INSECT and CLIMATE INTERACTIONS

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Insect and Climate Interactions

This multi-authored book "**Insect and Climate Interactions"** is a compilation of the information on insect and climate interactions, which is a demand of the day, to understand impact of climate changes on life activities of insects, the largest species biodiverse taxon on the Earth, and is published by **Applied Zoologists Research Association (AZRA), Bhubaneswar, India,** pp 376, HB, Rs. 1500/- in India and US$/- 50/-for other countries excluding postage and handling charges Rs. 100/- and US$ 15, respectively.

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Foreword

Climate change, a pressing global challenge, is reshaping our planet in profound ways. As temperature rise, sea levels increase, and precipitation patterns shift, the delicate balance of life on Earth is increasingly threatened. Insects, as pivotal components of ecosystems, are particularly vulnerable to these changes.

Over the past century, global temperatures have been rising, with an average increase of approximately 0.7°C, with even more significant warming observed near the poles, reaching 2–5°C. This warming trend has led to a range of environmental changes, including rising ocean levels due to the melting of polar ice, milder winters, earlier springs, and delayed onset of winter. The primary driver of this climate change is the excessive emission of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), as well as chlorofluorocarbons (CFCs) resulting from the combustion of fossil fuels. Atmospheric CO_2 levels have surged by 35% over the past 200 years, contributing to a projected temperature rise of 1.8–4°C from 2007 to 2100.

A recent survey of around 1,100 insect species highlights the profound impact of climate change on biodiversity. It is estimated that global warming could drive 15–37% of these species to extinction by 2050. This underscores the urgent need for continued research and action to mitigate the effects of climate change and preserve our planet's delicate ecosystems.

Insects, like all living organisms, are significantly affected by rising temperatures, increased CO_2 levels, and shifting precipitation patterns. These changes are leading to a range of ecological impacts, including the expansion of insect ranges, increased frequency of epizootics (insect outbreaks), and the introduction of new species into regions where they were previously absent.

The rise in temperature and CO_2 levels is altering the carbon-nitrogen balance in plants, which affects insect-feeding behaviors, defensive chemical concentrations in plants, competition among insect species, and plant responses to herbivory. Such alterations have substantial implications for plant-insect interactions and the effectiveness of integrated pest management programs. Understanding these dynamics is crucial for developing strategies to mitigate the effects of climate change on insect population and the broader ecological systems, they influence.

Recent data indicates that losses due to insect pests have increased by up to 32%. While there is substantial knowledge regarding the effects of weather and climatic events on insect pests in developing countries such as India, research specifically addressing the impacts of climate change on these pests remains limited. A significant portion of India's agricultural land relies on rainfed farming, which is directly influenced by climate variations. Thus, a comprehensive study of the climate change scenario, its impact on insect pest management, and the development of effective coping strategies is essential.

Globally, the use of pesticides has become a crucial component of pest management. However, the sole reliance on pesticides can significantly disrupt arthropod community structures and dynamics, with potential cascading effects on ecosystem services. Understanding how pesticides may disrupt top-down control mechanisms and contribute to secondary pest outbreaks is a key area of interest and concern.

This compilation of studies on climate change and insect interactions is a valuable contribution to our understanding of this critical issue. It provides a diverse range of perspectives for audiences including the public, students, educators, researchers, agricultural practitioners, and extension specialists. By providing insights and strategies to mitigate risks associated with insect pests in the context of climate change, this work serves as a valuable resource for all those involved in pest management and agricultural sustainability.

I commend the authors, Drs. S.K. Shrivastava, Ravindra C. Joshi, Anand Prakash, and Jagadiswari Rao for their excellent work in bringing together this collection of studies. I also applaud Dr. Anand Prakash, Founder & General Secretary of the Applied Zoologists Research Association (AZRA), India, for his unwavering dedication to advancing the field of insect science through this AZRA's 34th publication.

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Foreword

Global warming presents an unparalleled, predominantly human-induced challenge to our planet's natural systems, significantly impacting species distribution across diverse geographical regions. The primary drivers of these shifts over the past century have been identified as climate change and land-use alterations, as confirmed by the IPCC's 2007 assessment. Widespread evidence reveals the precise impact of warming on global physical and biological systems, ranging from destabilizing permafrost and escalating rock avalanches to altered plant life cycles and shifting species ranges.

As the Earth's most diverse organisms, insects are sensitive to temperature fluctuations because they are ectotherms. This sensitivity significantly impacts their physiology, development, behavior, and interactions with other species. Due to their complex morphology, physiology, behavior, and unparalleled diversity, insects are critical indicators of environmental disturbance. They are sensitive to xenobiotics and can respond to climate change through acclimation, adaptation, dispersal, and behavioral plasticity.

This comprehensive book is dedicated to exploring the interplay between climate change and insect populations, particularly the greenhouse effect. It delves into the disproportionate vulnerability of tropical insect species to rising temperatures and the potential advantages of warming temperatures for insect species inhabiting higher latitudes. The book provides crucial insights into the complex and multifaceted nature of insect ecology in a warming world.

Drs. S.K. Shrivastava, Ravindra C. Joshi, Anand Prakash, and Jagadiswari Rao are commended for their innovative approach to this subject. Their exploration significantly contributes to global understanding, informing strategies to mitigate the effects of climate change on insect biodiversity, food security, and crop losses. Dr. Anand Prakash, Founder & General Secretary of the Applied Zoologists Research Association (AZRA), India, is applauded for his steadfast commitment to advancing insect science through AZRA's 34th publication. This book, with its significant contribution to global understanding, is an invaluable resource for a diverse audience, including the public, students, educators, researchers, agricultural practitioners, and extension specialists, emphasizing the need for robust research and concerted action to address the interplay between climate change, insect populations, food security, and crop productivity.

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Preface

The intricate interplay between insects and climate is a critical, yet often overlooked, component of global ecological stability. As our planet undergoes unprecedented transformation due to human-induced climate change, the implications for insect populations are profound. This book delves into the heart of this complex relationship, examining how shifting climatic patterns are reshaping insect communities and, in turn, influencing ecosystems, food and nutrition security, and human well-being on a global scale.

Insects, the most diverse group of organisms on Earth, are vital to the functioning of terrestrial and aquatic ecosystems. They play indispensable roles in pollination, nutrient cycling, and natural pest control. However, the accelerating pace of climate change, characterized by rising temperatures, altered precipitation patterns, and more frequent extreme weather events, is pushing insect populations to their limits across the globe.

Direct impacts of climate change on insects include physiological stress, altered development rates, and shifts in behavior. Indirect effects are equally significant, as climate change modifies habitats, host plant availability, and the dynamics of predator-prey interactions worldwide. The convergence of climate change with habitat loss, another major anthropogenic pressure, creates a perfect storm for insect decline on a global scale.

While this book offers a comprehensive analysis of the Indian context, highlighting the specific challenges and opportunities presented by this rapidly changing climate, its primary focus is on understanding the global implications of insect-climate interactions.

By unraveling the complexities of these interactions, we aim to inform effective strategies for mitigating the negative consequences of climate change while maximizing the benefits that insects provide worldwide. This knowledge is essential for developing sustainable agricultural practices, protecting global biodiversity, and safeguarding human well-being.

This book is a call to action, urging researchers, policymakers, and the public worldwide to recognize the critical importance of insect conservation in a changing world. By fostering a deeper understanding of insect-climate interactions, we can work together to build a more resilient future for both insects and humans on a global scale.

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Introduction

Understanding the effects of anthropogenic climate change on natural systems could be considered the defining challenge for the ecological sciences in the 21st century (Garcia *et al*., 2014). Over the last three centuries, the global percentage of ice-free land in a natural state has shrunk from 95 to less than 50% (Ellis *et al*., 2010), with consequences that include the extirpation and extinction of plants and animals (Thomos *et al.,* 2004; Leadley *et al.,* 2010). Due to industrialization, habitat loss continues, and it is possible that we are living through a period of transition where the importance of changing climatic conditions could begin to rival the importance of habitat loss as shifting climatic means and extremes stress individuals and populations beyond historical limits (Urban, 2015; Thomas *et al*., 2004a). Beyond the direct effects of climate change, interactions with habitat loss, invasive species, pesticide toxicity (Noyes *et al*., 2009), and other factors complicate the picture. While this is an area ripe for experimental work (Lepetz *et al*., 2009), the multitude of potential interacting factors makes it challenging to design comprehensive experiments. Thus, observational studies will be essential to guide future research. Insects, as the most diverse lineage of multicellular organisms on the planet and fundamental to the functioning of freshwater and terrestrial ecosystems, are particularly vulnerable to climate change. The recent and ongoing reports of insect declines from around the globe (Wagner, 2020) underscore the urgency of understanding how these creatures will respond to the changing climate.

The intricate relationship between insects and climate has emerged as a critical area of ecological research. Numerous studies have investigated the impact of various atmospheric and climatic factors, including temperature, carbon dioxide, ozone, and water availability, on insect distribution, abundance, and pest risk (Hare, 1992; Caulfield and Bunce, 1994; Roth and Lindroth, 1995; Skendzic *et al*., 2021). While much of this research has focused on managed ecosystems, the influence of climate change on insect populations in unmanaged systems remains relatively unexplored. A diverse range of research methodologies, from laboratory and field experiments to simulation modeling, has been employed to assess future pest risks. Given the complex and diverse climatic conditions prevalent in India, a deeper understanding of how climate change interacts with other stressors to impact insect populations is essential. Insects play a pivotal role in various aspects of human life, including agriculture, ecosystem services, and public health. Therefore, comprehensive research is required to elucidate the multifaceted effects of climate change on these vital organisms.

Climate change is profoundly altering the intricate relationship between plants and insects, with far-reaching consequences for agriculture and food security. Shifts in temperature, precipitation, humidity, and other meteorological factors are driving changes in insect populations, distribution, and behavior. These changes, in turn, affect plant growth, development, and reproductive success.

Rising temperatures have contributed to increased insect pest populations, expanded geographic ranges, and enhanced pest damage potential. Concurrently, climate change-induced stressors such as heat stress, water scarcity, and soil degradation are weakening plant resilience. The delicate balance between plants and insects is further disrupted by the accelerating rate of plant phenology and the mismatching of plant-pollinator interactions. The increasing concentration of carbon dioxide in the atmosphere also plays a crucial role in this complex interplay. While elevated CO_2 levels can stimulate plant growth, they can also alter plant nutritional quality, affecting insect herbivores and pollinators. Additionally, the combined effects of climate change and other environmental factors, such as solar radiation and changes in rainfall patterns, are creating new challenges for both plants and insects.

Climate change is a potent driver of insect pest dynamics, with rising global temperatures, altered weather patterns, and extreme climatic events significantly influencing insect populations. These environmental shifts impact insect survival, reproduction, dispersal, and the number of generations per year. Consequently, the distribution, abundance, and damage potential of insect pests are undergoing substantial changes. Abiotic factors, such as temperature, humidity, and carbon dioxide levels, directly affect insect physiology and behavior. For example, increasing temperatures can enhance insect development, survival, and reproductive rates, as demonstrated by the expanded range and increased winter survival of the pink bollworm, *Pectinophora gossypiella*, under warmer conditions (Gutierrez *et al*., 2006). Conversely, extreme weather events, like droughts and heavy rainfall, can indirectly influence insect populations by impacting their natural enemies. The oriental armyworm, *Mythimna separata*, often thrives during periods of drought followed by heavy rainfall due to the reduced abundance of its natural enemies (Sharma *et al*., 2002). Climate change is exerting a profound influence on the intricate relationship between plants and insects, with far-reaching consequences for ecosystems, agriculture, and human well-being. Beyond affecting temperature and precipitation patterns, climate change is also altering plant physiology and chemistry. Rising temperatures, increased atmospheric CO_2, and the changing duration of dry seasons are significantly impacting tropical plant-herbivore interactions (Lobell and Gourdji, 2012). These environmental shifts are leading to a decline in plant defenses against insect pests. For instance, the early initiation of *Helicoverpa armigera* infestations in cotton and pulses in Northern India highlights the increased vulnerability of crops to pests under changing climatic conditions (Sharma, 2014). Moreover, elevated CO_2 levels have been shown to suppress plant defense pathways, such as those mediated by jasmonic acid (JA), rendering plants more susceptible to insect attacks (Zavala *et al*., 2008). Consequently, insect pests like the Japanese beetle (*Popillia japonica*) and the western corn rootworm (*Diabrotica virgifera*) are thriving due to reduced production of defensive compounds like cysteine proteinase inhibitors (CPIs). Climate change is also affecting insect behavior and communication. For example, herbivore-induced plant volatiles (HIPVs) are influenced by higher temperatures and CO_2 levels (Gouinguené and Turlings, 2002). Additionally, pheromone-mediated insect communication can be disrupted by climate change. Studies have shown that elevated CO_2 levels can reduce aphid (*Chaitophorus stevensis*) dispersal, while increased ozone levels can stimulate dispersal behavior (Edward *et al*., 2004).

Host plant resistance is a cornerstone of sustainable pest management, relying on plant-based defenses against insect herbivores. These defenses, encompassing antixenosis, antibiosis, and tolerance (Painter, 1968; Dhaliwal and Dilavari, 1993), are significantly influenced by environmental conditions, including temperature, sunlight, soil moisture, and air pollution. Climate change, by altering these factors, is disrupting the delicate balance between plants and insect pests (Sharma *et al*., 2010). Under stressful environmental conditions, plants become more vulnerable to insect attacks due to weakened defenses, leading to increased pest outbreaks and crop losses (Rhoades, 1985). In regions like India, rising temperatures and water scarcity have contributed to the breakdown of host plant resistance in sorghum against key pests such as the midge *Stenodiplosis sorghicola* and the spotted stem borer *Chilo partellus* (Sharma *et al*., 2005). As climate change intensifies, the effectiveness of host plant resistance is likely to decline further. Plants have evolved various mechanisms to defend themselves against herbivores, including the production of secondary metabolites. However, climate change can interfere with these defense strategies, making plants more susceptible to insect damage. Some plants can induce chemical changes in response to herbivory, deterring further feeding (Sharma, 2002). Yet, the capacity of plants to mount such defenses can be compromised under stress conditions.

Insects, comprising nearly half of global biodiversity, are pivotal to ecosystem structure and function. Their intimate association with host plants makes them particularly susceptible to the impacts of climate change. As global temperatures rise, precipitation patterns shift, and atmospheric composition changes, the interactions between insects and plants are undergoing significant transformations (Kazakis *et al*., 2007). Climate change directly influences insect physiology, behavior, and life history traits. Indirectly, it affects insect populations by altering host plant morphology, biochemistry, and distribution. As herbivores, pollinators, predators, and parasitoids, insects play critical roles in ecosystem services. Changes in insect abundance and diversity have the potential to modify these services (Hillstrom and Lindroth, 2008). Climate change is fundamentally altering the economics of crop protection. Rising temperatures and shifting weather patterns are reducing the efficacy of traditional pest management strategies, including host plant resistance, transgenic crops, natural enemies, biopesticides, and synthetic chemicals (Sharma, 2010a). The effectiveness of these control tactics is further compromised by climate change-induced physiological and biochemical alterations in both plants and insects. For instance, global warming can deactivate genes responsible for producing plant volatiles that attract natural enemies (Casteel *et al*., 2009), hindering biological control efforts. Extreme weather conditions, such as increased temperature, UV radiation, and low relative humidity, can also reduce the effectiveness of pesticides and other chemical control measures. To address these challenges, a comprehensive understanding of how climate change impacts insect-plant interactions is essential. This includes studying the changing dynamics of host plant resistance, identifying stable resistance sources, and developing strategies for pyramiding resistance genes. Additionally, research on the efficacy of transgenic crops under changing climatic conditions is crucial for informed decision-making.

Host plant resistance is a cornerstone of sustainable pest management, offering an environmentally friendly approach to insect control. However, the effectiveness of this strategy is increasingly challenged by climate change. As temperatures rise, precipitation patterns shift, and atmospheric conditions change, the complex interactions between plants and insect pests are being altered (Bale *et al*., 2002; Sharma *et al*., 2010). One of the most concerning impacts of climate change is the breakdown of host plant resistance. For example, sorghum varieties resistant to the sorghum midge, *Stenodiplosis sorghicola*, have become susceptible to this pest under conditions of high humidity and moderate temperatures (Sharma and Ortiz 2000). Furthermore, climate-induced changes in plant physiology and chemistry can reduce the effectiveness of host plant defenses. Plants often respond to biotic and abiotic stresses by altering their chemical composition, making them less suitable for insect survival and development (Sharma, 2002). These changes have significant implications for the use of transgenic crops. Studies have shown that elevated carbon dioxide levels can reduce the expression of resistance genes in transgenic plants, making them more susceptible to insect pests. For instance, the beet armyworm, *Spodoptera exigua*, has demonstrated increased survival on transgenic cotton grown in elevated carbon dioxide conditions (though specific references for this finding would strengthen the argument).

Climate change is a significant driver of the emergence and spread of insect-borne plant diseases. As global temperatures rise and weather patterns become increasingly unpredictable, insect vectors are expanding their geographic ranges and reproducing at accelerated rates (Petzoldt and Seaman, 2010; Sharma *et al*., 2005, 2010). For instance, the early colonization of potato crops by aphid vectors under warmer early-season conditions has contributed to increased incidence of potato viral diseases in Northern Europe (Robert *et al*., 2000). Climate change is also influencing the abundance, distribution, and activity of insect pests and the pathogens they transmit (Kovats *et al*., 2001; Brooks and Hoberg, 2007; Rosenthal, 2009). The Intergovernmental Panel on Climate Change (IPCC) projects a global temperature increase of 1.5-5.4°C by 2100 compared to pre-industrial levels (IPCC, 2018). Such warming is expected to have detrimental impacts on various organisms, including livestock (Hoegh-Guldberg *et al*., 2018).

Climate change is a potent driver of the complex interactions among insect vectors, pathogens, and their hosts. Weather conditions significantly influence the life cycle dynamics of these organisms, impacting their survival, reproduction, distribution, and abundance. Additionally, climatic factors affect the development and transmission of pathogens within their vector hosts (Rogers and Randolph, 2006; Semenza and Menne, 2009).

Precipitation patterns are also critical determinants of insect and pathogen populations. Decreases in precipitation can lead to the extinction of certain insect species due to water scarcity, while favoring others adapted to arid conditions, such as aphids (Rosenzweig *et al*., 2001). Conversely, increased precipitation and rainfall intensity can promote the proliferation of specific crop pests and pathogens (Karl *et al*., 1997; Sylla *et al*., 2016; Bichet and Diedhiou, 2018). These extreme weather events can disrupt both natural and artificial pest control measures by impacting the populations of beneficial organisms and their target pests (Cannon, 1998). However, in some cases, warmer temperatures associated with climate change can enhance the effectiveness of natural enemies, making pest populations more susceptible to biological control (Awmack *et al*., 1997).

Beyond direct impacts on insect vectors and pathogens, climate change is also altering the dynamics of plant-insect-pathogen interactions. These complex relationships are fundamental to ecosystem health and agricultural productivity. A deeper understanding of these interactions is essential for developing effective strategies to mitigate the negative consequences of climate change and ensure food security. Despite significant advancements in climate change biology, research on the impact of climate change on insects and subsequent effects on plant health remains limited. Critical knowledge gaps exist in understanding the influence of climate change on pest management strategies, below-ground pests, and ecosystems beyond agricultural landscapes, such as forests and natural habitats. A comprehensive, long-term, and multidisciplinary approach is essential to address these challenges in both developed and developing countries. International collaboration and investment in capacity building are required to strengthen pest risk analysis, surveillance, and monitoring systems.

Human activities and governmental policy on forestry, farming and road planning have great effect on the geographic range and climate (Andrewartha and Birch, 1954). Studies on phytophagous insects indicated temperature as the dominant abiotic factor that directly affects development, survival, range and abundance (Bale *et al.,* 2002; Kaloveloni *et al.,* 2015). Though, such climatic effects are likely to differ among species, depending on their existing environments and life-histories, as well as their ability to adapt. (Bale *et al.,* 2002). Many insects have tracked climate change rather than adapted to it (Coope, 1987). As insect are a good indicators of rapid climate change during present developmental era are needed to be studied through insect migration, as predicated changes in precipitation and temperature associated with the continued elevation of atmospheric CO_2 concentration will trigger the insect to their suitable latitude and longitude.

This book delves into the intricate relationship between insects, plants, and climate change, exploring how these factors influence ecosystems, agriculture, and human well-being. By examining both managed and unmanaged ecosystems, we provide a comprehensive understanding of the challenges and opportunities presented by our warming planet. We explore how climate change is altering insect behavior, distribution, and population dynamics, with significant implications for plant health and the transmission of diseases. The book also examines the breakdown of host plant resistance and the emergence of new pests, highlighting the urgent need for innovative pest management strategies. By synthesizing the latest scientific research, we equip readers with the knowledge and tools necessary to develop effective solutions. Our goal is to contribute to a global understanding of insect-climate interactions and to foster a future where food and nutrition security, ecosystems, and human societies thrive in the face of climate change.

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Dr. Anand Prakash born on 5th July 1952, completed M.Sc. (Zool.) in 1974 from Meerut University and Ph.D. in 1985 from Utkal University. Served at Central Rice Research Institute, Cuttack (1977-2014) as Scientist-1, Sr. Scientist, Principal Scientist. Head Division of Entomology, Head Division of Crop protection, & Director of Institute. He published over 200 research papers and 32 books and guided 10 Ph.D. students & also completed 4 EAPs. Dr. Prakash is the founder of AZRA and serving as its General Secretary since 1989 & also Managing Editor of Journal of Applied Zoological Researches since 1990.

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