, 2023). Low-income countries were found to experience yield gaps in vegetable and nut production averaging twenty-six percent and eight percent respectively, substantially exceeding the global average, a disparity attributable to these countries' greater reliance on wild, unmanaged pollinators and their more limited capacity to substitute lost pollination services through managed beekeeping or technological alternatives (research published in Environmental Health Perspectives, cited in Beyond Pesticides, 2023). This evidence supports an analytical conclusion with significant equity implications: pollinator decline, although a global phenomenon in its drivers, generates economic and nutritional harm that is concentrated disproportionately among the populations least responsible for, and least able to buffer against, the underlying causes of that decline.

It would, however, be analytically incomplete to characterize pollinator dependence as uniform across all crops, and the literature offers an important corrective on this point. Soybean, one of the world's most widely cultivated crops, is self-compatible and does not strictly require insect pollination, yet research has found that bee pollination can nonetheless increase soybean yields by up to forty percent in some studies, even as other studies report more modest or inconsistent effects (Blettler et al., 2018; Cunha et al., 2023; Chiari et al., 2005; Gazzoni & Barateiro, 2023, as cited in research on pollinator decline and global protein production, 2024). This variability illustrates a broader analytical point often elided in alarmist accounts of pollinator decline: the agricultural consequences of decline are highly crop-specific, ranging from crops that are entirely dependent on insect pollination for any yield at all to crops that are nominally self-pollinating but still receive a meaningful yield benefit from insect visitation, to crops that are genuinely unaffected. Aggregate global statistics, while useful for conveying overall scale, can obscure this underlying heterogeneity in ways that matter considerably for prioritizing conservation and agricultural policy responses.

6. INTERROGATING MITIGATION STRATEGIES: PROMISE AND LIMITATIONS

The dominant policy response to pollinator decline across much of Europe and North America has been the implementation of agri-environmental schemes, particularly the establishment of flower strips and other semi-natural habitat features along field margins, often supported through direct government subsidy (Albrecht et al., 2020; Haaland et al., 2011, as cited in

Sydenham et al., 2023). The evidence supporting these interventions is genuinely substantial with respect to their direct ecological effects: flower strips have been shown to increase wild bee population abundance and species diversity both within the strips themselves and in the surrounding landscape, and recent research demonstrates that combining flower strips with extensively managed meadows produces synergistic effects, increasing bee abundance and broadening dietary niches more effectively than either intervention alone, while also reducing the local extinction risk of bee species relative to either intervention in isolation (research on synergistic enhancement of wild bee abundance, 2026).

A rigorous analytical treatment of this evidence, however, must also confront a striking and underappreciated limitation: while flower strips reliably increase pollinator abundance and diversity at the margin, their effect on the variable that ultimately matters most for food security—actual crop yield in adjacent fields—is far less consistently demonstrated. A review of agri-environment scheme literature notes that while wide success has been observed in studies measuring increases in insect diversity and richness within flower strips, no consistent pattern has been detected with respect to pollinators spilling over from these strips into adjacent crop fields and positively influencing crop yield, and that two separate meta-analyses found no overall increase in crop yield following flower strip implementation (research on pollen collection by honeybees and bumblebees in agri-environment schemes, 2025). This is a critical and somewhat uncomfortable finding for proponents of flower-strip-based conservation: it suggests that current agri-environmental policy may be effectively achieving its stated biodiversity conservation goals while failing to deliver on its often-implied promise of resolving the agricultural production consequences of pollinator decline, at least as currently designed and at current scales of implementation.

Several factors help explain this disjunction between biodiversity gains and yield outcomes, and identifying them is essential for designing more effective interventions. The effectiveness of flower strips has been shown to depend heavily on their age, since pollinator populations require multiple years to build up persistent numbers following establishment, with wildflower plantings in some studies showing substantially greater bee abundance three to four years after establishment compared to the first year (Blaauw & Isaacs, 2014, as cited in Sydenham et al., 2023). Effectiveness is also strongly moderated by the surrounding landscape context, with research finding that sown flower fields are no substitute for perennial semi-natural habitat, underscoring that flower strips function best as a complement to, rather than a replacement

for, broader landscape-level habitat conservation (research on size, age, and surrounding semi-natural habitats, 2019). Different pollinator taxa also respond differently to these interventions: honeybees tend to forage preferentially on mass-flowering crops, wild bees show a stronger preference for semi-natural habitats, and bumblebees behave as relative habitat generalists, meaning that a single intervention type is unlikely to optimally serve the full diversity of pollinator species present in any given agricultural landscape (research on pollen collection by honeybees and bumblebees, 2025).

A further, less commonly discussed complication is that agri-environmental interventions designed to support pollinators may carry unintended costs alongside their benefits. Research examining disease transmission in bumblebees has found that agri-environment schemes such as flower strips, despite their established benefits for nutrition and survival, may also increase rates of viral disease transmission among bumblebees by concentrating individuals from multiple colonies at shared floral resources, suggesting that the design of these schemes may need further refinement to maximize net health benefits to wild pollinator populations rather than assuming that habitat provision is an unambiguous good (research on host density and viral transmission in a key pollinator, 2020). This finding exemplifies the broader analytical theme running through this paper: interventions targeting any single dimension of the pollinator decline problem risk being undermined by interactions with other, less visible dimensions of pollinator biology and ecology, reinforcing the conclusion that effective mitigation requires systems-level thinking rather than isolated, single-mechanism solutions.

7. SYNTHESIS: RECONCILING ECOSYSTEM AND AGRICULTURAL PERSPECTIVES

Bringing together the ecosystem stability and crop production literatures reveals a layered and mutually reinforcing structure of risk. At the ecological level, pollinator decline erodes the structural properties—connectance, nestedness, species richness—that confer resilience on plant–pollinator networks, with the paradox that the keystone species whose loss would be most destabilizing are often also the species most vulnerable to coextinction. At the agricultural level, this same erosion translates into measurable and in some cases already-realized yield gaps, with economic and nutritional consequences that fall disproportionately on low-income countries and populations least equipped to substitute lost pollination services through managed alternatives or international trade. These two levels are not independent: the

same drivers—habitat loss, agrochemical exposure, climate change, and their synergistic interactions—operate simultaneously on wild ecosystems and agricultural landscapes, meaning that policies addressing one domain in isolation are unlikely to fully resolve the other.

The evidence on mitigation strategies suggests that current responses, while not without genuine merit, remain only partially adequate to the scale of the underlying problem. Flower strips and related agri-environmental schemes demonstrably support pollinator abundance and diversity, yet the disconnect between these biodiversity gains and actual crop yield outcomes suggests that conservation and agricultural production goals, while theoretically aligned, are not yet practically integrated in most current policy frameworks. This points toward a broader structural critique echoed in recent literature on insect ecosystem services more generally: conservation efforts are too often designed in isolation by environmental agencies, disconnected from agricultural and food policy, such that protected pollinator habitat may exist immediately adjacent to cropland still subject to intensive agrochemical use, limiting the practical conservation and production benefits that either domain might otherwise realize.

8. CONCLUSION

Pollinator decline represents a convergence of ecological and economic risk that resists simple characterization or singular solution. The evidence reviewed in this paper demonstrates that the decline is real, substantial, and driven by multiple interacting stressors whose combined effects exceed what any additive model would predict. Its consequences for ecosystem stability operate through the destabilization of mutualistic networks whose resilience properties are more fragile and more unevenly distributed across species than is commonly assumed, while its consequences for crop production are already measurably constraining global agricultural yields and disproportionately burdening the food security and economic welfare of low-income, import-dependent regions. Current mitigation strategies, particularly agri-environmental schemes such as flower strips, have demonstrated real success in supporting pollinator biodiversity but have not yet been shown to reliably translate into the crop yield improvements that motivate much of their public and political support, revealing a gap between ecological intervention and agricultural outcome that future policy and research must work to close. Addressing pollinator decline at a scale commensurate with its risks will require treating ecological conservation and agricultural production not as separate policy

domains but as interdependent components of a single food system whose stability depends on the health of the pollinators that quietly sustain it.

References

1. Bascompte, J., Jordano, P., Melián, C. J., & Olesen, J. M. (2003). The nested assembly of plant–animal mutualistic networks. *Proceedings of the National Academy of Sciences*, 100(16), 9383–9387.
2. Beyond Pesticides. (2023, January 10). *Pollinator decline leads to crop losses, malnutrition, and highest threat to low-income* [Summary of study published in Environmental Health Perspectives]. <https://beyondpesticides.org/dailynewsblog/2023/01/pollinator-decline-leads-to-crop-losses-malnutrition-and-highest-threat-to-low-income/>
3. CABI Reviews. (2024). What are the main reasons for the worldwide decline in pollinator populations? <https://www.cabidigitallibrary.org/doi/10.1079/cabireviews.2024.0016>
4. Duchenne, F., et al. (2021). The role of climate change in pollinator decline across the Northern Hemisphere is underestimated. *Science of the Total Environment*. <https://www.sciencedirect.com/science/article/abs/pii/S004896972100855X>
5. Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörrén, T., Goulson, D., & de Kroon, H. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLoS ONE*, 12(10), e0185809.
6. Klein, A. M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences*, 274(1608), 303–313.
7. Nature Communications. (2025). The economic, agricultural, and food security repercussions of a wild pollinator collapse in Europe. <https://www.nature.com/articles/s41467-025-65414-7>

8. Ollerton, J., Winfree, R., & Tarrant, S. (2011). How many flowering plants are pollinated by animals? *Oikos*, 120(3), 321–326.
9. PLOS ONE. (2013). Plant-pollinator coextinctions and the loss of plant functional and phylogenetic diversity.
<https://journals.plos.org/plosone/article?id=10.1371%2Fjournal.pone.0081242>
10. Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: Trends, impacts and drivers. *Trends in Ecology & Evolution*, 25(6), 345–353.
11. ScienceDirect. (2021). Ecosystem complexity enhances the resilience of plant-pollinator systems.
<https://www.sciencedirect.com/science/article/pii/S2590332221004668>
12. ScienceDirect. (2023). Impacts of degraded pollination ecosystem services on global food security and nutrition.
<https://www.sciencedirect.com/science/article/abs/pii/S0921800923003312>
13. ScienceDirect. (2024). The impact of pollinator decline on global protein production: Implications for livestock and plant-based products.
<https://www.sciencedirect.com/science/article/pii/S2351989424000192>
14. ScienceDirect. (2026). Synergistic enhancement of wild bee abundance at the landscape scale through multiple types of agri-environmental interventions.
<https://www.sciencedirect.com/science/article/pii/S016788092600068X>
15. ScienceDirect. (2019). Size, age and surrounding semi-natural habitats modulate the effectiveness of flower-rich agri-environment schemes to promote pollinator visitation in crop fields.
<https://www.sciencedirect.com/science/article/abs/pii/S0167880919302063>
16. PMC. (2025). Pollen collection by the western honeybee and common eastern bumble bee foraging in a common landscape and applications for agri-environment schemes.
<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC12311847/>

17. PMC. (2020). Host density drives viral, but not trypanosome, transmission in a key pollinator. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7003466/>
18. Sydenham, M. A. K., Eldegard, K., Venter, Z. S., Evju, M., & Åström, S. (2023). The contributions of flower strips to wild bee conservation in agricultural landscapes can be predicted using pollinator habitat suitability models. *Ecological Solutions and Evidence*, 4(4). <https://besjournals.onlinelibrary.wiley.com/doi/full/10.1002/2688-8319.12283>
19. Turo, K. J., et al. (2024, July 30). Global crop yields threatened by insufficient pollinator visitation. *BC3 Basque Centre for Climate Change*. <https://info.bc3research.org/2024/07/30/global-crop-yields-threatened-by-insufficient-pollinator-visitacion-according-to-new-study/>
20. University of Cambridge. (2024). *Pollinators: First global risk index for species declines and effects on humanity*. <https://www.cam.ac.uk/stories/pollinatorsriskindex>
21. Vanbergen, A. J., Woodcock, B. A., Koivunen, E., Potts, S. G., Gabriel, D., Stone, G. N., & Tscharntke, T. (2017). Network size, structure and mutualism dependence affect the propensity for plant–pollinator extinction cascades. *Functional Ecology*, 31(6), 1285–1294.