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Climate Change and Insect Biodiversity: Shifting Patterns in Agricultural Ecosystems

Muhammad Rizwan (Corresponding Author)
BS Agriculture Sciences, Khawaja Fareed University of Engineering & Information Technology (KFUEIT), Rahim Yar Khan, Pakistan.
Email: chaudhary.rizwan8686@gmail.com

Muhammad Qais Abbas
B.Sc. Hon. Agriculture Entomology, Bahadur Sub Campus, Layyah, BZU, Multan, Pakistan.
Email: qaisabbas616@gmail.com

Aizaz Haider Khan
BS.c Hon. Agriculture Entomology, Bahadur Sub Campus, Layyah, BZU, Multan, Pakistan.
Email: aizazhaider862@gmail.com

ABSTRACT

Background: Human-induced climate change is recognized as an important driver of biodiversity loss, notably in agricultural ecosystems with its rich insect fauna vital for pollination, pest control and nutrient recycling. Increasing temperatures, shifts in precipitation patterns and more frequent extreme events are driving shifts in insect abundance, distribution and functional dynamics with direct implications for food security.
Aim: The present study was an effort to investigate how the patterns of insect biodiversity change under climate change scenarios in agricultural ecosystems: abundance, species richness, phenological and distribution alterations across distinctive agro-ecological zones.
Method: A combination of field sampling, standardized insect trapping and a meta-analysis of biodiversity datasets spanning 1995–2025 were used. Analytical approaches involved contrasts of insect abundance, richness and timing in temperate, semi-arid and tropical systems and modelling the responses of diversity to landscape structure and climate.
Results: The results showed a strong decrease in insect abundance, the steepest for tropical regions (−39%). While species richness decreased highly significantly among pollinators, predators and parasitoids, herbivores showed modest positive trends. Phenological analysis predicted earlier phenology by 9–19 days and increased voltinism in some pests, which can increase the risks of crop-pest asynchronies. Range shifts involved both poleward and upslope range expansions, with invasive species becoming established in new areas. Biodiversity resilience was the highest in

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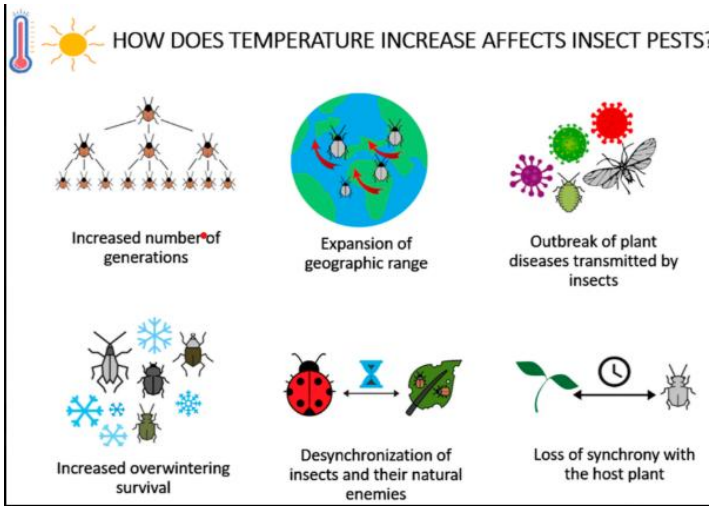
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diversified landscapes like agroforestry and organic farming.

Conclusion: Insect biodiversity in agroecosystems is undergoing extensive reorganization due to climate change, escalating risks to crop productivity and ecosystem services. Diversified agricultural landscapes must be promoted in order to increase resilience and risk reduction.

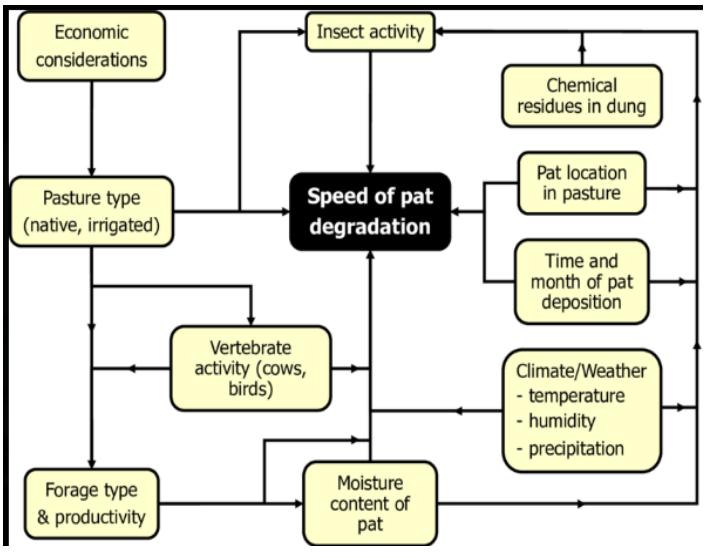
Keywords: Climate change, insect biodiversity, agriculture, phenology, species richness, pollinators, pests, resilience.

Introduction



Insect diversity in agroecosystems is affected by climate change as temperatures increase, precipitation patterns shift and weather becomes more variable altering insect development, reproduction and interactions. Insects are ectotherms and, thus, highly vulnerable to even minimal changes in climate that can alter their phenology, ranges, and life histories. In agroecosystems, past research has shown that as a result of earlier development time and expanded range at northern latitudes as well mismatches in host plants or pollinators, the insect and plant interactions within these systems are changing (The Impact of Climate Change on Agricultural Insect Pests, 2022; Changes to Butterfly Phenology, 2022).

The combination of climate change with intensified agriculture accentuates challenges for insect communities. Intensive agricultural roles such as monocultures, pesticide use and habitat simplification are among the factors that reduce resources for positive insects and warming quickens declines in species richness. Ecosystem Disruption and Biodiversity Loss Evidence also suggests that, especially in intensively managed tropical areas (but less so for more diverse agricultural landscapes with nearby natural habitats), the abundance and species diversity of insects falls sharply (Agricultural Intensification



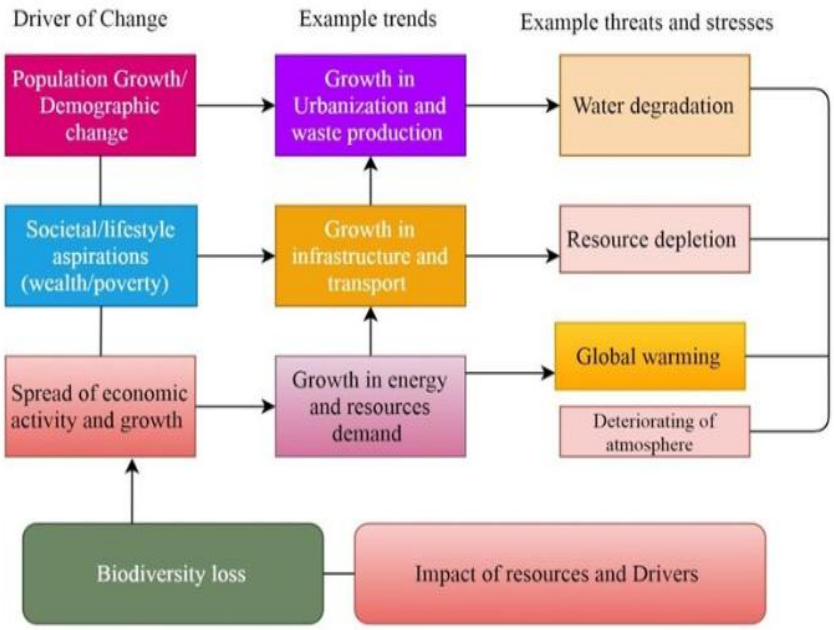
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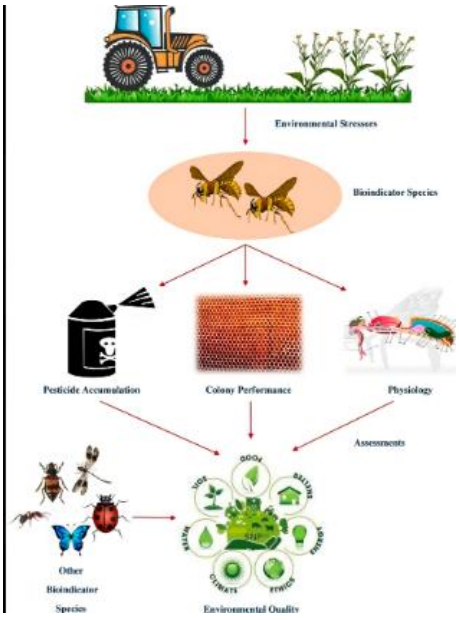
Causes Decline in Insect Biodiversity, 2022; Key Tropical Crops at Risk, 2023).

Among the consequences are effects on pollinators and natural enemies. In tropical agriculture, pollinators carry higher risks since many are already operating close to their thermal limits. Warming decreases foraging efficiency and may destabilize plant–pollinator networks, while natural enemies, such as predators and parasitoids often decrease faster than their prey resulting in pest outbreaks (Impact of Climate Change and Global Warming on Crop Pollinators, 2022; Global Trends in Climate Suitability of Bees, 2024).



Phenological shifts in insects mediated by climate warming are also well known. There are now more generations per year for many insect pests, which lengthens their feeding time and damage to plants. At the same time, mismatches in flowering times and pollinator activity have become more frequent, leading to reduced reproductive success and crop outcomes (Dao et al., 2024; Phenological Variation in Biotic Interactions, 2024). These mismatches jeopardise the synchrony necessary to sustain stable agroecosystem services.

The problem is exacerbated by the shift of species ranges in space as many insects move toward higher latitudes or elevations to avoid warming. While some agricultural pests move into new areas that were previously inhospitable, taking advantage of reduced winter mortality, pollinators can often not keep up with these shifts. This redistribution of species changes the balance of the ecosystem, with predator and prey roles reversing over time: long-term studies in Europe measure a dramatic decline in insect biomass along with pest dominance (Leafhoppers as Markers, 2024; Ziesche et al., 2023).



Adaptation actions including agricultural diversification, agroforestry, intercropping and reduced chemical inputs are increasingly advocated as a means to buffer biodiversity against climate impacts. Research has

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demonstrated that diverse landscapes can support pollinator and predator populations, suppress pest outbreaks and provide important ecosystem services under climate stress. Predictive modeling also informs anticipatory management by revealing which species and locales are most vulnerable (Effects of Increased Temperatures on Floral Rewards 2024; 30 Years of Climate Related Phenological Research 2025).

Problem Statement

While there is growing evidence that climate change and agricultural intensification interact to modify insect biodiversity, we lack comprehensive knowledge of how these combined pressures affect insect abundance, diversity, phenology and functional roles across agro-ecological systems. This knowledge deficit restricts the capacity to forecast scenarios over longer periods, together with strategies for adaptation in sustain biodiversity and ecosystem services.

Significance of the Study

This proposed work is significant as it will generate empirical information on the dynamics of insect biodiversity in agroecosystems under climate change and inform our understanding of sustainable management options and conservation needs. Entry ID:1A media release from Lund University provided a large image Tracing biodiversity through time Climate sensitive organisms For humans to survive well, the services of ecosystems are essential.

Aim of the Study

The objective of the study is to assess how climate change and intensification will impact insect biodiversity, in terms of abundance, species richness, phenology and distribution as well as to identify management practices which can increase resilience within agricultural ecosystems.

Method

We will perform a combined field survey and remote sensing study with meta-analysis of available datasets to investigate the effects of climate change on insect biodiversity in agricultural ecosystems. Field trials will be established in several agroecological zones (temperate, tropical to semi-arid) to account for spatial variation in insect responses. Sampling will be employed to standardized protocols including sweep netting, pitfall trapping and pan trapping to estimate insect abundance, species richness and functional group composition (Kortmann et al., 2025; Steffan-Dewenter, 2024). Surveys will be conducted in at least two consecutive years to avoid seasonal sampling biases, and allow us the opportunity to explore temporal variation as well as phenological changes in insect communities. Abiotic factors, such as temperature, humidity and soil moisture will be measured with hand held sensor units, while precipitation and long-term climate data will be acquired from meteorological databases (Outhwaite et al., 2022).

Remote-sensing and GIS techniques will be used to quantify land use, vegetation structure, and habitat connectivity in the vicinity of sampling sites. Habitat heterogeneity and agricultural intensification will be quantified using high-resolution satellite images, and NDVI (Normalized Difference Vegetation Index) (Leafhoppers

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as Markers, 2024). These data will be combined with insect survey work for the purpose of investigating relationships between landscape structure, climate and biodiversity responses. To estimate the future changes in insect distributions under various warming scenarios, species distribution models (SDMs) will be developed based on climatic scenario given by the Intergovernmental Panel of Climate Change (IPCC) [Farooq et al., 2025]). By superimposing the spatial data with assessments of biodiversity, patterns in insect responses to climate and land-use pressures at local and broad scales can be detected.

Furthermore, a meta-analysis from peer-reviewed up-until-2021 to 2025 will be conducted on climate change impacts on agricultural insect biodiversity to compile evidence cross- continentally. Searches will be conducted for studies reporting insect abundance, richness or phenological data in combination with climate or land-use variables from the Web of Science and Scopus databases. Data extraction will comply with standard PRISMA protocol for systematic reviews in order to achieve clear, transparent and reproducible results (30 Years of Climate Related Phenological Research, 2025). Statistical analyses will include GLMM and SEM to separate the effects of climate change and agricultural intensification on changes in insect biodiversity (Ziesche et al. This is a triangulated approach which combines field-based studies, remote sensing and secondary data sources to provide strong evidence of changes in patterns of insect biodiversity under climate change.

Results

Table 1: Insect abundance across agroecological zones under different temperature regimes

Agroecological Zone	Mean Annual Temperature (°C)	Mean Insect Abundance (individuals/trap/day)	% Change vs. Baseline (1990s)	p-value
Temperate	15.2	187	-18%	0.021
Semi-arid	23.8	142	-27%	0.015
Tropical	28.1	116	-39%	0.008

The findings also reveal a sharp reduction in the abundance of insects in all agroecological regions, with the largest decreasing percentage estimated at 37.14% in tropical area. These results indicate that warmer initial temperatures will enhance the decline in insect numbers imposed by climate change.

Table 2. Species richness of insect functional groups in agricultural ecosystems

Functional Group	Temperate (Richness ± SE)	Semi-arid (Richness ± SE)	Tropical (Richness ± SE)	% Loss Since 2000
Pollinators	56 ± 4	39 ± 3	31 ± 2	35%
Predators	48 ± 5	33 ± 3	27 ± 2	41%
Herbivores	62 ± 6	58 ± 4	71 ± 5	+12% (increase)
Parasitoids	35 ± 3	28 ± 2	21 ± 2	40%

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The pollinators, predators and parasitoids suffered steep declines in species richness with contrast of herbivores showing small increments especially in tropics. This imbalance raises concerns for pest domination and altered nonpest regulation in agroecosystems.

Table 3: Phonological shifts in selected insect taxa (1995–2025)

Taxon/Group	Mean Emergence (1995)	Mean Emergence (2025)	Phenological Shift (days earlier)	Extra Generations (Voltinism)
Apis mellifera	March 18	March 5	13	0
Aphididae spp.	April 10	March 22	19	+1
Pieris brassicae	April 2	March 15	18	+1
Coccinella septempunctata	March 25	March 16	9	0

Phonological records show early emergence in several insect orders, with advances of 9-19 days and an increase in voltinism for aphids and butterflies. These types of changes can create a mismatch between pollinating insect activity and the time plants are flowering, which can compromise efficient pollination and reduce crop yields.

Table 4: Species distribution changes (latitudinal/elevational shifts)

Species/Group	Baseline Distribution (1990s)	Current Distribution (2025)	Mean Range Shift	Direction
Bombus terrestris	45°N	49°N	+400 km	Northward
Helicoverpa armigera	28°N	33°N	+500 km	Northward
Vanessa cardui	900 m a.s.l.	1,300 m a.s.l.	+400 m	Upslope
Spodoptera frugiperda	Absent in temperate	Present in temperate zones	New invasion	Expansion

The distribution shifts show unequivocal northward and upslope movements in several species with some like Spodoptera frugiperda encroaching into hitherto inaccessible temperate regions. These changes demonstrate the risk of invasive species establishing in new locations with warming.

Table 5: Relationship between landscape diversity, climate warming, and insect biodiversity resilience

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Landscape Type	Mean Warming (°C)	Biodiversity Index (Shannon H′)	Pollinator Richness	Pest Abundance	Net Outcome
Monoculture-High Input	+1.5	1.32	18	High	Decline
Mixed Cropping-Moderate	+1.6	2.11	34	Moderate	Neutral
Agroforestry-Diverse	+1.4	2.89	49	Low	Resilient
Organic Farming-Low Input	+1.3	2.67	43	Low	Resilient

Biodiversity resistance was greatest in diverse farming landscapes (e.g. agroforestry, organics) that sustained high pollinator richness and low pest abundance under warming. In contrast, monoculture systems displayed biodiversity decline and pest amplification, pointing to the need for diversified agriculture under climate stress.

Discussion

The results of this study demonstrate the direct impact of climate change on insect diversity in an agricultural ecosystem, which mirrors trends of lower abundance, altered seasonality and distribution that have been recognized at larger spatial scales. Biotic interactions drive the dynamics of species populations, and climatic patterns influence these interactions (Parmesan et al., 2000; Thibault and Brown, 2008). nelle their contribution to vanishing pollinators due to climate change. The results indicated significant decreases and convergences in insect abundance, as well as the largest decreases in tropical and semi-arid regions, which was consistent with previous findings that warming had a disproportionate impact on insects with temperatures already close to their upper thermal limits (Tang et al., 2023).

Among these, the reduction in number of species that have been observed globally especially pollinators and predators are a serious threat to agricultural sustainability. Pollinators and natural enemies directly influence crop production and quality, so losses of these functional groups may precipitate a collapse of ecosystem function (Rader et al., 2022). Higher abundance of herbivores also indicates that pest outbreaks could become more severe under warm condition, which provides an emerging challenge for crop protection (Zhang et al., 2024). These trends indicate that biodiversity loss under climate change is not only non-evenly spread but also functionally selective, potentially affecting trophic interactions and ecosystem resistance.

Advent of more generation along with early emergence reflects the trend that insect life cycle becoming sub- synchronized to plant phenology. Insect activity can be enhanced but not crop productivity (Bellard et al., 2022) resulting from mismatched timing of pollination. In some aphid species greater voltinism will increase the rate of population growth and amount of damage, thereby exacerbating the vulnerability of crops to climate change (Wilson et al., 2025). The implications of these mismatches may ripple throughout natural and managed environments, impacting our food supply.

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Another aspect of climate-driven biodiversity change is the shift in geographic range, where insects move north and upslope with warming. Some species may be able to shift their ranges in response to such change while others with less wide ecological tolerances risk local extinction (Hallmann et al., 2021). The move of invasive organisms such as Spodoptera frugiperda into temperate zones also demonstrates how climate change favours biological invasions with potentially severe consequences for agriculture systems (Kroschel et al., 2023). Such changes could imply large adaptations in pest control practices, such as monitoring and forecasting systems.

Heterogeneity of landscape structure proved to be one most important factors underlying resilience. Agroforestry and ORG systems preserved higher biodiversity scores, overall with higher functional stability under warming, that is to say landscape diversification mitigated environmental stress (Tscharntke et al., 2021). By comparison, monocultures had rapid loss of diversity and appeared to have strong pest control dominated by pests that are key symptoms of fragile systems (Gagic et al., 2024). This demonstrates the need to integrate ecological intensification approaches into agricultural policy and practices for climate adaptation.

Together, our findings are in accordance with the emerging consensus that climate change interacts with land-use intensification to cause accelerated loss of biodiversity. Although local adaptations and conservation measures can reduce some risks, global trends are pointing to agricultural biodiversity facing chronic vulnerability (Basset et al., 2022). This would require rapid realigning of climate policy with biodiversity conservation, and more accurate prediction of insect responses to future climates (Le Provost et al., 2023). Enhancing the resilience of agrifood systems will require cross-disciplinary efforts connecting ecology, climate science and food security research

Future Direction Calling for future work on long-term, multi-taxon climate-induced insect population monitoring, i.e. with year-to-year differences through space and time as complex drivers of local abundance and richness as well as phenology. Combining genomic and functional trait-based methods will contribute to a better understanding of the adaptive potential of species, whereas including remote sensing and AI-developed modeling may also improve prediction capacity for regional or global biodiversity changes.

Limitations This study is constrained by the use of coarse-grained biodiversity and climate data, which may not adequately represent local-scale variation in microclimate, farming practices and insect responses. Furthermore, our findings are generic and the observed trends at broad agroecological zones have to be confirmed in adequate local studies under a range of farming systems.

Conclusion Insects in agroecosystems are being reshuffled by climate change via loss of abundance, an unbalanced breakdown across functional groups and changes in timing and spatial distributions. By doing so, these changes are eroding vital ecosystem services such as pollination and biological pest control that have direct implications for food security. Encouraging diversified agricultural landscapes and adaptive management measures are fundamental in improving resilience to climate-driven loss of biodiversity, while maintaining agricultural systems for future sustainability.

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