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Changing Global Insect Diversity and Distribution Influenced by Climate Change

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Abstract:

Climate change is a major global concern that impacts every facet of agriculture. Human-induced activities are currently thought to be the main driver of climate change. Among all life forms, insect communities are more vulnerable to climate change, as they are central component of many ecosystems. Climate change threatens insect biodiversity and the ecological benefits they provide. Insects are a crucial component of the environment, and their array of species is rapidly dissipating around the world. Changes in environmental variables, such as increased atmospheric CO_2 levels, high temperature and altering precipitation, have a substantial impact on insects. These leads to changes in insect diversity, abundance, population growth rate and biotic interactions result in more severe economic losses in agriculture. This paper provides the possible effects of global climate change on insect diversity, distribution, and their main driving factors for the dispersal in agro ecosystems.

Keywords:

Climate change, Insect diversity, Global warming, Distribution, Atmospheric temperature, Elevated carbon dioxide.

1.1 Introduction:

Increased population growth has resulted in a constant rise in the need for agricultural production, which places global food security at serious risk. Quality and quantity of agricultural commodities are affected by meteorological components at field level.

Climate events like storms, droughts, floods, elevated carbon dioxide (eCO_2), altered precipitation and increased temperature have significant impact on the availability of food. Thus, climate change is a major global issue that has a significant impact on all facets of agriculture. The Intergovernmental Panel on Climate Change (IPCC) defines 'climate change' as "a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer". By the end of the century, an increase in mean temperature of 1.1 to 6.4^{o} C, an increase in CO_2 of around 560 ppm, and a 10-25 cm rise in mean sea level have been estimated (IPCC, 2021).

Climate change is expected to cause the extinction of 15 to 37 per cent of all species by 2050 (Hance *et al.*, 2007). The extinction of arthropod species and communities is impacted by climate change in terms of range, abundance, and communities have been studied by Butchart *et al.* (2005). Climate change leads to alteration of pest distribution, the incidence, pest population growth rate, and outbreaks, resulting in more severe losses in agricultural production (Sharma, 2014). Furthermore, crop plant production leads to increased geographic spread of most tropical and subtropical insects (Sharma, 2014; Gonzalez and Bell, 2013).

1.2 Causes of Climate Change:

Climate change is mainly influenced by two factors: natural and anthropogenic activities. Oceanic processes, biotic processes, fluctuations in solar radiation that the planet receives, plate tectonics, and volcanic eruptions are examples of natural processes. Higher emission of greenhouse gases, patterns of land use, forest clearing, industrialization, and ozone depletion are human-caused changes to the natural environment. Anthropogenic activities are currently considered as the primary cause for climate change and global warming compared to natural processes. The greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), nitrogen oxide (NO_2), water vapour, chloro fluorocarbons (CFC`s), and others, concentration in the environment has risen dramatically as a consequence of human-induced activities. Increasing concentrations of these gases increased absorption of solar energy, which raises the surface temperature of the earth. It leads to varied weather patterns and has shown to severely impact on agricultural production.

From individual species to entire ecosystems, organisms of all kinds are being affected by climate change (Hickling *et al.,* 2006).

By 2050, 15 to 37 per cent of all species are expected to be extinct as the outcome of warming temperature, raising issues about the sustainability of life on Earth. It negatively affects humans, animals and insects. Human implications include displacement of people, hunger, poverty, risk of disease, food and water shortages globally. Effects on animals comprise habitat loss, migration, and loss of species. Insect population size, survivability rate, and geographic distribution have been significantly impacted. It is known that the abiotic factors affect the dynamics of insect populations both directly and indirectly. The direct impact includes effect on survival, reproduction, developmental rate, fecundity, dispersal, population size, geographic range and change in physiological processes of the host plants. Indirect impacts include disruption of tritrophic interactions significantly, by changing inter/intra specific relationship, host plant changes, competitor shifts, vectors, predators and parasitoids (Prakash *et al.,* 2014). Temperature is regarded as being the most significant abiotic characteristic.

1.2.1 Effects of Climate Change on Insects:

Insect communities are more prone than other life forms to be affected by the climate change since, they are an essential part of many ecosystems. Insects are poikilothermic organisms; their body temperature is influenced by external environment. The insects are the most widely distributed kind of animals in the animal kingdom, which offer a variety of ecological services (Schleuning *et al.,* 2020). It threatened insect biodiversity and the ecological services that they provide. Insect growth, development and multiplication are mainly affected by temperature, CO_2 and altered precipitation patterns. The metabolic rate of insects tends to rise by twice with the rising temperature of 10° C as their physiology is highly sensitive to temperature fluctuations (Dukes *et al.,* 2009). The abundance, distribution, species assemblage, composition, and relationships with other species undergo significant changes as a result (Harvey *et al.,* 2022). Climate is a significant driver of pest population dynamics. The consequence of changing climate on insects are discussed below in respect to their diversity; life history traits; population dynamics and abundance of insects; biotic interactions and community structure; and geographical distribution.

A. Impact on Diversity of Insects:

Since insects are good indicators of environmental changes and play a vital role in food chains, the diversity of insects in a habitat reveals the health of an ecosystems (Gregory *et al.,* 2009).

The diversity of insects is greatly impacted by climate change. Warmer temperatures, eCO_2, severe droughts, and storms are the effects of climate change. High temperatures limit thermal performance range, which influences the global spread of insects.

The impact of rising CO_2 levels on insect pests is strongly influenced by the plants which act as their hosts. Plants and trees grow more quickly by efficient utilization of water when atmospheric CO_2 levels are higher. As carbon-nitrogen (C: N) ratios increase as a result of this higher production, nitrogen concentrations in trees and plants decrease, which lowers the nutritional value of vegetation to insects. Generally, eCO_2 typically results in an increase in carbohydrates, a decrease in Nitrogen, rising C: N ratio, and C-based defenses that are harmful to defoliating herbivores (Robinson *et al.,* 2012 and Boullis *et al.,* 2015).

Wheat, rice, cotton and other C_3 crops would be more impacted by higher levels of CO_2 than C_4 crops like corn and sorghum. C_3 plants have a greater potential to be favorably affected by elevated CO_2 and negatively affected by insect reaction. Whereas C_4 plants are less reactive to elevated CO_2 and thus less affected by changes in insect consumption behavior (Skendizc *et al.,* 2021). The effect of eCO_2 on insects results in greater consumption rate, increased developmental time, increased abundance and reduced predation.

Insect population grows quickly as a result of increased summer rainfall and dry conditions. Insect survival is threatened by prolonged water stagnation and flooding caused by heavy rain. Insect survival is at risk, and their diapause is impacted by this event.

Heavy precipitation causes washing away of insects and increased incidence of insect pests. Droughts causes decrease in multi-trophic diversity; plants become more susceptible to insect attack and has negative/positive effect on natural enemies.

B. Effect on Life History Traits:

The life history attributes that are associated to fitness, such as development, reproduction, and survival, are altered by high temperatures. Although heat stress affects insects at all life stages, different life stages or instars have varying thermal sensitivity. An essential factor in determining the effects of high temperatures is the stage at which insects are exposed to heat stress (Zhang *et al.,* 2015). High temperatures may therefore result in thermal reactions that are stage-specific. Thermal reactions that affect growth, survival, reproduction and lifespan typically change with the life stage. Development and survival have the broadest thermal range, while reproduction has the narrowest thermal range (making it the most vulnerable).

In comparison to the mature larval stages, the early instar larvae and reproductive stages of *Sitobion avenae* and *Plutella xylostella* are more vulnerable to high temperatures. When the temperature rises consistently and beyond the optimum, growth is hindered and mortality occur rapidly. The critical maximum thermal limits for reproduction are therefore lower than those for development followed by survival. At warmer temperatures, *Plutella xylostella* reproduction is more severely inhibited. Transgenerational impacts have been linked to decreased offspring survival in insects like *Plutella xylostella* (Zhang *et al.*, 2015).

Development is impeded and mortality occurs when temperature rises continually and beyond the optimum (Ma and Ma, 2015). In *Grapholita molesta*, short-term exposure to high temperatures reduced reproduction, but had no effect on the species ability to survive (Liang *et al.,* 2014). The molecular, physiological, and morphological pathways that lead to heat death or delayed growth are the immediate consequences of high temperatures. Due to a rise in the metabolic rate of diapause, the time of diapause in the flesh fly, *Sarcophaga crassipalpis* was shorter as temperature rises (118 days at 17^{o} C, 70 days at 25^{o} C, and 57 days at 28^{o} C) (Hahn and Denlinger, 2011). The survival and fecundity of *Sitobion avenae* can be lowered by extreme temperatures that occur in the egg and other immature stages. Depending on the intensity of the temperature, high temperatures in the early stages of life can affect the performance of later phases or the following generation (Ma *et al.,* 2021). Extreme temperatures in *Plutella xylostella* lowered offspring survival through transgenerational effects (Zhao *et al.,* 2017).

Zhang *et al.* (2013) studied the effect of prolonged exposure to heat on adult *Plutella xylostella* and found no effect of rapid mortality at 3h, 4h or 5h. At 4 to 5 hours of exposure, have no impact on female longevity. However, females stressed at 40^o C for 3 hours lived 5.1 days longer than the control group, whereas it had no effect on male longevity. Females exposed to 40^o C for 4 and 5 hours showed a greater decrease in fecundity and hatchability (21 per cent). Therefore, a single hot event negatively affects diamondback moth reproduction, egg hatching, and ultimately has an impact on the dynamics of the population.

Under eCo_2, insects consume more food to obtain enough dietary nitrogen, which accelerates larval growth and increased mortality. *Achoea janata,* castor semilooper, consumes more foliage, which causes the increased larval weight and develop more slowly. Due to a decrease in leaf hardness, the winter moth, *Operophtera brumata* consumes more oak (*Quercus robur*) leaves (Borkataki *et al.,* 2020). The consequences of increasing CO_2 on sucking insects have conflicting reports, while in some circumstances, fertility and abundance may rise (Hance *et al.,* 2007). Population sizes of whole-cell feeders like trips are increasing (Bezemer *et al.,* 1998). Whiteflies and aphids are examples of phloem-feeding insect pests that exhibit both an increase in growth rates and a decline in density of population (Sutherst *et al.,* 2011).

According to Giri *et al.* (2022), the duration of the *Scirpophaga incertulas* larval period extended when CO_2 concentration raised. Under high CO_2 concentrations as compared to ambient concentration, a 3-4-day delay in larval growth and lower adult longevity were observed. The insect development from egg to adult emerged in 38.95 ± 1.66 days as compared with 41.15 ± 1.38 and 43.85 ± 1.53 days at 550 ppm and 700 ppm, respectively. Adult lifespan was shown to be considerably shorter in environments with high concentrations of CO_2.

C. Population Dynamics and Abundance of Insects:

The relative abundance of different insect species may shift quickly as a result of climate change, and those that are unable to cope with stress may swiftly become extinct (Thomas *et al.* 2004; Jump and Penuelas, 2005).

Longer growing seasons, higher seasonal and annual average temperatures are all effects of rising temperatures that alter the phenology and dynamics of insects. Insect reproduction, survival, and abundance are typically decreased by constant exposure to high temperatures. The impact of high temperatures, however, depends on the insect species thermal sensibility. For instance, rising temperature causes *Sitobion avenae* and *Schizaphis graminum*, heat-sensitive species to become less abundant, while *Rhopalosiphum paid*, heat-tolerant species become more abundant (Ma *et al.,* 2021). It benefits soil insects by increasing their population and reproduction.

Increased CO_2 levels will promote plant growth, but they could also make phytophagous insects more destructive (Gregory *et al.* 2009). Many species of herbivorous insects will eat few nutrient-rich host plants in the CO_2 enriched environment, which could result in longer larval development durations and higher mortality rates (Coviella and Trumble, 1999).

Depending on the species and the specific insect-plant interaction, increased atmospheric CO_2 will have different effects on herbivory. Losing one host is detrimental for gypsy moth, *Lymantria dispar* L., because it grows on both red and black oaks, *Quercus rubra* L. and *Quercus velutina* Lam. Insect eggs will hatch before budburst and starve, whereas eggs that hatch late after budburst will have a negative impact on the leaf quality and fecundity (Ward and Masters, 2007).

The influence of eCO_2 on population dynamics has been well documented in the Brown Plant Hopper (BPH), *Nilaparvata lugens*. When grown under $eCO_{2,}$ the population doubled (55.2 ± 5.7 hoppers/hill) compared to ambient CO_2 (25.5 ± 2.1 hoppers/hill). The fecundity was also increased by 29.5 per cent (Pandi*et al.*, 2018; Prasannakumar, *et al.*, 2012). In comparison to those under ambient CO_2, *Helicoverpa armigera* larvae fed more artificial food and produced more frass when exposed to increased CO_2 (Wu *et al.* 2006a).

The effects of eCO_2 on the population dynamics of insects can be studied by Open Top Chamber (OTC) and Free Air Carbon Dioxide Enrichment (FACE) technology. FACE technology allows field testing of crops by setting the environment with CO_2 and O_2 concentrations without altering the microclimate assuming the projected condition in middle of 21st century.

The tobacco caterpillar, *Spodoptera litura* fed on peanut foliage grown in OTC under $eCO_{2,}$ exhibited increased consumption, higher larval weights and longer larval duration which was significantly influenced by the leaf nitrogen (Rao *et al.*, 2014).

In comparison to soybeans grown under ambient atmospheric conditions, those grown using FACE technology at elevated atmospheric CO_2 concentrations showed 57 per cent more insect damage from pests like the Mexican bean beetle (*Epilachna varivestis*), Japanese beetle (*Popilia japonica*), potato leafhopper (*Empoasca fabae*) and Western corn rootworm (*Diabrotica virgifera*). Soybean leaf was found to contain more simple sugars when exposed to eCO_2, which encouraged insects to consume more plant matter and enhanced plant damage (Hamilton *et al.*, 2005).

Heavy rains cause increased incidence of insect pests. Staley *et al.* (2007), found wireworm populations in the upper part of the soil increased quickly at summer rainfall than the other times of the year or during a drought. Outbreak of *Amsacta albistriga* was reported after heavy rains in India (Saradana and Bhat, 2016). The increase in population of *Helicoverpa armigera* occurs in October, it depends on rainfall all through the rainy season during the peak months of March and April (Srivastava *et al.,* 2010). Prathapan and Hiremath (2018) reported the outbreak of two ambrosia beetles, *Xylosandrus crassiusculus* and *Diuncus corpulentus* from Northern Kerala, India on nutmeg due to an excess of 23 per cent rainfall from 1st June to 30th September, 2018. The continuous rainfall during the period caused dearth of sunlight, enhanced soil acidity by leaching down alkaline elements which affected the overall health of plants.

Increased precipitation can also have detrimental effects on insect abundance. Flooding and severe rains have the potential of washing away insect eggs and larvae. Aphids, mites, jassids, whiteflies, and other small-bodied pests might be washed away by a severe rainfall (Shrestha, 2019). Heavy rains kill or remove onion trips from crops because they are sensitive to precipitation (Pathak *et al.*, 2012).

Drought has a variety of effects on insects that feed on plants. Herbivorous insects may be able to thrive and grow in dry regions. Some insect species become attracted to plants that are stressed by drought. When water columns in the xylem break as plants lose moisture through transpiration, an ultrasonic sound emission is created that can be detected by hazardous bark beetle (Scolytidae). Drought-stressed plants produce less secondary metabolites with a defense role, the population of insects quickly increases, making them more vulnerable to damage (Yihdego *et al.*, 2019). Insects that feed on the phloem and xylem might find favorable climatic circumstances in dry areas. Prolonged dry spells lead to outbreak of cutworms.

According to Soman *et al.* (1994), sorghum shoot fly, *Atherigona soccata*, damage was reported to be reduced by high water stress levels. Sugarcane aphid, *Melanaphis sacchari* and spotted stem borer, *Chilo partellus*, do more harm to sorghum plants that are water-stressed than to those grow under irrigation (Sharma *et al.*, 1999). Sorghum genotypes that had previously displayed tolerance to the sorghum midge, *Stenodiplosis sorghicola*, are susceptible to the pest in conditions of high humidity and moderate temperature near the equator. (Sharma *et al.*, 2003).

1.3 Biotic Interactions and Community Structure:

Top-down and bottom-up processes in plant-insect herbivore natural enemy systems may be affected by biotic interactions and community structure (Table.1.1). High temperatures may influence the competition of species at the same trophic level or in between different trophic levels, which could modify the composition, structure, and functioning of communities and ecosystems. At same trophic level, difference in thermal tolerance of insects alter relative dominance and inter-specific competition.

Heat stress in cereal aphid, *Rhopalosiphum padi* alters the community structure in wheat ecosystem. When competition from the larger aphid species, *R. maidis*, allows *R. padi* out of cooler places, due to the genes Hsp70 A, B, and C in the species permitted the species to migrate to warmer regions. The Barely Yellow Dwarf Virus (BYDV-PAV) increases the thermal tolerance of its vector, *R. padi*, and raises plant surface temperatures. This had a deleterious impact on the aphid fertility and lifespan (Ma and Ma, 2015). Similar to this, the southern rice black-streaked dwarf virus enhanced the heat tolerance of its vector, *Sogatella furcifera*. Climate change has distinct effects on insect hosts and their parasitoids, changing the distribution of various species and causing diverse changes in insect communities and their parasitoids (Hance *et al.*, 2007). *Mythimna separata* outbreaks have been documented in regions that had prolonged drought followed by heavy rainfall (beneficial to the armyworm), which are harmful to the natural enemies (Sharma *et al.*, 2002b). The endosymbiont bacteria related to parasitoids or their insect hosts that influence the predation rate are likewise decreased by brief exposure to high temperatures.

The rate of consumption of prey by predators are influenced by elevated CO_2. The ladybird beetle, *Leis axyridis* consumed 3 per cent more on *Aphis gossypii* at 3X ambient CO_2 and 17 per cent more at 2X ambient CO_2 compared to ambient CO_2 (Chen *et al.*, 2005). A study conducted under eCO_2 environment using OTC showed that the predatory ability of the larval stage of the green lacewing, *Chrysopa sinica* reared on *Aphis gossypii* was reduced substantially when CO_2 concentrations were increased, compared to ambient CO_2 (Gao *et al.*, 2010). Aphids lose their sensitivity to the alarm pheromone at warmer temperatures, which leads to greater predation by predators (Ma *et al.*, 2021; Lindo, 2015).

Table 1.1: Effect of Temperature on Insect Pest - Natural Enemy Interactions

Parameter	**Nature of Effect**	**Natural Enemy**	**Reference**
Survival	Reduced when subjected to sudden temperature changes, such as those between 12° C and 35° C	*Campoletis chlorideae*	Dhillon and Sharma, 2009
Host search ability	At higher temperatures, decreased	*Trichogramma carverae*	Thomson *et al.*, 2001
Fecundity	At temperatures beyond the threshold, reduced (>35°C)	*Trichogramma pretiosum* *Trichogrammatoidea bactrae*	Naranjo, 1993

1.4 Shift in Geographical Distributions:

Climate change has major impact on geographic distribution of insects. Distributions can change as a result of local extinction driven by mass mortality in extremely high temperatures.

Heat stress results in decreased fitness and phenology mismatches between insects and their hosts. The interaction of insects with landscape fragmentation are influenced by climate change e.g. Tephritidae (Hill *et al.,* 2016). High temperature at winter leads to increased winter survival and dispersal abilities. Prolonged heat waves and warm winter led to rapid distribution of pine processionary moth, *Thaumetopoea pityocampa* in Alps (Yoro and Daramola, 2020).

The desert locust, *Schistocerca gregaria* migrated from Pakistan to Gujarat and Rajasthan due to congenial breeding condition during May to November, 2019. Four serious attacks were recorded in North Gujarat, India, during 2019 and 2020 (Joshi *et al.*, 2020).

In 2019, an outbreak of desert locust was reported in Eastern Africa due to unusual heavy rainfall providing congenial conditions for their breeding and survival (Salih *et al.*, 2020). Heavy rainfall provided conducive conditions for the growth of the vegetation and moisture in arid regions.

The species that are confined to high latitudes and mountain terrain are those that are probably to become extinct as the result of climate change. Insects that are used to cool climates will be compelled by global warming to migrate upward to higher latitude. Eventually, some of the species may migrate out of habitat and go extinct.

Between 1970 and 1999, the diversity of butterfly species in Britain noticed a considerable change (Menendez *et al.*, 2006). In the United Kingdom, four butterfly species have vanished at lower latitudes over the past 25 years, with climate change being the cause of at least half of the population extinctions (Franco *et al.,* 2006). As a result of global warming, 16 mountain butterflies in Spain, whose lower elevation restricts species, have risen in altitude by about 212 meters (Wilson *et al.,* 2005).

It is crucial to take into consideration between temperature and other variables, including rainfall, humidity, radiation and CO_2 concentrations because temperature does not operate solely to influence pest status (Harrington *et al.,* 2001). Insect species whose geographic distribution is constrained by low temperatures at higher latitudes may be better able to overwinter as a result of rising temperatures (Elphinstone and Toth, 2008).

Worldwide, a wide range of taxa have experienced many cases of distributional shifts (Wilson *et al.*, 2005). In North America, *Heliothis zea* populations, which cause harm to maize and other crops, may spread to higher latitudes and elevations. Due to climate change and global warming, *Helicoverpa armigera* and *Maruca vitrata*, which are currently restricted to tropical regions in America, Africa and Asia are prone to migrate to Northern America and North Europe during the next fifty years (Sharma, 2010).

The potential distribution would shift northward for every increase in temperature between 1^{o}C and 3^{o}C. *Ostrinia nubilalis*, the European corn borer, can travel up to 1220 kilometers and has an extra generation in all regions (Porter *et al.*, 1991).

Wang *et al.* (2020) studied the distribution *Ceroplastes cirripediformis* under present climate conditions and the effects of climatic variables on the patterns of distribution of invasive wax scale. The most significant variables showed that *C. cirripediformis* distribution was greatly influenced by average temperature and precipitations. The most significant variables are the mean temperature of dry quarter (Bio 9), precipitation of the cold quarter (Bio 19) (29.4%), and precipitation of the warm quarter (Bio 18) (18.8%). Shan *et al.* (2022) conducted a study on the invasive pest, the fig wax scale, *Ceroplastes rusci*, with the objective to predict potential distribution areas using Maximum Entropy (MaxEnt) model. It is based on data on occurrence, environmental factors under present and future climate conditions. The MaxEnt model revealed that the annual temperature range (Bio 7) contributed 37.6% as the most significant environmental variable to *C. rusci* distribution. According to the study, the geographic distribution of the species will expand relative to its existing potential distribution by ~2.24 × 104 km^2 (2.38%) in 2021–2040, ~8.62 × 104 km^2 (9.17%) in 2061–2080, and ~1.23 × 105 km^2 (13.09%) in 2081–2100.

1.5 Effect on Pollinators:

Increase in temperature have the potential impact on pollinator and plant phenology. Early flowering is one way that many plants have responded to rising temperatures. Plants pollinated by insects typically respond to rising warmth more strongly than plants pollinated by wind. According to Miller-Rushing *et al.* (2007), plant species that bloom early in the season seem to be the most responsive.

Pollinator activity will be out of sync due to extinction and/or the invasion of new species, changing plant phenology and altered pollinator composition in response to global warming. Due to their low thermal tolerance, tropical insects are more likely to be affected by the detrimental effects of global warming than their temperate counterparts, despite tropical regions experiencing smaller temperature increases (Deutsch *et al.,* 2008).

1.6 Conclusion:

For the sustainability of ecosystems and food production, insect biodiversity in agro ecosystems is undoubtedly crucial. Arthropod diversity, geographic distribution, population dynamics, abundance, interactions between herbivores and plants, natural enemy activity, abundance, and crop losses brought on by insect pests will all be impacted by climate change and global warming. Global warming will decrease the efficacy of resistant cultivars, natural enemies and insecticides. As a result, there will be a significant change in the economic relationships between pest treatment benefits and expenses. It is vital to collect information on the expected effects of climate change on insect pests in order to design resilient solutions that will be efficient and cost-effective in the future context of global warming. In order to increase system resilience and reduce the severity of insect pest losses, it is necessary to increase functional diversity in susceptible agro ecosystems.

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