Environment and Ecology 42 (4A) : 1774—1782, October—December 2024
Article DOI: https://doi.org/10.60151/envec/DXDR8910
ISSN 0970-0420

The Impact of Climate Change on insects

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Received 11 August 2024, Accepted 19 October 2024, Published on 29 November 2024

ABSTRACT

It is widely accepted that climate change has a significant impact on the production of agricultural plants and the insect pests associated with them. Some of the uncertainties about insect pests are related to small-scale climatic variability, including temperature variations, relative humidity, atmospheric CO_2, and precipitation patterns. Due to their great diversity, the plants that serve as their hosts, and the variations in global temperatures, different insect species are expected to react to global warming differently depending on where they live. Numerous factors, including range, variety, abundance, growth, and development, are impacted by climate change's effects on insects. Certain insects are favored while others are hampered. In this review we have discussed the impact of climate change on invasive species, how it is affecting the species distribution of insects, and various secondary effects of increase in temperature on the insects. We have further analyzed how the increased level of CO_2 is going to adversely affect the various insect species and thus impact our agriculture.

Keywords Climate change, Carbon dioxide, Temperature, Parasitoid, Agricultural pest.

INTRODUCTION

Through time we had a lot of changes in our agricultural system, lifestyle, technology, and economy. As the Indian population has blasted away to the top of the world, we are struggling as a community to adjust our needs with the resources that we have. By 2050, it is forecasted that the global crop demand will be met by intensification to elevate croplands' yield in underlying nations (Tilman *et al*. 2011). Impacts on potential yields would highly depend on climate change trends that follow in the years to come and the kind of agricultural techniques that are going to be followed.

It is generally acknowledged that climate change has a significant impact on the production of agricultural plants and the insect pests that are linked with them. Some of the uncertainties surrounding various components of climate change that are pertinent to insect pests include small-scale climatic variability, such as changes in relative humidity, temperature, atmospheric CO_2, and precipitation patterns. Insect species are likely to respond differently to global warming depending on where they live due to the great diversity of these creatures, the plants that serve

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as their hosts, and the fluctuations in the worldwide temperature (Skendžić *et al.* 2021). The impacts of climate change on insects are multifaceted, affecting their range, variety, abundance, growth, and development while favoring certain insects and hindering others. Climate change has most significantly impacted insects, which play crucial roles in ecosystems as pollinators, decomposers, and as a part of the food web. Our review explores the various ways in which climate change influences insect populations, their reproductive behaviors, migration patterns, and overall distribution.

The global impact of climate change on invasive species

Climate change is a significant factor in the spread and assistance of establishing alien invasive species (Walther *et al.* 2009). Invasive species are non-native organisms that can cause harm to the environment, economy, or human health. They often outcompete native species and disrupt the balance of ecosystems they invade.

For an alien insect to become invasive, they must arrive in that region, survive and reproduce. Human activities such as international trade, agriculture, and global trade have caused the exponential spread of species beyond their native regions (Ricciardi 2012). Climate change may have a positive or negative effect on the invasiveness of a species (Tobin *et al.* 2013). Various climatic factors such as temperature, wind, humidity, could control the dispersal of pests and insects to a new geographic area. According to a global meta-analysis conducted by Parmesan and Yohe (2003), the average rate of spread of insect species is 6.1 km per decade. The temperature rise contributes to the survival of insects where they could not survive earlier (Raza *et al.* 2014). The toleration levels and bioclimatic range of invasive species give them an upper hand over native species to adapt to a wider habitat (Walther *et al.* 2009). The fruit tree mealybug, *R. invadens,* is expanding its geographical range to new arrears, and climate change is reported to increase the chances of its infestation (Azrag *et al.* 2023). Changes in precipitation patterns may potentially be more significant for crop production than increases in temperature, especially in regions where dry seasons pose a barrier to agricultural output. Plants may lose their biological processes due to a lack of water in the soil, making them even more vulnerable to disease and pests (Zayan 2020). Flooding and severe rains have the potential to sweep away insect eggs and larvae (Shrestha 2019). When it rains heavily, little pests like aphids, mites, jassids, whiteflies, can be washed away (Indian Agricultural Research Institute 2012).

One of the key insect characteristics associated with invasion success is their diet patterns. Finding a suitable host plant to feed on is the first and most crucial duty for introduced insects. During the development of the Gypsy moth (*Lymantria dispar*) on black and red oak trees (*Quercus velutina* and *Quercus rubra*), the larvae that hatch before budburst will starve to death, especially if there is no other host plant available. On the other hand, if egg hatching takes place too soon after budburst, the quality of the foliage may deteriorate, which would lower fecundity (Hunter & Elkinton 2000). Rising temperatures and changing precipitation patterns can lead to shifts in vegetation patterns, affecting the availability of host plants and nectar sources for butterflies. To alter the impact of invasive species, effective monitoring and management efforts are required. Monitoring the pest populations for a considerable amount of time may give us significant input about the biological response of an invasive species and farmers can apply certain tactics for the prevention of pests (Heeb *et al.* 2019). Global risk assessments are extremely crucial for the prevention of the introduction of a harmful non-native species (Hellmann *et al.* 2008). Countries as well as organizations need to cooperate to analyze the “sink” and “source” capacities and risks involved with the same for proper mitigation of the harmful effect of invasive species (Perrings *et al.* 2010).

The impact of climate change on the distribution of species

Insects are highly sensitive to changes in temperature, precipitation patterns, and habitat conditions, making them valuable indicators of environmental changes. Moths are highly mobile and can disperse over long distances. As temperatures change, suitable habitats for different moth species may shift. Some species may expand their ranges into new areas as warmer conditions become favorable, while others may contract their ranges or face local extinctions if suitable conditions disappear. The European corn borer (*Ostrinia nubilalis* Hubner), for instance, has moved more than 1000 kilometers north in Europe. According to Lopez-Vaamonde *et al.* (2010), 97 non-native Lepidoptera species from 20 families have established themselves in Europe, and 88 European Lepidoptera species from 25 families have increased their range there of these, 74% have done so in the past century.

By 2055, it is anticipated that insect pest ranges will relocate to higher elevations, with an increase in the number of generations in central Europe. Moths are highly sensitive to changes in environmental conditions, particularly temperature and precipitation patterns, which are influenced by climate change. Changes in temperatures and precipitation patterns in their overwintering locations (North Africa) have a considerable impact on the migration patterns of the Migratory Silver Y Moth (*Autographa gamma*) to the UK (Robinet & Roques 2010).

It is believed that the pink bollworm, a significant cotton pest, is extending its present range from the frost-free zones in southern Arizona and California into the cotton-growing regions of Central California (Gutierrez *et al.* 2006). According to Gutierrez *et al.* (2009), rising summer temperatures and milder winters will have a negative impact on adult flies, causing their ranges to move north instead of south in both Europe and North America. The *Bactrocera oleae* is currently restricted to the desert regions of Arizona and southern and central California due to high summer temperatures, while the cold restricts its habitat in the far north.

Insects whose geographic range was restricted by low temperatures at higher elevations may be able to overwinter more successfully as a result of rising temperatures (Pareek *et al*. 2017). Betzholtz *et al*. (2013) have uncovered a variety of features that enable specialist butterfly and moth species to adapt to climate change, even though generalist species are generally regarded as winners in the fight for habitats affected by global warming. The northern range boundaries of Swedish butterflies and moths that feed on early larvae rich in nitrogenous plants have increased more quickly than those of specialists who prefer alternative diets. An increase in temperature speeds up the development and reproduction of insects, producing more generations annually and ultimately causing more crop damage (Bale *et al.* 2002). Insects that reproduce asexually frequently have a greater capacity for colonization and dispersal, at least in part because single individuals can start new populations, they don't need to find partners, and their population growth rates are roughly twice as fast (Orive 2020, Garnas *et al*. 2016). Climate change is directly linked to larger population densities, faster rates of development, and more frequent outbreaks of the Green Peach Aphid (Bale and Hayward 2010). Another globally important insect group is that of ants. Ants are found on all continents, except Antarctica. Their high biomass and abundance in the majority of terrestrial habitats make them an important part of the terrestrial ecosystem (Tuma *et al.* 2019). It has been said that ants are either thermophilic or cryophobic (Bishop *et al.* 2016). Similar to many other poikilothermic ectotherms, ants exhibit a thermal performance curve where the ecological performance or fitness increases with temperature up to a maximum level before abruptly falling when the temperature rises beyond what is necessary for normal cellular and organismal functioning. As a result, at extremely low and high temperatures, ant performance and diversity are almost non-existent (Hurlbert *et al.* 2008, Jenkins *et al.* 2011). Fitzpatrick *et al.* (2011) use species distribution modelling tools to predict that while ant diversity would likely decrease in the tropics as temperatures become intolerable, it will likely grow in temperate regions as temperatures rise. It is anticipated that as temperatures rise, ant populations will mostly follow their thermal envelopes and migrate to higher latitudes and altitudes like other creatures (Pecl *et al.* 2017). It's important to note that while ants may be affected by climate change, they are also resilient and adaptable creatures. Some species may be able to adjust their behavior, nesting habits, or foraging patterns to cope with changing conditions.

Secondary effects of temperature increase on insects

The effects of temperature increase due to climate

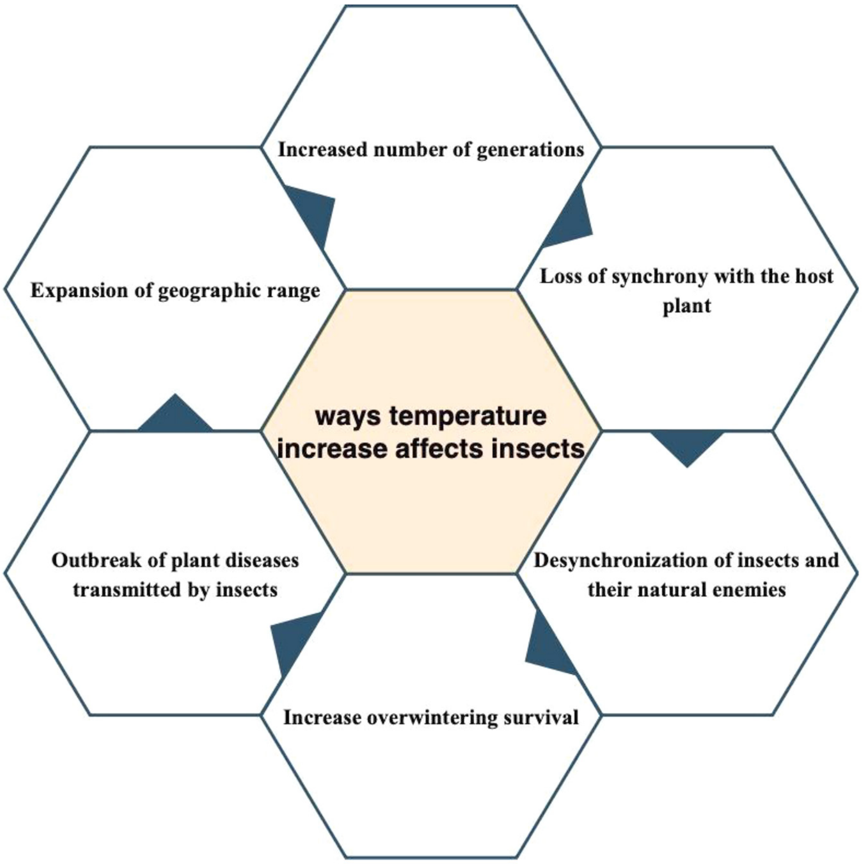

Fig. 1. Effect of temperature rise on insect.

change bring above differences in factors such as availability of water, the incidence of strong winds, and the timing and intensity of sun (Rehman *et al.* 2015). Other secondary effects of temperature rise include the increased occurrence of heat waves and the effects on pests (Field *et al.* 2014).

Another molecular marker that is likely to be important in the response to temperature change is the heat shock protein (Hsp70). The genes of heat shock protein called Hsp70 genes have an important role in protecting insects from very high temperatures. They increase the tolerance capacity of the insects (L Wang *et al.* 2015). It is known that the expression of Hsp70 protein, though normally low, has a high expression level during heat-related stress (Bahar *et al.* 2013). This response was observed in widespread moth pests such as *Plutella xylostella* and *Xestia cnigrum* where changes in the various Hsp70 genes expression became more regular due to heat or cold stress (Bahar *et al.* 2013, L Wang *et al.* 2015). The relationship between temperature and the growth rate of forest insects is well known to give an irregular curve, a no straight-line graph (Rebaudo & Rabhi 2018), the speed of their developmental stages is found to increase at a low rate in between a lethal cold threshold and an optimal threshold, and are found to then swiftly decrease till an extreme hot lethal threshold (Davídková & Doležal 2019). Various laboratory studies have furthermore shown that excessive irregularity in day-by-day temperature may lower the survivorship of insect species (David *et al.* 2016). The rise in temperatures cuts the generation period, resulting in higher generation in a year, and increases the quantity of brood, which may lead to a sudden increase in insect populations (Bentz *et al.* 2019).

However, several species of insects, particularly those that undergo diapause, do not shrink generation time in response to an increase in temperatures (Levesque & Marshall 2021). Mainly in summer, a temperature rise may lead to increased death (Mech *et al.* 2017), as well as reduced size and drop in distribution capacity of early adults (Pineau *et al.* 2016). Insects that are restricted to certain areas due to low temperatures may have the benefit of increasing their range of distribution (Roques *et al.* 2014). Ants are poikilothermic ectotherms; their performance or capabilities increase with temperature but speedily decline as the temperature becomes too high beyond the range for proper cellular functioning. Insects often have specific temperature and seasonal cues that regulate their life cycles. Temperature changes can disrupt these cycles affecting events in the life cycle leading to variations in the entire insect population (Fig. 1).

Insects responses to CO_2

Understanding ecological dynamics is essential to predicting and mitigating potential effects on insect populations and their ecosystems as climate change advances and carbon dioxide (CO_2) levels rise. Because of the rise in CO_2 levels, climate change has a substantial impact on insect populations. Although other factors also have a role in the fall of insects, the effect of CO_2 will be the main emphasis of this section of the article. Among the atmospheric changes of the last half-century, the increase of CO_2 is one of the most important documented (Prentice *et al.* 2001). Its concentration has increased and is expected to double by 2100. It has changed from 280 ppm to 416 ppm in the pre-industrial era. Carbon dioxide is a greenhouse gas because it absorbs thermal infrared radiation of certain wavelengths emitted from the surface of the land. The more infrared radiation is absorbed the greater the fraction of radiation emitted from the atmosphere to the Earth's surface, bringing above a rise in air temperature. According to research, variations in CO_2 levels brought on by climate change may affect insects in several ways, including population dynamics, behavior, and interactions with the environment (Skendžić *et al*. 2021). The physiology and behavior of insects are reported to be impacted by the growing atmospheric CO_2 concentrations. Spiracles, which are microscopic apertures that allow insects to exchange gases with the environment, are their primary means of respiration. Insect respiration can be impacted by higher CO_2 levels by changing the relationship between oxygen and CO_2. This may affect their growth, development, and metabolic rates, which could alter population size. Increased CO_2 levels might affect insects indirectly by changing the physiology and makeup of plants. It causes plants to accelerate photosynthesis, which increases the production of carbohydrates. This may also result in

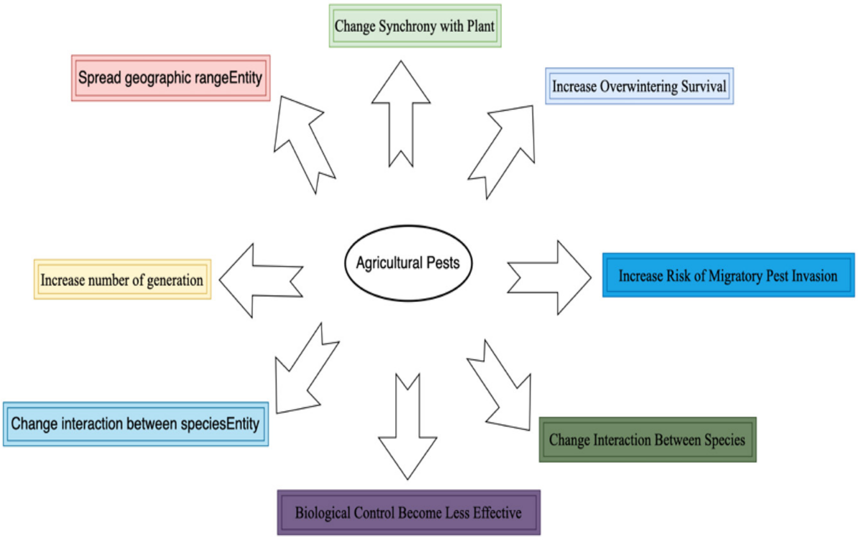

Fig. 2. Effect of increase CO_2 on agricultural pest.

plants having less nitrogen or other nutrients. Growing, surviving, and reproducing insects that depend on these plants as food sources may have lower nutritional quality (Xu *et al*. 2019). Also, a study on the long-term consequences of increased CO_2 on the pea aphid (*Acyrthosiphon pisum*) discovered that over six generations, higher CO_2 levels lengthened nymph duration, decreased adult longevity and fecundity, and changed the nutritional makeup of aphids. In particular, the amount of protein decreased while the amount of lipids, soluble sugar, and glycogen rose. Potentially, the aphid population could decrease as a result of these changes in nutritional composition (Li *et al.* 2021) (Fig. 2).

According to a study on insect-plant interactions, increased CO_2 also affects herbivorous insects in a variety of ways. Under conditions of elevated CO_2, insects may react by changing their feeding habits and their rate of growth. The behavior of pests and crop output may be affected by such reactions. The study also underlines that such an effect on insect populations can ultimately change the dynamics of an ecosystem (Hunter 2001). In a review by Nihal (2020) stated that rising levels of CO_2 bring above more growth of plant vegetative parts, but at the same time, it also increases the incidence of injury caused by many herbivorous insects. However, the impact related to insect herbivory is not species-specific all the time. The changes in the concentration of CO_2 may also cause a small rise in carbon-based defense systems as well as an opposite effect of a decrease in the nitrogen-based defense system. It is also observed that there is a rise of 40% in the consumption of leaves by herbivores, this is attributed to the decrease in foliar nitrogen as a result of CO_2 rise. The increased atmospheric CO_2 levels have an enormous impact on pests related to agriculture. Incidences have been reported where their range of distribution is affected. The range of spread of insects can vary widely on the species and another environmental factor. The ability to endure the winter season using certain adaptations such as hibernation, diapause, are also reported to increase due to a rise in the concentration level of CO_2, their duration of completing their life cycle also increases, and the coordination and relation of pests and plants also change, there is also modification in the species engagement and influence on each other, the risk of migrated pest also increase, there is also change in the effectiveness of biological control and occurrence plant diseases caused by insect (Skendžić *et al.* 2021). Increases in CO_2 also have the potential to alter crucial ecological relationships and affect the timing of insect life cycles. For instance, variations in CO_2 concentrations might impact when plants flower or when insects emerge that rely on these flowering plants for pollination. Insects and the plants they interact with may suffer as a result of asynchrony between plant and pollinator phenology, which may result in decreased reproductive success and population decreases (Crowley *et al.* 2021).

An increase in the rate of parasitism was observed in another study which was on examination of grain aphid fed by parasitoid wasp on elevation of CO_2 level, but the same effect of CO_2 level lower fertility of the wasps (Chen *et al.* 2007). Many more studies have reported the effect of elevated CO_2 concentration on the prey-predator relationship. For instance, an investigation by (Chen *et al.* (2007), Chen *et al.* (2005) brought above the view that the preferences of food choice of ladybirds, which is among one of the largest groups of insect species vary with the change in the concentration of CO_2. The species *H. axyridis* preyed on aphids under elevated CO_2 concentration compared to ambient CO_2 concentration. Furthermore, the effects of other stressors on insect populations can be made worse by CO_2 induced climate change. Threats to insects include invasive species, pesticide use, and habitat degradation. These stressors and climate change may combine, increasing the susceptibility of insect populations to their impacts. To create efficient conservation plans and minimize the potential ecological effects of these changes, it is essential to comprehend the intricate relationships between changing CO_2 levels, insect populations, and climate change.

DISCUSSION

This review paper highlights the profound effects of climate change on insect populations and, by extension, on agricultural systems. As global temperatures rise and weather patterns become increasingly erratic, the impacts on insects, critical players in ecosystems, are becoming more pronounced. Insects influence various ecological processes, from pollination to decomposition, and their responses to climate change can significantly affect agricultural productivity and ecosystem health. Insects are integral to ecosystem functioning, serving as pollinators, decomposers, and as prey for various animals. The alteration in their population dynamics due to climate change threatens the stability of these roles. For instance, the decline of pollinator populations like bees can lead to reduced plant reproduction, affecting food supplies for both wildlife and humans (Potts *et al.* 2010). Similarly, changes in decomposer activity can influence nutrient cycling, impacting soil health and plant growth (Wall *et al.* 2015). The impact of climate change on insects also poses significant challenges for agriculture. As pest species proliferate under warmer conditions, crop damage is expected to rise, leading to increased economic losses (Deutsch *et al.* 2018). Farmers may face heightened pressure to adopt new pest management strategies, potentially involving greater use of pesticides, which can have further environmental consequences. Moreover, the shifting distribution of beneficial insects, such as pollinators, can affect crop yields and food security. These agricultural implications underscore the importance of integrating climate resilience into farming practices. Insects play a critical role in the transmission of diseases, and climate change can exacerbate these public health threats. Warmer temperatures and altered precipitation patterns create favorable conditions for the proliferation of vectors like mosquitoes, increasing the risk of diseases such as malaria, dengue, and Zika. The expansion of vector habitats into new regions poses a growing health risk, requiring enhanced surveillance and public health measures. The intersection of climate change and insect-borne diseases highlights the urgency of addressing these challenges to protect human health. Addressing the impact of climate change on insects necessitates a multifaceted approach. Conservation efforts must prioritize habitat protection and restoration, ensuring that insects have access to suitable environments as their ranges shift. Additionally, research and monitoring are crucial for tracking changes in insect populations and developing adaptive management strategies. Policies aimed at reducing greenhouse gas emissions and mitigating climate change can also help alleviate the pressure on insect populations and the ecosystems they support. Research should focus on understanding species-specific responses, interspecies interactions, and the cumulative effects on ecosystems. Collaborative efforts between scientists, policymakers, and stakeholders are essential to translate research findings into effective conservation and management practices. Moreover, public awareness and engagement are vital for fostering support for policies that address climate change and its ecological impacts.

CONCLUSION

In conclusion, climate change exerts a multifaceted influence on insect populations, affecting their population dynamics, reproductive success, migration patterns, and ecological roles. Understanding these impacts is crucial for predicting future ecological changes and developing strategies to mitigate the negative consequences of climate change on biodiversity and ecosystem services. Continued research and monitoring are essential to grasp the full extent of these effects and to inform conservation and management practices aimed at preserving insect diversity and the vital functions they perform in ecosystems. The pervasive effects of climate change on insects reveal a complex web of interactions that extend far beyond individual species. As a result of climate change, the delicate balance that sustains insect populations and their ecological roles is disrupted.

ACKNOWLEDGMENT

The authors are grateful to the University of Delhi's Gargi College for all of their assistance with this research.

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