Research Article

Climate Change as a Threat to Pollinators, Food Security and Biodiversity

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Abstract | Pollinators play significant roles in preserving the production of food globally, environmental stability and biodiversity. Around 75% of the total crops are dependent on pollination for their production through animals like beetles, flies, butterflies, bees, bats and birds, which makes them an essential component of natural ecosystem. Pollinator populations, on the other hand, are rapidly dropping over the world due to a variety of factors such as parasite infestations, aggressive species, climate change, chemical exposure, agricultural expansion, and habitat degradation. All of these interrelated causes affect pollination efficiency, limit flora diversity, and weaken ecosystem resilience, resulting in worse crop quality and yields. The social and economic consequences of pollinator population decline are as serious, as pollination services provide USD 235-577 billion to the world economy each year. The declination in pollination products significantly threatens food security four pillars that are stability, utilization, access and availability through reductions in rich food productions like oilseeds, nuts, vegetables and fruits. Increased oversupply lowers food costs, increases the danger of starvation, and has a significant impact on small holder growers in developing nations. To address these concerns, major global action is necessary, including the implementation of integrated pest management (IPM), a reduction in chemical dependency, habitat restoration, and agricultural sustainability practices. Initiatives in policy from organizations such as Convention on Biological Diversity (CBD), Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), and Food and Agriculture Organization (FAO) place a strong emphasis on biodiversity-friendly farming and cross-sector collaborations to safeguard pollinators. Pollinator conservation requires coordinated research, effective framework laws, and public awareness to maintain global food security, environmental balance, and long-term sustainability in the agriculture sector.

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Introduction

Pollinators are essential constituents of both regular bio-networks and agricultural efficiency, sustaining the propagative accomplishments of an enormous group of blossoming plants (Bie *et al.*, 2025). Due to an important service of transferring pollens among the flowers, the pollinator fauna comprises primarily of different species of bees, bugs, beetles, butterflies, birds and bats (Kaur and Kaleka, 2022) as well, facilitating the sexual reproductions in floras, helps to sustain biodiversity, maintains the balance of ecology and safeguards food system globally (Patil *et al*., 2024). Pollinators are more important in agricultural contexts because of their role in determining the quantity of yields, the quality of fruits and their nutritional qualities, the formation of healthy diets, and the stabilization of the food supply chain (Jones and Radar, 2022). The most economically and efficiently valuable species of bees in terms of pollination are *Meliponini, Apis* spp. and *Bombus* spp (Khalifa *et al*., 2021). They ecologically serve far beyond the reproduction; they significantly enhance the resilience of ecosystem, diversity of genetics and sustainability of agriculture, connecting conservation of biodiversity straight to the survival of humans (Diyaolu and Folarin, 2024).

Pollinators have immense importance in the quantification of worldwide agriculture (Ulyshen *et al*., 2023). Around 75 % of the crops are totally or partially dependent on the pollination mediated by animals (Silva *et al*., 2021), 66 % of which comprises nuts, legumes, oilseeds, vegetables and fruits (Devi *et al*., 2024). These crops are significant in terms of micronutrient availability and calorie consumption for human health (Polmann *et al*., 2023). Different economic researches stated that services of pollination can be economically valued from USD 235 to 577 billion yearly, highlighting their exceptional role in the sustainability of agricultural economy (Khalifa *et al*., 2021). Beyond economic measures, pollinators are very important for human diets nutritional diversities (Porto *et al*., 2021). While the sufficient calories are being provided by the staple crops like cereals which are limited nutritionally (Kumar *et al*., 2023). The decline in crops that rely on pollination poses a double risk: a decrease in both the amount and quality of nutrients in food, which is consumed globally by the population (Nath *et al*., 2023).

Along their crucial agricultural and ecological responsibilities, pollinators are drastically decreasing in distribution, quantity, and diversity worldwide (Ulyshen *et al*., 2023). In Europe, continuous monitoring indicated the reduction in the colonies of honeybees by about 30 % (Hristov *et al*., 2021)] and the diversity of wild bees were declined up to 50 % of the early 96% population (Abudulai *et al*., 2022), while reports from North America states that around one-quarter species of bees are at threat of extinction (Quandahor *et al*., 2024). The mono-cultural farming and rigorous usage of pesticides in Asia are causing considerable losses in the abundance and diversity of pollinators (Pervez and Manzoor, 2023). Global assessment led by IPBES stated that around 40% of pollinators that are invertebrates, specifically butterflies and bees, facing extinction (Nath *et al*., 2023). These drifts posed the productivity and balance of the ecosystem and global stability of food system which relied regular pollination services (Gutgesell *et al*., 2024).

The main declination causes of pollinators are multifarious and interconnected. The sites of nesting and resources of flora are significantly reduced by the expansion of agriculture and urbanization resulting in the losses of habitats of various pollinator species, while thorough farming and mono-cropping have significantly limited the opportunities of foraging (Nath *et al*., 2023). The persistant pesticide usage like neonicotinoids significantly impairs the health of pollinators, reproduction and navigation (Paoli and Giurfa, 2024). These pressures are further intensifies by the climate change through disturbing the cycles of flowers and causes alteration in the pattern of rainfall and temperature, resulting in host plants and pollinators mismatches (Ghosh *et al*., 2025). Parasites and pathogens like *Nosema* species and *Varroa destructor* also devastates the population of bees (Figure 1) (Morfin *et al*., 2023). The interaction of these variables increases the scale of the crisis, posing serious risks to 21st century agriculture and biodiversity (Luo *et al*., 2025).

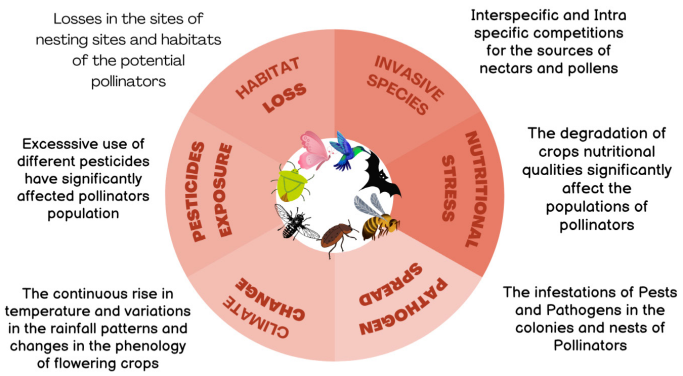

Figure 1: *Different factors influencing the declination of pollinator's population*

Worldwide food security is significantly implicated by the loss of pollinators (Tanda, 2024). Pollinators significantly enhances the alleviated production and yields of various crops, and increases food nutrient values through accumulative important micronutrients availability like calcium, folate and vitamins E, C and A (Zariman *et al*., 2022). The four important aspects of food security are greatly affected by the loss of pollinators that are access, stability, availability and utilization (Muluneh, 2021) through significant reductions in diversity of crops, higher costs of production and threatening livelihoods of farmers (Hailay, 2024). Global analysis carried out in 2023 correlating pollination insufficiency with substantial reductions in yields of nuts, vegetables and fruits, resulting in around 400,000 deaths in premature stages annually because of the deficiencies of nutrients (Levitt *et al*., 2022). In numerous underdeveloped areas, such effects ignite vulnerability in economics and significantly lead to malnutrition, hunger and excavating social inequalities (Nath *et al*., 2023).

Resolving these crises needs collective, coordinated and urgent worldwide actions (Stout and Dicks, 2022). Pesticides usage reductions, expanded systems of cropping and natural habitats conservations are important for pollinator population sustainability (Duque-Trujillo *et al*., 2023). The protection of pollinators must be integrated with the policies frameworks into climatic and agricultural strategies, reinforced through initiatives from international organizations like FAO, IPBES and CBD (Nogués-Bravo *et al*., 2025). Solidification of researches, development of multi and interdisciplinary partnerships and promotion of communal awareness are of significant responses (Bie *et al*., 2025). The protection of pollinators is not just an environmental responsibility but an economical and moral authoritative vital for the assurance of food security, enhancement in sustainability and future generation resilience (Arif and Mukhtar, 2023).

Agricultural and economical significance of pollinators

Main pollinator groups

Pollinators include an extremely varied group of organisms that helps in the mediation of pollen transfers in flowering plants, maintaining both global agriculture and natural ecosystem (Loy and Brosi, 2022). Globally above 200,000 species of animals performs the duty of pollination (Shah *et al*., 2023), with around 20,000 bee species signifying the most prevailing cluster (Dar *et al*., 2025). Around 90% of activities of pollination are being carried out by the insects comprised of bees (*Apis* spp., solitary bee species like *Megachile and Osmia*, *Bombus* spp.), Lepidopteran group insects (moths and butterflies), Hemipteran group insects like bugs, and coleopteran group insects like beetles (Reddy *et al*., 2022). These groups make distinctive contributions to the ecosystem, including significant pollination by bees due to flora consistency and specialized adaptations in pollen transfer (Tanda, 2024). Apart from the insects, the vertebrate creatures like birds specifically honeyeater, sunbirds and hummingbirds and bats (Torezan-Silingardi *et al*., 2021) plays their role in the pollination of plants that bloom at night such as Saguaro and Agave which are ecological significantly important (Figure 2) (Maggi *et al*., 2025). Together, all these pollinators enables the global production of flowering plants around 75% and three-quarters roughly of major crops of food, highlighting the worldwide agricultural and biodiversity output (Sabbahi *et al*., 2025).

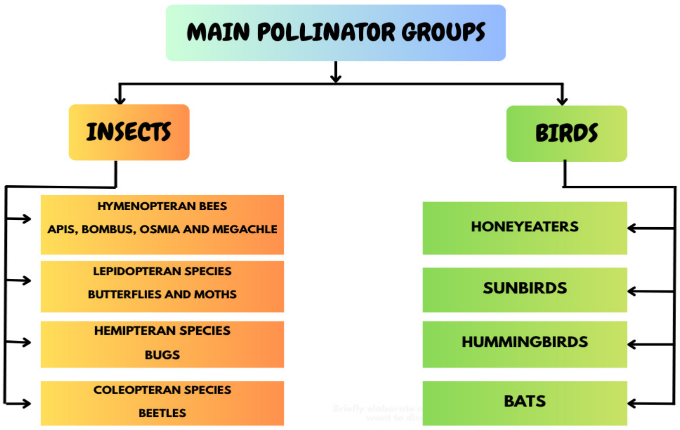

Figure 2: *Flowchart illustration of the main insect and bird groups involve in active pollination.*

Role in services of ecosystem and crops productivity

Pollinators are of significant importance for the sustainable productivity of agriculture and ensure lasting ecosystem resilience (Figure 3) (Rehman *et al*., 2022) . Around 75% of global production of crops dependent on the pollination is mediated by animals including 87 out of 115 worldwide food crops significantly relying up to some extinct on pollinators (Tanda, 2024). The maintaining of yields in important commodities like canola, apples, almonds, cocoa and coffee, quality of crops and sets of seeds and fruits are significantly enhanced by the activities of pollinators (Khalifa *et al*., 2021). Environmentally, in plants the genetic diversity is maintained by pollinators, promotes structures of habitats and strengthens resilience of ecosystem under environmental and climatic stresses

(Arif and Mukhtar, 2023). Elsewhere an economic and ecological dimension, pollinators holds aesthetic and cultural values among societies, signifying natural balance and biodiversity (Katumo *et al*., 2022). As a result, pollinators provide the biological foundations that connect human food security, agricultural sustainability, and environmental stability, and their continued decline is a severe challenge internationally for both people and nature (Rehman *et al*., 2022).

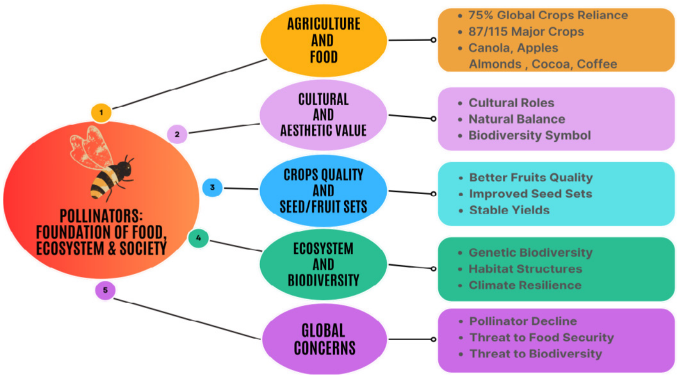

Figure 3: *Pollinators role in the ecosystem, food and society.*

Global drivers and patterns of decline in pollinators

Intensification in agriculture

The worldwide pollinators are declined significantly by the intensification of agriculture (Abdulai *et al*., 2022). The monocultural systems prevalent expansion, combined with simplification of habitat, has significantly reduced the resources of flora availability and nest sites in agricultural lands (Hederström *et al*., 2024). Synthetic pesticides broad usages, specifically fungicides and neonicotinoids, significantly exposes different pollinators to chronic and acute toxicity, which ultimately leads to reduced efficiency of foraging, navigation impairments, immunity weaknesses and collapse of bee colonies (Ara and Haque, 2021). Furthermore, mechanized practices of farming, extreme tillage, and hedge row removals or a strip of wildflowers eliminates important wild pollinators' habitats (Alarcon-Segura *et al*., 2025). In advanced agriculture the declination of floral diversity has created nutrient stress because the pollinators are significantly dependent on the continuous pollen supplies and sources of nectar for normal immunity and development (Figure 4) (El-Seedi *et al*., 2022). Subsequently, intensification govern landscapes have significantly became environmental traps, yield oriented practices of management negotiates the sustainability of eco-systems balance and services of pollination (Lundin *et al*., 2021).

Environmental and ecological stressors

Different environmental and ecological pressures significantly accelerate the losses of pollinators globally (Dicks *et al*., 2021). Fragmentation and habitat losses, led by expansion in urbanization, conversion of land use and deforestation, have seriously reduced heterogeneity of sites that retains the diversity of pollinators (Ekka *et al*., 2023). Aggressive species, like *Apis mellifera* in some areas, competes the indigenous pollinators because of the floral sources, resulting in imbalance community (Abou-Shaara, 2025). Additionally, parasites and pathogens, comprising Nosema infections and *Varroa destructor* mites, are chief biological stressors significantly affecting the health and reproduction of bees (Figure 5) (El-Seedi *et al*., 2022). Contamination-specifically particulate matters, heavy metals and agrochemicals-supplementary disrupt the physiology and olfactory communication of pollinators (Reshi *et al*., 2024). The degradation of environment has thereby produces

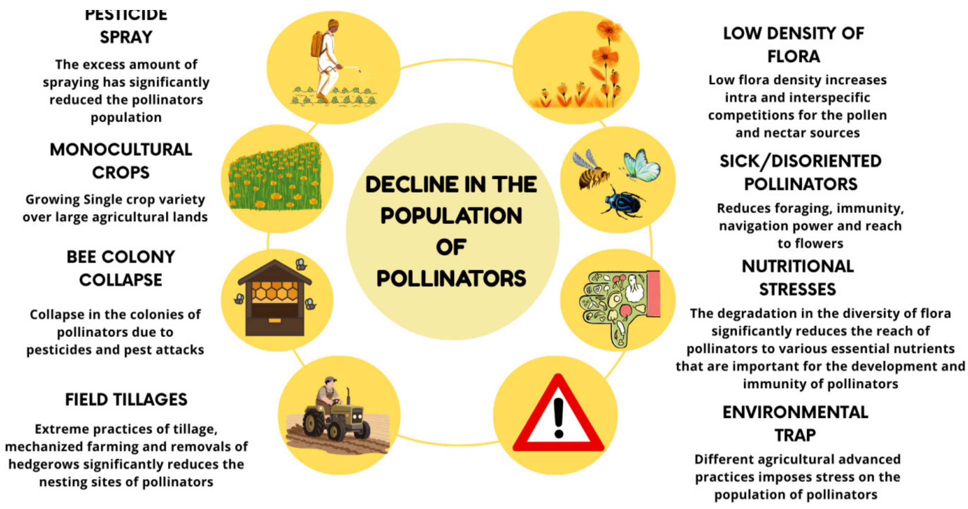

Figure 4: *Agricultural intensifications impact on the pollinators population.*

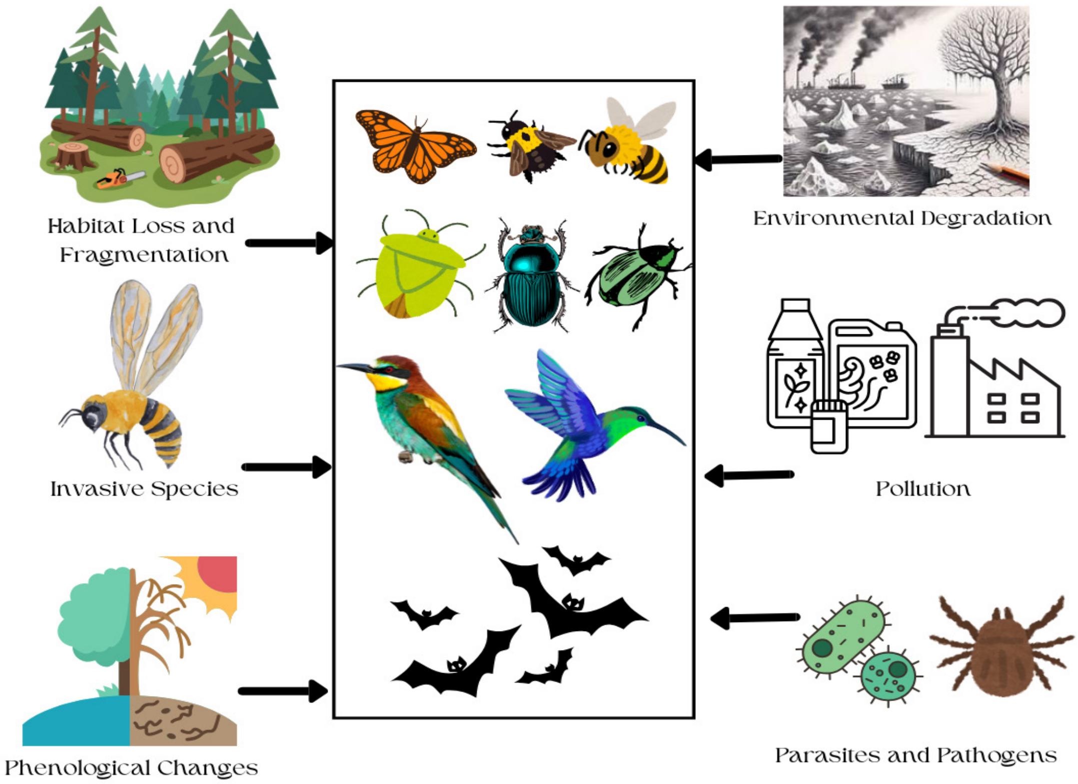

Figure 5: *Different ecological and environmental stresses affecting pollinator's population.*

complex stressed conditions, weakening resilience of pollinators, alteration in the behavior of foraging and disturbing the rates of reproduction (Kumar *et al*., 2024). The growing effects of these pressures have significantly caused a notable decline in functional diversity and richness of species, risking the network of pollination globally (Doré ey al., 2021).

Impacts of climate change

Climate change is known to be the global pervasive driver of decline in pollinators, affecting distribution of species, foraging behavior and phenology (Ghosh *et al*., 2025). The rise in temperature, alteration in the patterns of precipitation and harsh weather increased frequencies are leading phenological disparities between host plant and pollinators, disturbing the flowering synchrony and periods of foraging (Freimuth *et al*., 2022). The climate zone shifts forces pollinators to transfer at higher latitudes or altitudes and significantly surpassing their capacity of adaptation and population fragments (Ghisbain *et al*., 2021). Moreover, temperature alleviations can significantly impair the metabolic efficiencies, reduces viability of pollens and alters pollen and nectars nutritional qualities (Althiab-Almasaud *et al*., 2024). Heatwaves and droughts reduce the flowering plants abundance, restricting sources of food during the important seasons of breeding (Figure 6) (Brunet *et al*., 2025). Together, these climate changes significantly intensifies vulnerability of wild and managed populations of pollinators, imposing lasting threats to food security, biodiversity and stability of pollination globally (Muluneh, 2021).

Consequences of pollinators loss socio-economically

Pollination services economic values

Services of pollination illustrates important functions of ecosystem that supports rural economic and agriculture globally (Sabbahi *et al*., 2025) Different crops like apples, almonds, coffee etc. get benefitted by the pollination services in terms of quality and yield, and make most species important for the stability of agriculture and international trades (Reddy *et al*., 2022; Singh and Adhikary, 2021). The wild pollinator species are most efficient pollinators than managed honeybee species that contributes to more sets of fruits and crops genetic diversities (Kline *et al*., 2022). Moreover, their declination imposes rise in the cost of production as the growers are dependent on the artificial methods of pollination or managed colonies of honey bees (Dingley *et al*., 2022). These methods are financially untenable for small growers and less efficient as compared to natural pollination in the emerging areas (Broussard *et al*., 2023). Therefore, loss of pollinators risks profitability of agriculture, stability of market, and security of earnings of many

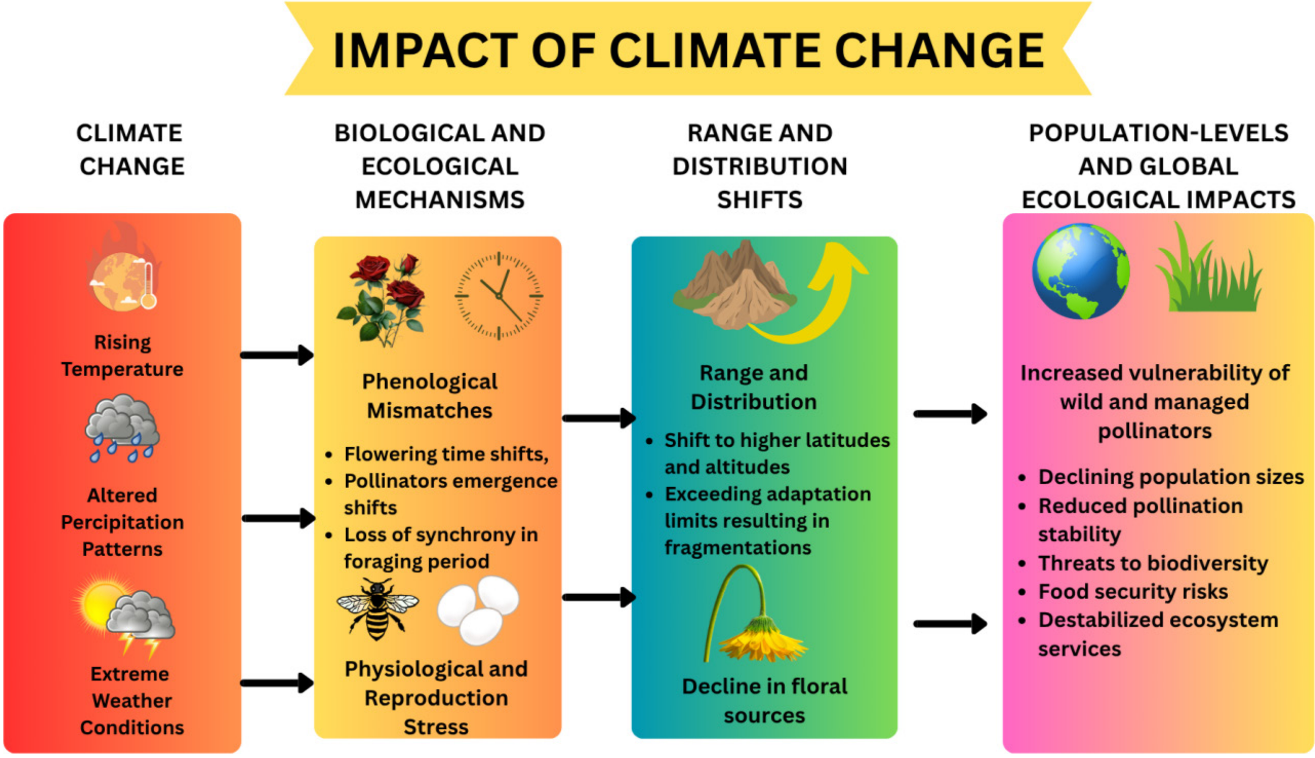

Figure 6: *Climate change Impacts on biology, ecology, reproduction, pollination services and distribution of pollinators.*

people, specifically in the economies where people are dependent on pollination like Latin America (Baylis *et al*., 2021), Africa (Upadhyaya and Bhandari, 2022) and Asia (Figure 7) (Zurek *et al*., 2022).

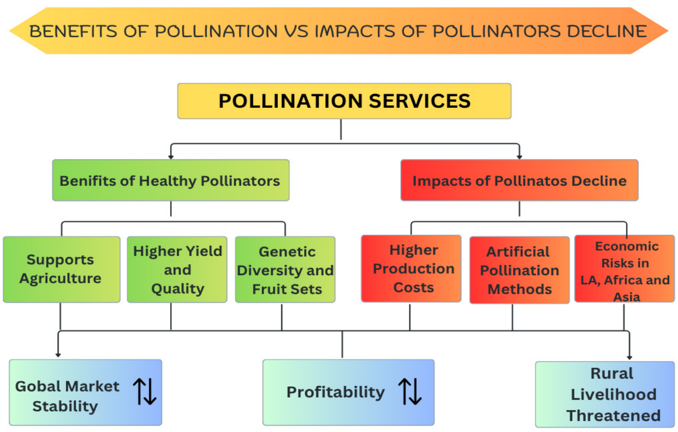

Figure 7: *This figure illustrates the benefits of pollination and significant impacts of pollinator's declination.*

Effect on nutrition and food security

Pollinator decrease is extended beyond the financial losses to straight compromise food globally and security of nutrition (Zurek *et al*., 2022). More than 70% of the leading crops of food are dependent of the services of pollination up to some extent and the productivity reduction can significantly affect the quality and quantity of available food (Bacelar *et al*., 2024). Antioxidants, minerals and vitamin are the important essential extracts of the crops that are dependent of the pollination like oilseeds, nuts, vegetables and fruits (Rahaman *et al*., 2023; Ibiapina *et al*., 2024). A continued declination in the yields can significantly results in the deficiencies of micronutrients, specifically in susceptible people that are dependent on diets which are plant-based (Neufingerl and Eilander, 2021). Furthermore, the reduction in the diversity of crops leads to homogenization of diets lowers the pliability of food web to climatic or economic shocks (Gawdiya *et al*., 2025). The losses in the services of pollination increases the prices of foods and spreads inequality, excessively upsetting low-capital populations and poor farmers (Figure 8) (Kumar *et al*., 2024). Hence the declination of pollinators is not just ecological issue but an important public health and socio-economic challenge, connecting conservation of biodiversity directly to well-being of human and stability of nutrition (Hunde, 2025).

Policy and conservation interventions

Habitat restoration and sustainable farming

Agricultural sustainable methods and restoration of habitats are important tools to reverse the declination of pollinators and maintain lasting productivity of ecosystem (Devi *et al*., 2021). Strategies like crops

Links Researchers

diversification (Fijen *et al*., 2025), agro-ecological growing (Joseph *et al*., 2022), and formation of flora-rich margins of field (Lowe *et al*., 2021) can significantly enhance the availability of floral resources and habitats for wild species of pollinators (Ludzuweit *et al*., 2025). An integrated pest management (IPM) method significantly minimizes usage of pesticides and encourages biological control, has illustrated benefits for the survival of pollinators and their diversity (Angon *et al*., 2023). Moreover, reduction in the utilization of dangerous chemicals like neonicotinoids and their alteration with ecofriendly methods can alleviate the risk of toxic exposures (Barathi *et al*., 2024; Pathak *et al*., 2022). Restoration of landscape levels by hedge rows, corridors of wildflowers, and management of fallow land significantly supports the linkages among population of fragmented pollinator species and enhances the genetic flow and resilience (Figure 9) (Vasiliev and Greenwood, 2023). The environment of urban also provides potentials of restoration by friendly-pollinator gardens and green rooftops (Passaseo *et al*., 2021), connecting efforts of conservation across urban-rural borders (Ranalli *et al*., 2025). Inclusively, an integrating friendly-biodiversity technique into the system of agriculture not just benefits the species of pollinators but positively contributes to pest regulation, soil health and production of food sustainability (Angaye *et al*., 2024; Böhm and Schäfer, 2025).

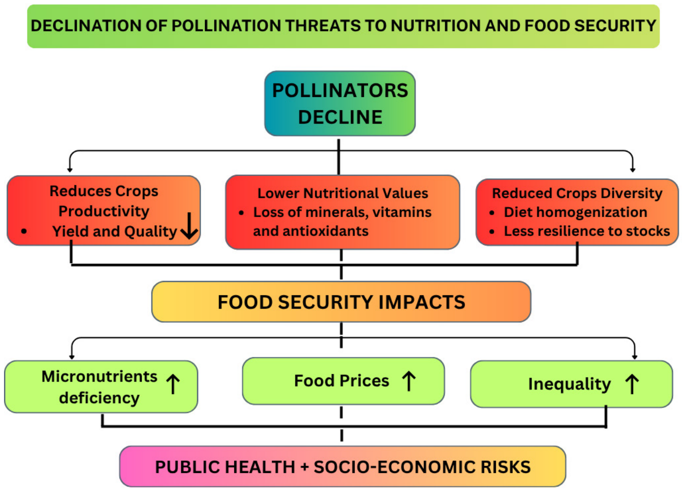

Figure 8: *This illustrates the declination of pollination and its impact on food and nutrition security.*

Global initiatives and policy frameworks

At the level of policy, numerous international guidelines have significantly recognized conservation of pollinators as an important aspect of safeguarding food security and biodiversity (Requier *et al*., 2023). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) pollinators' assessment in 2019 was a breakthrough effort highlighting the protection urgency of pollinators globally (Ruckelshaus *et al*., 2020).

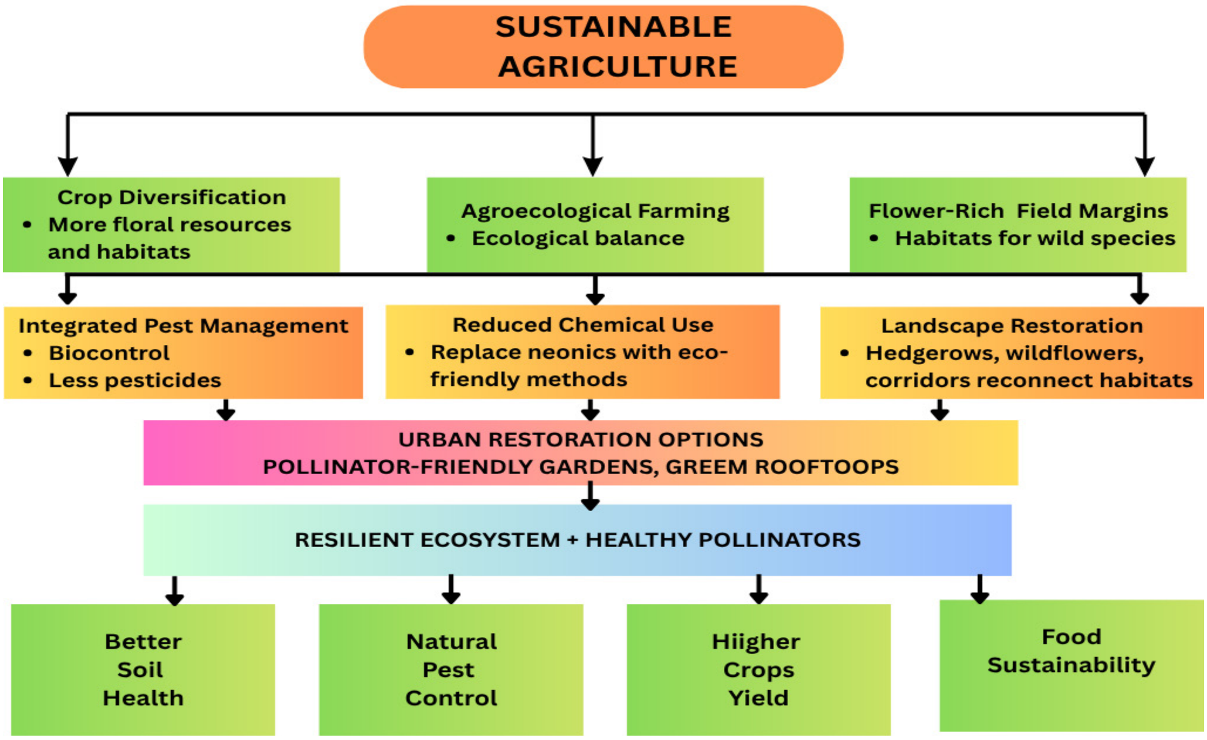

Figure 9: *This figure illustrates the sustainable farming and habitat restoration effects.*

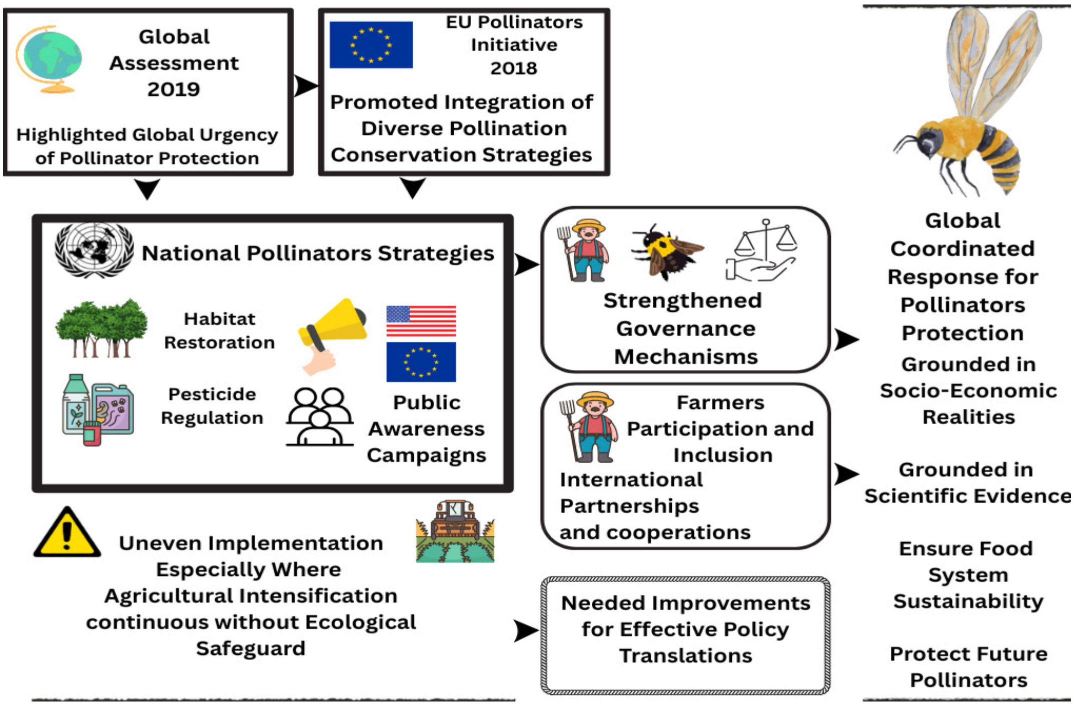

Figure 10: *Policy frameworks illustrations and initiatives done for the betterment of pollinator's conservation.*

The integration promotion of diverse strategies of the conservation of pollinators in environmental and agricultural policies was proposed by the EU pollinators Initiative in 2018 (Albertazzi *et al*., 2021), FAO's Global Action on Pollination Services (Peixoto *et al*., 2022) and The Convention on Biological Diversity (CBD) (Figure 10) (Hoban *et al*., 2021). Few countries like the United States and European Countries have applied National Pollinator Strategies emphasizing on restoration of habitats, regulation of pesticides and campaigns of public awareness (Stout and Dicks, 2022). Though, implementation of policies still remains uneven, specifically in emerging areas where the intensification of agriculture is continued without safeguarding ecology (MacLaren *et al*., 2022). Strengthening the mechanisms of governance, ensuring the presence and participation of farmers and advancing international partnerships are hereby important for the translation of scientific information in to actual policy actions (Prajapati *et al*., 2025). Worldwide coordinated responses, grounded in socio-economic and scientific realities are important to protect pollinators of future and for the sustainability of food systems (Galetto *et al*., 2022).

Conclusions and Recommendations

The future pollinator researches on declination must be prioritize the climate resilient, data driven and integrative strategies for the good understanding of diverse interactions among stressors of environment, behavior of pollinators and stability of ecosystem. Important research urgencies comprises the advance lasting networks of monitoring that includes remote sensing, surveys of fields, and molecular information like metabarcoding of DNA to examine dynamics of floral resources and diversity of pollinators. Genomics and ecophysiology advancements can offer vision of adaptive traits that helps pollinators to withstand climate change and fragmentation of habitats. Furthermore, synergistic effects knowledge of pathogens, pesticides and nutrition on the health of pollinators is still an important area of study. The study should be expanded further from the honeybee specie (*Apis mellifera*) and must include the wild species of bees, flies, butterflies and other significant pollinators will result in complete information of ecosystems resilience. Developing data base open access globally and consistent protocols will enhance the results across different areas, promoting proof based development of policy.

The sustainability pathway of the conservation of pollinators needs multi-sectorial partnerships among local communities, farmers, policy makers and scientists. The integration of friendly-pollinators strategies in policy of climate, planning or urban areas and agriculture can provide mutual benefits for food security and biodiversity. Institutions and different governments should work on initiatives of citizen sciences, public education and capacity building which empower the public who will contribute in the monitoring of pollinators and creation of habitats. Resultantly, a combine vision for the conservation of pollinators would include societal engagements, scientific innovations and policy commitments to safeguard the persistency of these important species in ecosystem.

Novelty Statement

This article provides new insights into pollinator conservation which requires coordinated research, effective framework laws, and public awareness to maintain global food security, environmental balance, and long-term sustainability in the agriculture sector.

Author's Contribution

Hamza Iftikhar: Conceptualization, investigation, and methodology
Ranra Jalal: Conceptualization, data curation, and software
Syed Anas Shah Bacha: Formal analysis and investigation
Saddam Hussain: Writing, review and editing
Misbahullah: Resources and validation
Syed Majid Rasheed: Writing, review, editing and finalizing the manuscript

Generative AI or AI assisted technology statement
Authors declared that they did not get assistance from any AI tool while completing this manuscript

Conflict of interest
The authors have no conflict of interest.

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