



Ecosystem services, climate impacts, and resilience: A comprehensive review of insect biodiversity in agroecosystems

Samudrapu Sanjay Raj^{1*}, Sanjay Kumar Sharma², Atul Diga¹, Selarka Karan Pareshbhai¹, Swagat Kumar Bhoi³

¹ Department of Entomology, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh, India

² Sr. Extension Specialist, KVK, Una, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh, India

³ Department of Agronomy, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh, India

Abstract

Insect populations have declined worldwide, with an estimated 5–10% of species lost since the Industrial Revolution. Nearly 70% of these declines are linked to anthropogenic pressures and climate-related stressors that disrupt reproduction. Insects support 35% of global crop production through pollination, biological control, and nutrient cycling, yet the extensive use of insecticides in Asia (59% of global consumption) endangers beneficial species, weakens pollination networks, and threatens food security. Evidence shows that crop rotation enhances maize yields by 28.1% and reduces drought losses by up to 89.9%, while agroforestry and ecological intensification sustain biodiversity with reduced chemical inputs. Climate change is expected to intensify pest pressures, with *Helicoverpa armigera* potentially reaching 14.2 generations annually in India by 2090 and *Spodoptera frugiperda* continuing its global expansion. Conserving insect biodiversity is therefore essential to stabilize crop yields and strengthen agroecosystem resilience under changing climatic conditions.

Keywords: Integrated Pest Management, biological control, nutrient cycling, *Helicoverpa armigera*, *Spodoptera frugiperda*, pollination, agroforestry, ecological intensification, crop rotation, biodiversity conservation, host–parasitoid interactions, agricultural sustainability, food security, climate change, pesticide impacts

Introduction

Globally, 5–10% of insect species have disappeared since the industrial age (Cardoso *et al.*, 2020) [8]. Insect populations are declining across all habitats owing to habitat destruction, farming intensification, climate change, invasive species, and pollution (Wagner, 2020) [56]. Reversing these declines is essential for ecosystem functioning and climate-resilient agriculture. Insects are crucial for ecosystems, yet their populations have decreased owing to environmental changes (Suresh *et al.*, 2025) [53]. In agroecosystems, both pests and beneficial insects affect food systems, making population monitoring essential for understanding biodiversity losses. The decline in pollinator populations is concerning, as 35% of the global crop production requires animal pollination. Modern agricultural practices such as monoculture and pesticide use have reduced habitat and floral diversity. Weeds in crop fields provide food and habitat for pollinators (Nicholls and Altieri, 2013) [35]. Factors such as habitat destruction, pollution, and climate change contribute to insect extinction and disrupt biodiversity (Eggleton, 2020; Cardoso *et al.*, 2020) [15, 8].

Global temperatures and weather patterns affect the life cycle and survival of insects. Neonicotinoid pesticides contribute to pollinator decline, whereas artificial lighting disrupts insect behavior. Urbanization fragments habitats and alters insect communities (Eggleton, 2020) [15]. Global stressors, including pesticides, invasive species, and light pollution, can severely affect insects. Meta-analyses show 70% negative effects on insect reproduction, with predators, pollinators, and decomposers most affected, disrupting ecosystem services (Vidal *et al.*, 2025) [55]. Insects provide essential ecosystem services including pollination, pest control, and

nutrient cycling. Social insects like termites maintain ecosystem resilience during climate change, particularly in arid regions. Ants, bees, wasps, and termites are vital to the ecological communities (Elizalde *et al.*, 2020) [17]. Ladybirds provide pest control and pollination but face declines due to climate change, requiring protection (Soares *et al.*, 2023) [52]. Beetles aid pollination, pest control, and nutrient cycling have supported plant evolution since the Early Cretaceous (Bibi *et al.*, 2025) [4]. Sustainable agricultural approaches are required to halt biodiversity loss. Although conservation and organic farming support biodiversity, insects may not be preserved (Jankielsohn, 2023) [27]. The 'Half-Earth' concept and 'agricultural boundaries' framework aim to balance food production with biodiversity by addressing agriculture's impacts on land, climate, water, and pollution. This framework proposes limiting farming to under 50% of ice-free land, reducing emissions, and restricting agrochemical use, while combining land-sparing and sharing strategies (García-Vega *et al.*, 2024) [19].

Targeted management strategies can enhance insect biodiversity through controlled burning, timber harvesting, grazing, invasive species removal, and wildflower replanting. Removing invasive species and adding wildflowers benefits pollinators, while grazing impacts vary by region, and burning shows neutral to positive effects on pollinators. Combined management actions often yield greater benefits than individual measures (Glenny *et al.*, 2022) [20]. Agroforestry systems that integrate trees with crops enhance biodiversity and improve ecosystem services. The benefits depend on management practices and location, with organic methods showing better results (Kletty *et al.*, 2023) [29]. Plants and insects shape biodiversity through co-evolution, with

plants using herbivore-induced volatile emissions as a defense mechanism. Insect herbivory affects plant productivity, whereas climate change affects pest management. These interactions inform sustainable agriculture (Dofuor *et al.*, 2024)^[14].

This study consolidates evidence on insect biodiversity, ecosystem services, and agroecological management to inform the design of climate-resilient cropping systems. It integrates ecological theory with conservation frameworks to merge high agricultural productivity and ecosystem stability.

The role of biodiversity in agroecosystems

Agroforestry systems, particularly shade-grown coffee and cocoa, maintain biodiversity while supporting agricultural practices. Biodiversity enables natural pest (insect) and disease control, reducing the utilization of chemical pesticides. These systems provide habitats for predators and parasitoids that manage pests, and diverse structures create microclimates disrupting pest proliferation (Leakey, 2014)^[31]. Barrier crops, such as mung beans, tomatoes, and eggplants, near chili peppers influence insect diversity and ecological functions in agricultural landscapes. These crops modify herbivorous insect populations and increase the number of beneficial insects. Pests include Gryllidae, Gryllotalpidae, Tetrigidae, and Tettigoniidae families. Predatory insects from Carabidae (*Cicindela decemguttata* and *Neocollyris* sp.) and Coccinellidae (*Coelophora inaequalis* and *Cheilomenes sexmaculata*) manage many insect pests. Parasitoids provide pest control by laying eggs in host insects. Pollinators enable plant reproduction, whereas scavengers aid nutrient cycling in these ecosystems (Sataral *et al.*, 2023)^[47]. Crop microbiomes enhance plant health and productivity by facilitating nutrient uptake, promoting growth, increasing disease resistance, and enabling stress tolerance in plants. Molecular and omics techniques help investigate microbiomes and develop resilient crop varieties (Rai *et al.*, 2023)^[40].

Asia uses 59% of global insecticides, showing heavy reliance on chemical pest control. Insecticides harm beneficial insects through mortality and behavioral changes. These insects contribute to 33% of global crop yields, threatening agricultural productivity. Integrated Pest Management is crucial for protecting beneficial insects in agriculture (Rahman *et al.*, 2022)^[39]. Honey bees are crucial for pollination, preserving plant biodiversity, and crop yield. As effective bioindicators of environmental pollution, they help to evaluate environmental health. Their importance extends beyond ecological and economic aspects to include symbolic and cultural significance (Papa *et al.*, 2022)^[37]. Weeds play a vital role in agricultural biodiversity. Wildflowers provide resources for pollinators, such as bees, butterflies, and insects. These insect-pollinated weeds indicate the ecological health and sustainability of agricultural ecosystems, reflecting the biodiversity of the farming regions (Benvenuti, 2024)^[2]. Climate change disrupts host-parasitoid interactions, thereby diminishing biological control and compromising ecosystem stability. The increase in temperature compels species to relocate and influences the development of both pests and predators. Additionally, milder winters modify the diapause patterns of insects, thereby impacting their populations (Ramos Aguila *et al.*, 2023)^[42].

Insect diversity and its importance

Tropical regions harbour more than 70% of the world's insect species, representing one of the richest biological resources

on the planet. This diversity supports essential ecosystem services, including pollination of nearly 75% of crops, decomposition, nutrient cycling and natural pest regulation in agricultural systems (Slade and Ong, 2023)^[51]. Butterflies, within this diverse group, are sensitive indicators of habitat quality and climate change, and as pollinators they maintain plant diversity and ecosystem stability, making their conservation crucial under current environmental change scenarios (Horák *et al.*, 2021)^[25].

Insects also reflect broader environmental diversity and shifts. Urbanisation generally reduces insect species richness, although generalist species may increase overall abundance in urban green spaces. The presence of native and drought-resistant plants is associated with a 30% increase in insect diversity, with seasonal peaks observed from March to May, moderate levels from June to August, and low diversity from September to February (Adams *et al.*, 2020)^[1]. Even intensively managed agroecosystems sustain substantial insect diversity; for example, managed pastures yielded 41,351 specimens representing 171 morphospecies, across 15 orders and 60 families, with spiders (Arachnida: Araneae) and beetles (Coleoptera) being the most diverse and abundant taxa (Wallon *et al.*, 2023)^[57]. Agricultural landscape complexity further enhances insect biodiversity, as complex systems support more pollinators and natural pest predators, thereby improving ecosystem resilience and stability (Estrada-Carmona *et al.*, 2022)^[18].

Plant-insect interactions

Pollination is a crucial mutualistic interaction between plants and insects, with bees and butterflies playing significant roles in plant reproduction and biodiversity. Pollinators enhance crop yields, highlighting the economic importance of this mutualism. Beneficial insects provide ecosystem services, and decomposers contribute to nutrient cycling and soil health. Predatory insects, such as ladybirds, regulate pest populations, maintaining an antagonistic relationship with pests while promoting plant health (Reddy *et al.*, 2025)^[44].

A study of 116,478 herbivorous insects on cabbage showed that 43% were phloem feeders (aphids/whiteflies), 26% were leaf-chewing insects (Lepidoptera), 20% were thrips, and 11% were flea beetles. The Strip diversity system increased the cabbage yield and insect abundance. In Strip cultivar, late-season herbivores decreased harvestable weight, but higher herbivore diversity improved yield. Late-season thrips reduced harvestable weight in this system, whereas late-season flea beetles increased the yield in monoculture. Early season herbivores affect subsequent crop colonization through plant visibility and niche occupation (Croijmans *et al.*, 2025)^[11]. Changes in host plant quality trigger insect dispersal. The brown planthopper (*Nilaparvata lugens*) shows morphological changes when host plant quality declines. Climate change causes insects to expand host ranges and migrate, as seen in the southern small white butterfly's decreased host specialization. Climate change may disrupt synchronization between insect cycles and plant development (Terblanche *et al.*, 2024)^[54].

Ecosystem services provided by insects

Natural predators and parasitoids of insects play crucial roles in controlling crop pests through predation and parasitism. This ecological service is a fundamental component of

integrated pest management (IPM) (Jaworski *et al.*, 2023)^[28]. Social insects, such as bees, ants, and termites, provide ecosystem services across all Millennium Ecosystem Assessment categories, including provisioning (food, pharmaceuticals), regulation (pollination, pest control), support (nutrient cycling, bioturbation), and cultural services (Figure 1).

Although honeybee pollination is well recognised, many services remain underappreciated. The effectiveness of these insects originates from their abundance, mutualistic relationships, nest-building abilities, and chemical production. Their caste systems, division of labour, food storage capacities, and extended lifespans ensure consistent service delivery (Elizalde *et al.*, 2020)^[17].

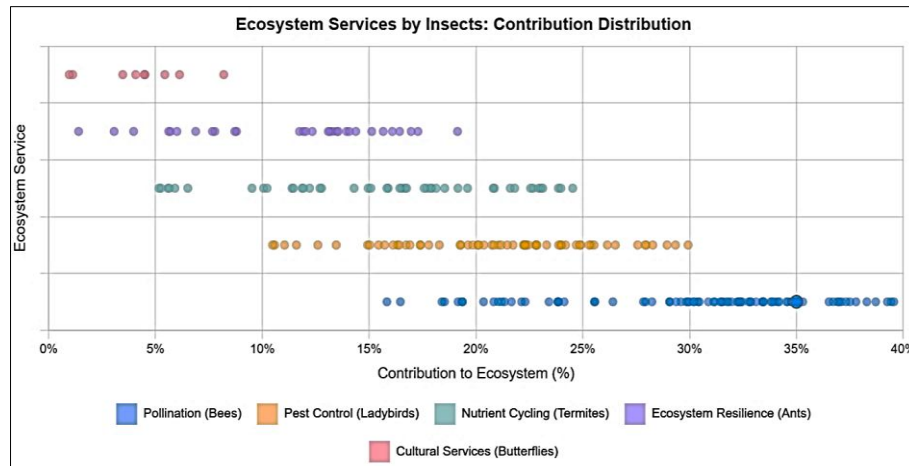


Fig 1: Scatter plot showing contribution ranges of insects: bees (20–38%), ladybirds (12–25%), termites (8–18%), ants (5–15%), and butterflies (2–10%)

Insects provide essential ecosystem services across multiple categories of species. Provisioning services include their use in food, silk, and honey production and maggot therapy. Regulating services include pollination for agriculture and biodiversity, biological pest control, herbivory affecting carbon cycles, dung removal for pathogen control, and soil modification by termites and ants. Supporting services include nutrient cycling, soil improvement, food chain resources, and plant distribution. Cultural services involve the role of insects in religious symbols and tourism. However, insect populations are declining globally, with projections suggesting that 40% of species could vanish in the coming decades, threatening these ecosystem services (Ramos *et al.*, 2020)^[43]. Aculeate wasps play a key role in regulating arthropod populations in natural and agricultural ecosystems, focusing on the predatory behaviors of solitary and social wasps. Social wasps demonstrate notable hunting adaptability and the capacity to reduce prey biomass. Aculeate wasps have potential as biological control agents and pollination services, including both exclusive and facultative relationships with plants (Brock *et al.*, 2021)^[6].

Climate change impacts on insects and cropping systems

Climate change affects insect physiology, reproduction, and survival, increasing pest problems across regions. It disrupts pest-predator relationships and biological control, with impacts varying by location. Farmers adopt climate-smart techniques like crop diversification, influencing pest-pollinator interactions (Eigenbrode and Adhikari, 2023)^[16]. Climate change alters insect populations through changes in distribution and phenology. Climate extremes and anthropogenic stressors compound these impacts, while microhabitats provide essential refugia for insects (Harvey *et al.*, 2023)^[23]. Insects indicate climate change through altered life events and distributions. Climate change affects arthropod diversity and survival by enhancing winter survival. Higher temperatures accelerate insect development,

increase generations, and cause crop damage. Elevated CO₂ levels affect insects by altering plant nutrition (Sangle *et al.*, 2015)^[46]. Climate change has influenced insect populations globally, affecting 30% of the species through extreme weather and disrupted food sources. Insects adapt through physiological changes, impacting pollination and food webs (Ojija *et al.*, 2025)^[36].

Climate change affects insects, which regulate organisms, recycle nutrients, pollinate plants, maintain soil health, and feed on other species. Global insect populations are declining with rising temperatures, CO₂ levels, and precipitation changes, affecting their biodiversity compounded by poor pest management. The Cotton Bollworm (*Helicoverpa armigera*) in India is projected to reach 14.2 generations annually by 2090, while Gypsy moth (*Lymantria dispar*) may reproduce faster due to higher temperatures (Bhagarathi and Maharaj, 2023)^[3]. After 2011, Montane butterfly populations declined during a megadrought, with univoltine species emerging earlier and responding positively to rainfall and temperature variations (Halsch *et al.*, 2021)^[22]. Climate change is expected to increase insect pest risk in agricultural systems, particularly in cooler regions. Pests may expand their range to include new areas and crops. The fall armyworm (*Spodoptera frugiperda*) has spread across Africa, Asia and Australia owing to climate change. Higher temperatures enable more insect life cycles, increasing crop damage (IPPC Secretariat, 2021)^[26]. Rising temperatures make new areas suitable for fall armyworm expansion, whereas warmer conditions accelerate development and outbreaks. Climate change also increases crop vulnerability through changes in temperature and precipitation (Yan *et al.*, 2022)^[58].

Pest management requires an understanding of ecology and climate-dependent control mechanisms. Ecological engineering supports natural predators through resources and shelters, thereby enhancing their effectiveness (Nayak *et al.*, 2020)^[34]. Climate change affects pest diversity and

phenology, thereby increasing crop loss. India's agricultural vulnerability threatens food security through pest damage (Singh, 2023) ^[50]. Increased CO₂ levels affecting insect physiology and behavior (Regina *et al.*, 2024) ^[45]. Climate change also has a cascading effect on insect ecology. For instance, a recent study by Raj *et al.*, (2025) ^[41] from Himachal Pradesh, focused on a wasp called *Vespa basalis* earlier a beneficial predator, but due to changes in climate it changed its ecological role as an emerging pest on Pear.

Consequences for crop production

The significant impact of climate change on yield increments and crop production globally presents a substantial challenge in safeguarding food resources in the 21st century (Radwan *et al.*, 2024) ^[38]. Climate change threatens ecosystems by altering environmental conditions. These changes affect heat waves and temperature, leading to new pests and disrupted plant growth by affecting photosynthesis and reducing crop yield and food security (Chaudhry and Sidhu, 2022) ^[10]. Climate change affects the water footprint (WF) of cereal production in India. The WF of cereal crops varies between 3.2% and 6.3% across climate scenarios. Paddy's blue WF is projected to decrease by 9.6%, while wheat may increase by 4.4% under RCP4.5 during the 2050s.

The green WF for rabi crops will increase significantly, affecting water resource management and crop production (Mali *et al.*, 2021) ^[32].

Climate extremes such as droughts, floods, and pests have impacted farmers' livelihoods. The Decision Support System projects rice and wheat yields declining by 15.2% and 14.1%, respectively, while the Agricultural Production Systems Simulator predicts 17.2% and 12% reductions during 2040-2069 (Habib-Ur-Rahman *et al.*, 2022) ^[21]. Industrialisation influences tropospheric ozone (O₃) levels, thereby affecting climate change. O₃ impact on crop yield is critical in India's Indo-Gangetic Plain. O₃ effects on yield and enzymes in six rice varieties, with and without ethylenediurea (EDU), showed significant impacts on crop yield and antioxidants. The four rice varieties showed O₃ sensitivity, whereas MTU 1010 and Kshitish demonstrated O₃ tolerance with better photosynthetic values. EDU application reduced O₃ toxicity in the sensitive varieties. The use of O₃-tolerant rice genotypes could minimise the impact on production (Singh *et al.*, 2022) ^[49]. The interplay between declining biodiversity, reliance on ecosystem services, and climate change poses significant threats to global agricultural productivity. Nevertheless, agroecological approaches offer considerable potential in mitigating these impacts (Figure 2).

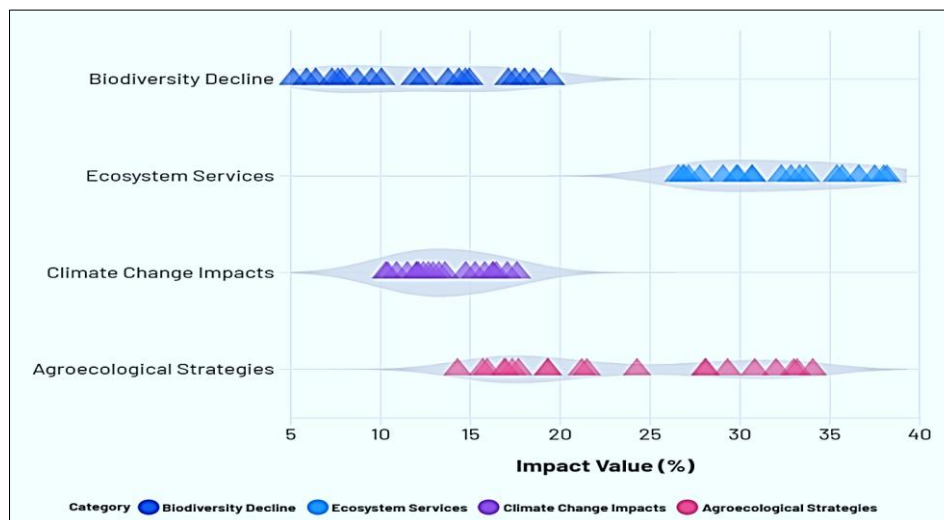


Fig 2: Violin plot illustrating the distribution of impact values, showing biodiversity decline (4–20%), ecosystem services (26–40%), climate change impacts (10–19%), and agroecological strategies (14–35%)

Strategies for designing Climate-Resilient cropping systems

Enhancing biodiversity through crop diversification and semi-natural habitats while balancing ecosystem services can achieve high efficiency (Dardonville *et al.*, 2022) ^[12]. Crop rotation increases resilience to extreme weather while maintaining yields, with maize yields increasing 28.1% across conditions, 22.6% under favorable conditions, and reducing losses by 14.0%–89.9% during droughts. Diversifying rotations reduces agricultural risk (Bowles *et al.*, 2020) ^[5]. Ecological Intensification (EI) enhances ecosystem services to replace human inputs, while maintaining yields and making farming sustainable. Plant biodiversity affects ecosystem functions across spatial scales (Brooker *et al.*, 2023) ^[7]. Systems must be designed with 10-50-year sustainability views (Carof *et al.*, 2022) ^[9]. Crop rotations with multispecies cover and cash crops increase biodiversity and system resilience compared with conventional methods (Delbaere *et al.*, 2025) ^[13]. Ecological

intensification aims to maintain food production, while promoting biodiversity and ecosystem services and agricultural systems (Kremen, 2020) ^[30]. Consideration of pests and predators that rapidly interact within agricultural ecosystems leads to effective pest suppression even the climatic conditions are not favourable (Hatt and Döring, 2023) ^[24].

Research gaps and future perspectives

The absence of plant teaming or intercropping among farmers reduces biodiversity and climate resilience (Scherber *et al.*, 2020) ^[48]. Although insects are vital for pollination and ecosystem functions, evidence linking biodiversity restoration to food security remains limited. This knowledge gap maintains misconceptions about ecosystem restoration that impedes agricultural productivity. Research must combine ecological and socioeconomic perspectives to understand the benefits of biodiversity restoration in agriculture (Nadeu, 2022) ^[33]. Evaluating insect diversity and

plant-insect interactions requires advanced molecular tools and ecological modeling. Regional studies should examine how intercropping and ecological intensification can enhance climate resilience. Developing frameworks that connect ecosystem services with farmers' adoption will advance biodiversity strategies. These approaches can create cropping systems that maintain food production while preserving the ecosystem.

Conclusion

Insect diversity enables pollination, pest control, and nutrient cycling, which are vital for climate resilience in agriculture. Agricultural intensification and climate change threaten food security through the decline of insects. Agroecological practices such as intercropping and ecosystem restoration can enhance resilience and stabilize yields for sustainable agricultural production.

Acknowledgements

The authors express gratitude for the academic support from Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishwavidyalaya, Palampur.

Financial support

The authors did not receive any funding for this review.

Author Contribution Statement

SSR and SKS conceptualized and designed the review. SKB, AD and SKP compiled literature and contributed analysis. SSR and SKS drafted the manuscript. All authors reviewed and approved the final manuscript.

Conflict of Interest: No

References

- Adams B J, Li E, Bahlai C A, Meineke E K, McGlynn T P, Brown B V. Local- and landscape-scale variables shape insect diversity in an urban biodiversity hot spot. *Ecological Applications*, Volume 30, Issue 4, 2020, Pages e02089.
- Benvenuti S. Weed Role for Pollinator in the Agroecosystem: Plant-Insect Interactions and Agronomic Strategies for Biodiversity Conservation. *Plants*, Volume 13, Issue 16, 2024, Pages 2249.
- Bhagarathi L K, Maharaj G. Impact of climate change on insect biology, ecology, population dynamics, and pest management: A critical review. *World Journal of Advanced Research and Reviews*, Volume 19, Issue 3, 2023, Pages 541–568.
- Bibi I, Zafar I, Iman S M, Warraich S, Asad I, Shah S, Hussain M, Sakhawat S, Afzal R, Fatima S, Butt S. Beetles (Coleoptera) in agricultural landscapes: contribution, challenges and conservation. *Zoo Botanica*, Volume 3, Issue 1, 2025, Pages 147–156.
- Bowles T M, Mooshammer M, Socolar Y, Calderón F, Cavigelli M A, Culman S W, Deen W, Drury C F, Garcia y Garcia A, Gaudin A C M, Harkcom W S, Lehman R M, Osborne S L, Robertson G P, Salerno J, Schmer M R, Strock J, Grandy A S. Long-Term Evidence Shows that Crop-Rotation Diversification Increases Agricultural Resilience to Adverse Growing Conditions in North America. *One Earth*, Volume 2, Issue 3, 2020, Pages 284–293.
- Brock R E, Cini A, Sumner S. Ecosystem services provided by aculeate wasps. *Biological Reviews*, Volume 96, Issue 4, 2021, Pages 1645–1675.
- Brooker R W, Hawes C, Iannetta P P M, Karley A J, Renard D. Plant diversity and ecological intensification in crop production systems. *Journal of Plant Ecology*, Volume 16, Issue 6, 2023.
- Cardoso P, Barton P S, Birkhofer K, Chichorro F, Deacon C, Fartmann T, Fukushima C S, Gaigher R, Habel J C, Hallmann C A, Hill M J, Hochkirch A, Kwak M L, Mammola S, Ari Noriega J, Orfinger A B, Pedraza F, Pryke J S, Roque F O, Settele J, Simaika J P, Stork N E, Suhling F, Vorster C, Samways M J. Scientists' warning to humanity on insect extinctions. *Biological Conservation*, Volume 242, 2020, Pages 108426.
- Carof M, Godinot O, Le Cadre E. Biodiversity-based cropping systems: A long-term perspective is necessary. *Science of The Total Environment*, Volume 838, 2022, Pages 156022.
- Chaudhry S, Sidhu G P S. Climate change regulated abiotic stress mechanisms in plants: a comprehensive review. *Plant Cell Reports*, Volume 41, Issue 1, 2022, Pages 1–31.
- Croijmans L, Mertens D, van Apeldoorn D F, Jia Y, Ríos Hernández N, Poelman E H. Herbivore prevalence poorly predicts yield in diverse cropping systems. *Journal of Applied Ecology*, Volume 62, Issue 5, 2025, Pages 1229–1242.
- Dardonville M, Bockstaller C, Villerd J, Therond O. Resilience of agricultural systems: biodiversity-based systems are stable, while intensified ones are resistant and high-yielding. *Agricultural Systems*, Volume 197, 2022, Pages 103365.
- Delbaere A, Carof M, Godinot O, Le Cadre E. Fostering creativity to design biodiversity-based cropping systems that consider the long term: a participatory framework. *Frontiers in Agronomy*, Volume 7, 2025.
- Dofuor A K, Osei-Owusu J, Osabutey A F, Lutuf H, Antwi-Agyakwa A K, Andoh-Mensah S, Asante K, Aidoo O F. Plant-insect interactions under agroecosystems: an overview of ecological implications for future research. *Cogent Food & Agriculture*, Volume 10, Issue 1, 2024, Pages 2379606.
- Eggleton P. The State of the World's Insects. *Annual Review of Environment and Resources*, Volume 45, Issue 1, 2020, Pages 61–82.
- Eigenbrode S D, Adhikari S. Climate change and managing insect pests and beneficials in agricultural systems. *Agronomy Journal*, Volume 115, Issue 5, 2023, Pages 2194–2215.
- Elizalde L, Arbetman M, Arnán X, Eggleton P, Leal I R, Lescano M N, Saez A, Werenkraut V, Pirk G I. The ecosystem services provided by social insects: traits, management tools and knowledge gaps. *Biological Reviews*, Volume 95, Issue 5, 2020, Pages 1418–1441.
- Estrada-Carmona N, Sánchez A C, Remans R, Jones S K. Complex agricultural landscapes host more biodiversity than simple ones: A global meta-analysis. *Proceedings of the National Academy of Sciences*, Volume 119, Issue 38, 2022, Pages e2203385119.
- García-Vega D, Dumas P, Prudhomme R, Kremen C, Aubert P-M. A safe agricultural space for biodiversity.

- Frontiers in Sustainable Food Systems, Volume 8, 2024, Pages 1328800.
20. Glenn W, Runyon J B, Burkle L A. A review of management actions on insect pollinators on public lands in the United States. *Biodiversity and Conservation*, Volume 31, Issue 8, 2022, Pages 1995–2016.
 21. Habib-Ur-Rahman M, Ahmad A, Raza A, Hasnain M U, Alharby H F, Alzahrani Y M, Bamagoos A A, Hakeem K R, Ahmad S, Nasim W, Ali S, Mansour F, El Sabagh A. Impact of climate change on agricultural production; Issues, challenges, and opportunities in Asia. *Frontiers in Plant Science*, Volume 13, 2022, Pages 925548.
 22. Halsch C A, Shapiro A M, Fordyce J A, Nice C C, Thorne J H, Waetjen D P, Forister M L. Insects and recent climate change. *Proceedings of the National Academy of Sciences*, Volume 118, Issue 2, 2021, Pages e2002543117.
 23. Harvey J A, Tougeron K, Gols R, Heinen R, Abarca M, Abram P K, Basset Y, Berg M, Boggs C, Brodeur J, Cardoso P, de Boer J G, De Snoo G R, Deacon C, Dell J E, Desneux N, Dillon M E, Duffy G A, Dyer L A, Ellers J, Espíndola A, Fordyce J, Forister M L, Fukushima C, Gage M J G, García-Robledo C, Gely C, Gobbi M, Hallmann C, Hance T, Harte J, Hochkirch A, Hof C, Hoffmann A A, Kingsolver J G, Lamarre G P A, Laurance W F, Lavandero B, Leather S R, Lehmann P, Le Lann C, López-Urbe M M, Ma C-S, Ma G, Moiroux J, Monticelli L, Nice C, Ode P J, Pincebourde S, Ripple W J, Rowe M, Samways M J, Sentis A, Shah A A, Stork N, Terblanche J S, Thakur M P, Thomas M B, Tylianakis J M, Van Baaren J, Van de Pol M, Van der Putten W H, Van Dyck H, Verberk W C E P, Wagner D L, Weisser W W, Wetzell W C, Woods H A, Wyckhuys K A G, Chown S L. Scientists' warning on climate change and insects. *Ecological Monographs*, Volume 93, Issue 1, 2023, Pages e1553.
 24. Hatt S, Döring T F. Designing pest suppressive agroecosystems: Principles for an integrative diversification science. *Journal of Cleaner Production*, Volume 432, 2023, Pages 139701.
 25. Horák J, Rada P, Lettenmaier L, Andreas M, Bogusch P, Jaworski T. Importance of meteorological and land use parameters for insect diversity in agricultural landscapes. *The Science of the Total Environment*, Volume 791, 2021, Pages 148159.
 26. IPCC Secretariat. Scientific review of the impact of climate change on plant pests - A global challenge to prevent and mitigate plant pest risks in agriculture, forestry and ecosystems. *FAO*, 2021.
 27. Jankielsohn A. Sustaining insect biodiversity in agricultural systems to ensure future food security. *Frontiers in Conservation Science*, Volume 4, 2023, Pages 1195512.
 28. Jaworski C C, Thomine E, Rusch A, Lavoie A-V, Wang S, Desneux N. Crop diversification to promote arthropod pest management: A review. *Agriculture Communications*, Volume 1, Issue 1, 2023, Pages 100004.
 29. Kletty F, Rozan A, Hahold C. Biodiversity in temperate silvoarable systems: A systematic review. *Agriculture, Ecosystems & Environment*, Volume 351, 2023, Pages 108480.
 30. Kremen C. Ecological intensification and diversification approaches to maintain biodiversity, ecosystem services and food production in a changing world. *Emerging Topics in Life Sciences*, Volume 4, Issue 2, 2020, Pages 229–240.
 31. Leakey R R B. The role of trees in agroecology and sustainable agriculture in the tropics. *Annual Review of Phytopathology*, Volume 52, 2014, Pages 113–133.
 32. Mali S S, Shirsath P B, Islam A. A high-resolution assessment of climate change impact on water footprints of cereal production in India. *Scientific Reports*, Volume 11, Issue 1, 2021, Pages 8715.
 33. Nadeu E. Nature Restoration as a driver for Resilient Food Systems. *Institute for European Environmental Policy*, 2022.
 34. Nayak S, Kolanthasamy E, Thangavel T, Kumar SV. Role of Ecological Engineering in Pest Management. *Ecological Engineering*, 2020, Pages 7–22.
 35. Nicholls C I, Altieri M A. Plant biodiversity enhances bees and other insect pollinators in agroecosystems: A review. *Agronomy for Sustainable Development*, Volume 33, Issue 2, 2013, Pages 257–274.
 36. Ojija F, Mng'ong'o M, Aloo B N, Mayengo G, Helikumi M. Effect of global climate change on insect populations, distribution, and its dynamics. *Journal of Asia-Pacific Entomology*, Volume 28, Issue 3, 2025, Pages 102442.
 37. Papa G, Maier R, Durazzo A, Lucarini M, Karabagias I K, Plutino M, Bianchetto E, Aromolo R, Pignatti G, Ambrogio A, Pellicchia M, Negri I. The Honey Bee *Apis mellifera*: An Insect at the Interface between Human and Ecosystem Health. *Biology*, Volume 11, Issue 2, 2022, Pages 233.
 38. Radwan M M, Hassan A I, El-Meneisy A A, El-Meneisy A H, El-Meneisy A M. The impact of various climate change factors on agricultural insect pests, crop production, and their control. *Egyptian Academic Journal of Biological Sciences (A. Entomology)*, Volume 17, Issue 1, 2024, Pages 1–22.
 39. Rahman M M, Riaz G M, Hassan J. Insecticidal exposures modulates the beneficial insect's biodiversity in agroecosystem. *Tropical Agroecosystems*, Volume 3, Issue 1, 2022, Pages 01–06.
 40. Rai S, Omar A F, Rehan M, Al-Turki A, Sagar A, Ilyas N, Sayyed R Z, Hasanuzzaman M. Crop microbiome: their role and advances in molecular and omic techniques for the sustenance of agriculture. *Planta*, Volume 257, Issue 2, 2023, Pages 27.
 41. Raj S S, Digal A, Kumar B, Krishna S S A. First record of *Vespa basalis* attacked on pear (*Pyrus communis*) fruits in Himachal Pradesh, India. *Journal of Scientific Research and Reports*, Volume 31, Issue 9, 2025, Pages 691–699.
 42. Ramos Aguila L C, Li X, Akutse K S, Bamisile B S, Sánchez Moreano J P, Lie Z, Liu J. Host-Parasitoid Phenology, Distribution, and Biological Control under Climate Change. *Life*, Volume 13, Issue 12, 2023, Pages 2290.
 43. Ramos D L, Cunha W L, Evangelista J, Lira L A, Rocha M V C, Gomes P A, Frizzas M R, Togni P H B. Ecosystem Services Provided by Insects in Brazil: What Do We Really Know? *Neotropical Entomology*, Volume 49, Issue 6, 2020, Pages 783–794.
 44. Reddy K S N, Nagarjuna T N, Tippimath S, Shwetha G S, Sugeetha G, Nagaraju M C. Safeguarding Beneficial Insects: Strategies and Innovations for Conservation

- Amidst Growing Threats. International Journal of Bio-resource and Stress Management, Volume 16, Issue 3, 2025, Pages 01–10.
45. Regina T, Chamola A, Ghosh C. The impact of climate change on insects. Environment and Ecology, Volume 42, Issue 4A, 2024, Pages 1774–1782.
 46. Sangle P M, Satpute S B, Khan F S, Rode N S. Impact of climate change on insects. Trends in Biosciences, Volume 8, Issue 14, 2015, Pages 3579–3582.
 47. Sataral M, Palebang M, Qodri A. Diversity and ecological role of macro insects on cultivated chili pepper using barrier crops. Comunicata Scientiae, Volume 14, 2023.
 48. Scherber C, Karley A J, Schöb C, Schmutz A, Weih M, Tavoletti S, Vaz Patto C, Rubiales D, Villegas Fernández Á, Kiær L P. Deliverable report 2.4 – Key mechanisms promoting performance of plant teams. EU-H2020 Project DIVERSify, 2020.
 49. Singh A K, Mitra S, Kar G. Assessing the impact of current tropospheric ozone on yield loss and antioxidant defense of six cultivars of rice using ethylenediurea in the lower Gangetic Plains of India. Environmental Science and Pollution Research International, Volume 29, Issue 26, 2022, Pages 40146–40156.
 50. Singh T V K. Climate Change and its Impact on Agricultural Pests. Indian Journal of Ecology, Volume 50, Issue 6, 2023, Pages 1874–1880.
 51. Slade E M, Ong X R. The future of tropical insect diversity: strategies to fill data and knowledge gaps. Current Opinion in Insect Science, Volume 58, 2023, Pages 101063.
 52. Soares A O, Haelewaters D, Ameixa O M C C, Borges I, Brown P M J, Cardoso P, de Groot M D, Evans E W, Grez A A, Hochkirch A, Holecová M, Honěk A, Kulfan J, Lillebø A I, Martinková Z, Michaud J P, Nedvěd O, Roy H E, Saxena S, Shandilya A, Sentis A, Skuhrovec J, Viglášová S, Zach P, Zaviezo T, Losey J E. A roadmap for ladybird conservation and recovery. Conservation Biology, Volume 37, Issue 1, 2023, Pages e13965.
 53. Suresh M D, Xin T, Cook S M, Evans D M. Bugs and bytes: Entomological biomonitoring through the integration of deep learning and molecular analysis for merged community and network analysis. Agricultural and Forest Entomology, Volume 27, Issue 1, 2025, Pages 35–49.
 54. Terblanche J S, Clusella-Trullas S, Lehmann P. How climate change might impact insect movement via physiological mechanisms. One Earth, Volume 7, Issue 4, 2024, Pages 608–622.
 55. Vidal M C, Abarca M, Backe K, Curé A E, Finke D L, Koltz A M, Lackey A C R, Mitchell J C, Prather R M, Welti E A R, Wimp G M, Murphy S M. What do we know about insect responses to global change? A review of meta-analyses on global change drivers. Insect Conservation and Diversity, Volume 1, 2025, Pages 17.
 56. Wagner D L. Insect Declines in the Anthropocene. Annual Review of Entomology, Volume 65, 2020, Pages 457–480.
 57. Wallon S, Tsafack N, Pozsgai G, Melo C, Borges P A V, Elias R. Effects of a short-term temperature increase on arthropod communities associated with pastures. Biodiversity Data Journal, Volume 11, 2023, Pages e107385.
 58. Yan X-R, Wang Z-Y, Feng S-Q, Zhao Z-H, Li Z-H. Impact of Temperature Change on the Fall Armyworm, *Spodoptera frugiperda* under Global Climate Change. Insects, Volume 13, Issue 11, 2022, Pages 981.