

EDITORIAL

Insect pollinators and their conservation strategies

Bhabesh Deka^{1*}, Azariah Babu², Chittaranjan Baruah³, Dharendra K Sharma⁴

¹Department of Entomology, Faculty of Agricultural Sciences, Rajiv Gandhi University, Arunachal Pradesh-791112, India

²UPASI Tea Research Foundation, Coonoor, Tamil Nadu-643101, India

³Postgraduate Department of Zoology, Darrang College (Autonomous), Tezpur- 784001, Assam, India

⁴Department of Zoology, University of Science and Technology, Baridua-793101, Meghalaya, India

Insect pollinators play a pivotal role in helping flowering plants the reproduction through the transfer of pollen between flowers and maintain biodiversity. Insect pollinators are essential for biodiversity and ecosystem health, contributing significantly to crop production, nutritional diversity, and inclusive quality of human diets (Jarpla *et al.*, 2024). However, these pollinators too face numerous threats viz., habitat loss and land-use intensification etc. Agricultural practices, urbanization, and climate change have resulted in the destruction and fragmentation of habitats, reducing food resources and nesting sites of these beneficial organisms. (Ganuza *et al.*, 2022). Pesticides, particularly neonicotinoids, have significantly contributed such catastrophic issues leading to the major issues like Colony Collapse Disorder which led to substantial declines in bee species (Jarpla *et al.*, 2024).

CONSERVATION STRATEGIES

A. Habitat protection and restoration

Habitat protection and restoration constitute the essential conservation strategies for insect pollinators. Strategies such as enhancing plant diversity, providing nesting and feeding sites, and establishing connectivity between habitats can contribute to the long-term survival and diversity of pollinator populations (Majewska & Altizer, 2019).

B. Sustainable agricultural practices

Integrated Pest Management (IPM) programmes provide a comprehensive pest control strategy while minimizing environmental impacts and ill-effects of chemical pesticide (Tiwari, 2024). Adopting these practices can significantly benefit insect pollinators and maintain an ecological balance and agricultural productivity. The Integrated Pest and Pollinator Management (IPPM) concept harmonizes pest control emphasizing the importance in preserving beneficial species, offering a holistic approach for sustainable crop production (Jarpla *et al.*, 2024).

C. Urban planning and green spaces

The effective conservation of urban pollinators necessitates a comprehensive approach which incorporates the urban greenspaces that have the capacity to preserve pollinator biodiversity, pollinator-friendly pest management protocols, and landscape-scale planning. Implementation of these strategies can contribute significantly to pollinator conservation efforts while simultaneously deriving benefits from the ecosystem services provided by these crucial beneficial insects (Braman & Griffin, 2022).

D. Public awareness and education

Conservation strategies should emphasize diverse approaches through community education popularization workshops/seminars etc. Citizen science initiatives can effectively disseminate essential information awareness to generate public support, and acquire valuable data about insect pollinators in a cost-effective manner (Braman & Griffin, 2022). Integrating social and ecological understandings while addressing the public enthusiasm for bees can facilitate the development of conservation practices and policies better suited for the Anthropocene era (Hall & Martins, 2020).

E. Policy and legislation to protect pollinators

However, effective pollinator-conservation necessitates the integration of social and ecological understandings to reconfigure the anthropological behaviors across the society (Hall & Martins, 2020). This encompasses the development of policies to address diverse threats to pollinator abundance and diversity, the implementation of the precautionary principle, and the maintenance of pollinator biodiversity at a landscape scale. Coordinated efforts have to be made between biological and socio-cultural researchers are essential to advance insect pollinator conservation practices and policies for the Anthropocene era.

PRACTICING CONSERVATION AGRICULTURE

Conservation agriculture practices can effectively integrate beneficial insects into crop systems for natural pest control, thereby offering a sustainable alternative to chemical pesticides. By maintaining within-field diversity, reducing nitrogen fertilization and soil tillage, and adopting organic farming practices, farmers can create favorable conditions for natural enemies and enhance biological control (Rusch *et al.*, 2016). Conservation biological control (CBC) utilizes habitat management to promote the survival and impact of natural arthropod enemies, relying on native or established invertebrate populations adapted to local agricultural ecosystems (Mkenda *et al.*, 2020).

Conservation systems demonstrated the highest overall agro-environmental benefits (71.9%), while integrated systems achieved the highest crop yield productivity score (83.3%), suggesting that a balanced approach may be optimal (Stavi *et al.*, 2016). However, a significant challenge in implementing CBC is the lack of knowledge among smallholder farmers about beneficial insects, with 98.7% of farmers in one study being

*Corresponding Author's E-mail: bhabesh.deka@gmail.com

completely unaware of natural enemies (Mkenda *et al.*, 2020).

Implementing conservation agriculture to integrate beneficial insects into natural pest control offers numerous advantages, including reduced reliance on chemical pesticides, improved ecosystem health, and enhanced crop productivity. To promote wider adoption, it is crucial to improve access to information and provide farmers and technical officers with direct training on agro-ecological intensification (Mkenda *et al.*, 2020). This approach aligns with the principles of Integrated Pest Management (IPM) and contributes to the sustainable intensification of agriculture, while minimizing adverse environmental impacts (Zhou *et al.*, 2024).

CURRENT CONSERVATION EFFORTS

A. International initiatives (e.g., IPBES, CBD)

The Inter-governmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has played a significant role in addressing pollinator conservation at the international level. International initiatives such as IPBES and the Convention on Biological Diversity (CBD) are critical in addressing pollinator conservation. However, there exists a need for more comprehensive and targeted approaches that consider regional variations in pesticide usage patterns, biocultural diversity, and the integration of scientific knowledge with local and indigenous practices to effectively conserve insect pollinators at a global level.

B. National pollinator strategies

Several countries have already adopted or plan to implement national pollinator conservation strategies in response to global insect pollinator declines and their potential impact on food security (Vasiliev & Greenwood, 2020). These strategies aim to address the necessity for pollinator conservation and sustainable agricultural landscapes which encompass a range of approaches. The "Farming with Alternative Pollinators" (FAP) approach, for instance, involves the establishment of pollinator-attracting plant strips adjacent to crops, thereby increasing flower visitors' abundance and diversity in agricultural fields (Sentil *et al.*, 2021).

C. NGO and grassroots movements

Current initiatives involve stakeholders from industry, environmentalists, NGOs, and conservation agencies (Dicks *et al.*, 2012). Enhanced coordination among biological and socio-cultural researchers is necessary to advance conservation practices and policies for the Anthropocene (Hall & Martins, 2020). Improved dissemination of scientific findings to growers and the public is essential for bridging perception and action gaps (Eraerts *et al.*, 2020).

Future research should prioritize: 1) Long-term monitoring of pollinator populations across different agro-ecosystems to understand species-specific responses to climate change (Halsch *et al.*, 2021). 2) Investigating interactive effects of multiple environmental change factors, including climate, land use, and agricultural practices (Eigenbrode & Adhikari, 2023). 3) Understanding how climate change affects chemical ecology and pheromone-mediated communication among insect pollinators (Boullis *et al.*, 2016). 4) Developing climate-smart integrated pest and pollinator

management strategies (Eigenbrode & Adhikari, 2023). Addressing these priorities would definitely enhance our capacity to conserve insect pollinators and maintain ecosystem services in the context of climate change.

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