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Climate change and its possible impact on the existence of insect pests

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ABSTRACT

The impact of climate change is evident from increase in global average temperature, changes in the rainfall pattern and extreme climatic events. Global warming resulting in climate change represents a substantial challenge on a broad range of organisms with diverse life-history, traits and geographical distributions. The abiotic parameters are known to have both direct and indirect impact on insect population dynamics through modulation of developmental rates, survival, fecundity, dispersal and change in the physiological activities of the host. Among the abiotic parameters, temperature is considered as the most important factor. Both positive and negative effect of climate change on pest and their natural enemies could be seen. The alteration in the voltinism may also be the results of warming and it is more profit to multivoltine species and voltinism could be reflected in changes in the geographical distribution. Also some pioneering studies showed that increased temperature may also influence the insect immunity. Beside these, elevated CO_2 also showed some impact on pest's population abundance, the crop grown under the elevated CO_2 could alter the nutritional value of host; it may alter the insect abundance and increase the consumption rate of herbivores. Therefore climate change would result in changes in the population dynamics of insect pests. Thus irreversible change in climate and gradual raise in temperature plays a pivotal role in insect population dynamics.

Key words: *Climate change, Global warming, Impact, Insect, Life history, Population.*

Introduction

The term Climate change has been recognized globally as the most impending and pressing critical issue affecting mankind survival in the 21st century. The last assessment report from the Intergovernmental Panel on Climate Change (IPCC) predicted an increment in the mean atmospheric temperature from 1.1 – 6.4^{o} C by 2100. The most of the warming observed over the last 50 years is attributable to human activities from pre-industrial era. The global atmospheric concentration of green house gases (GHG) *viz*., carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO_2) has increased tremendously as a result of these human activities. Increasing concentration of these gases is expected to have great effect on global climate change and thereby affect on agriculture. If temperatures rise by about 2°C over the next 100 years, negative effects of global warming would begin to extend to most regions of the world. Such changes in climate and weather could profoundly affect pest population both directly and indirectly. Direct affect generally influences the pest population including change in phenology, distribution, community composition and ecosystem dynamics that finally leads to extinction of species. In addition, indirect effects can occur through the influence of climate on the insect's host plants, natural enemies and interspecific interactions with other insects.

Climate change

The most general definition of *climate change* is a change in world's climate which is identifiable and which persist for a prolong period of time. Climate change may also be defined as a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions, or in the distribution of weather around the average conditions (i.e., more or fewer extreme weather events). According to the Intergovernmental Panel Climate change (IPCC) climate change can be defined as "*a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer".* Climate change is caused by factors that include oceanic processes (such as oceanic circulation), biotic processes, variations in solar radiation received by Earth, plate tectonics and volcanic eruptions, and human-induced alterations of the natural world; these human-induced effects are currently causing global warming, and "climate change" is often used to describe human-specific impacts.

Causes of climate change

The equilibrium temperature and climate of Earth are determined by the rate at which energy is received from the sun and the rate at which it is lost to space. This energy is distributed around the globe by winds, ocean currents, and other mechanisms to affect the climates of different regions.

Factors that are widely known to shape the climate are called as climate forcings or "forcing mechanisms" and include processes such as variations in solar radiation, Earth's orbit, mountain building and continental drift and changes in the concentrations of greenhouse gases. A variety of climate change feedbacks are there that can either amplify or diminish the initial forcing. Some parts of the climate system, such as the oceans and ice caps, respond slowly in reaction to climate forcings, while others respond more quickly. Forcing mechanisms can be either "internal" or "external". Internal forcing mechanisms are natural processes within the climate system itself (e.g., the thermohaline circulation). External forcing mechanisms can be either natural (e.g., changes in solar output) or anthropogenic (e.g., increased emissions of greenhouse gases). Whether the initial forcing mechanism is internal or external, the response of the climate system might be fast (e.g., a sudden cooling due to airborne volcanic ash reflecting sunlight), slow (e.g. thermal expansion of warming ocean water), or a combination (e.g., sudden loss of albedo in the arctic ocean as sea ice melts, followed by more gradual thermal expansion of the water). Therefore, the climate system can respond abruptly, but the full response to forcing mechanisms might not be fully developed for centuries or even longer.

Internal forcing mechanisms

This includes changes that are occurring naturally which in turn influence the various components of Earth's climate system and interactions among them". e.g., Thermohaline circulation.

External forcing mechanisms

These includes – variation in sun's output, variation in earth's, increased emission of greenhouse gases, etc.

Major cause of climate change

Scientists have considered that different human activities that either directly or indirectly helps in the emission of green house gases and increasing their concentration in the atmosphere are the major reason that are inducing these changes in the global climate. These changes are causing what is known as the "Green House Effect" on Earth. Green House Effect may be defined as the capacity of the green house gases that are present in the atmosphere to trap heat emitted from the Earth's surface, thereby insulating and warming the Earth. Different green house gases are CO_2, CH_4, NO_2, water vapour, CFC, etc.

Impacts of climate change on insect pests and natural enemies

Changes in the patterns of population and distribution of both agricultural and forest pests are expected under a changing climate as a result of warmer temperatures, changes in precipitation, increased drought frequency and higher carbon dioxide concentrations. These changes will play a major role in shaping the world's agriculture and forest sectors.

Changes in the climate can affect both agricultural and forest pests. This may lead to direct and indirect damages. Direct damage may include direct impact on development, survival, reproduction, distribution and spread of a pest. Indirect damage may include alteration in the host physiology and defences which may influence the relationships between pests, their environment and other species such as natural enemies, competitors and mutualists.

Direct impacts

The development, reproduction, survival and innate immunity of insect pests and their natural enemies are known to be strongly influenced by climate, temperature and precipitation of a particular region. As a result it is highly predictable that these organisms will be affected by any changes in climate. With their short generation times, high mobility and high reproductive rates it is also likely that they will respond more quickly to climate change than long-lived organisms, such as higher plants and mammals and thereby may be the first predictors of climate change.

Impact on physiology

Changes in the climate influence insects both directly on population dynamics and indirectly by influencing the rate of growth and development. Some information on the impacts of increased CO_2, and O_3, is becoming available but only for specific environments and only very partial information is available on changing UVB levels and altered precipitation regimes. Temperature is considered to be the most important factor of climate change influencing the physiology of insect pests. The magnitude of the impacts of temperature on agricultural and forest pests and natural enemies will differ among species depending on their environment, life history, and ability to adapt. Flexible species that are polyphagous, occupy different habitat types across a range of latitudes and altitudes, and show high phenotypic and genotypic plasticity are less likely to be adversely affected by climate change than specialist species occupying narrow niches in extreme environments. Increases in summer temperature will generally accelerate the rate of development in insects and increase their reproductive capacity while warmer winter temperatures may increase overwinter survival. Some of the examples are:

- In case of *Myzus persicae* the no. of generation increases from 18-23 for every 2ˆC rise in temperature
- The no. of light trap catches of Rice stem borer and leaf hopper in summer increases with increase in temperatures in previous winter.
- Reproduction period of *Aphis gosypii ranges* from 20-22 days at 10-25ˆ C. But at 30ˆ C the pest complete its reproductive period within 6-9 days.
- Aphids become less responsive to alarm pheromone resulting in the potential for greater predation

Some of the examples of natural enemies showing changes in their behaviour are:

- Decrease in size in case of Trichogramma carverae.
- Decrease in longevity and fecundity in case of *Scelionid wasp* and *Trichogramma brassicae*
- *Anagyrus ananatis* produce only male when immature are exposed to low temperature
- Reduction in feeding and mating capacity. of *Trichogramma nerudai*

Impact of a change in temperature will vary depending on the climatic zone. In temperate regions, increasing temperatures are expected to decrease winter survival while in more northern regions, higher temperatures will extend the summer season thereby increasing growth and reproduction. Deutsch *et al.* (2008) suggested that, in the absence of ameliorating factors such as migration and adaptation, the greatest extinction risks from global warming may be in the tropics. Warming in the tropics, though proportionately smaller in magnitude, could have the most deleterious impacts because tropical insects have very narrow ranges of climatic suitability compared to higher latitude species, and are already living very close to their optimal temperature.

Some important agricultural and forest insect pests have critical associations with symbiotic fungi but limited information is available on how temperature changes may affect these symbionts and thus indirectly affect host population dynamics. In some cases insect hosts and their symbionts may be similarly affected by climatic change while in other cases, hosts and symbionts may be affected asymmetrically, effectively decoupling the symbiosis.

Distribution

Climate plays a major role in defining the distribution limits of a species. With changes in climate, these limits are shifting as species expand into higher latitudes and altitudes and disappear from areas that have become climatically unsuitable. Such shifts are occurring in species whose distributions are limited by temperature such as many temperate and northern species. It is now clear that poleward and upward shifts of species ranges have occurred across many taxonomic groups and in a large diversity of geographical locations during the 20th century. Parmesan and Yohe (2003) reported that more than 1 700 Northern Hemisphere species have exhibited significant range shifts averaging 6.1 km per decade towards the poles (or 6.1 m per decade upward).

The range expansions of many lepidopterans have been particularly well documented. Parmesan *et al.* (1999) reported a poleward shift of 35-240 km for 22 out of 35 non-migratory European butterfly species during the last century. Wilson *et al.* (2005) noted that the lower elevational limits of 16 butterfly species in central Spain had risen on average by approximately 212 m in 30 years, a rise attributed to an observed 1.3 °C rise in mean annual temperature. Wilson *et al.* (2007) showed uphill shifts of approximately 293 m in butterfly communities in the Sierra de Guadarrama of central Spain between 1967-1973 and 2004-2005 as a result of climate warming. Climate change may also weaken the association between climatic and habitat suitability. Franco *et al.* (2006) concluded the importance of climate warming and habitat loss in driving local extinctions of northern species of butterflies in northern Great Britain over the past few decades.

Agricultural and forest pests are also occurring outside historic infestation ranges and at intensities not previously observed. Some examples of agricultural and forest pest species that have responded or are predicted to respond to climate change by altering distribution include the following:

- European corn borer *(Ostrinia nubilalis)* has been spreading Northward upto 1200 km or between 165 to 500 km for every 1˚C rise in temperature.
- A major epidemic of the mountain pine beetle (*Dendroctonus ponderosae*) has been spreading northwards and upwards in altitude in western Canada (British Colombia and more recently, Alberta) for several years.
- Warmer temperatures have influenced the southern pine beetle (*D. frontalis*) resulting in range expansions in the United States.
- The pine processionary caterpillar (*Thaumetopoea pityocampa*) has significantly expanded its latitudinal and altitudinal distribution in Europe.

The ability of a species to respond to global warming and expand its range will depend on a number of life history characteristics, making the possible responses quite variable among species. Bale *et al.* (2002) suggested that fast-growing, non-diapausing insect species or those not dependent on low temperature to induce diapause, will respond to warming by ex-panding their distribution whereas slow-grow-ing species which need low temperatures to induce diapause (i.e. boreal and mountain species in the northern hemisphere) will suffer range contractions. Range-restricted species, show more severe range contractions than other groups and are considered most at risk of extinction due to recent climate change. Range shifts may be limited by factors such as day length or the presence of competitors, predators or parasitoids. For example, the range expansion of insects which are very host-specific (specialists) may be limited by the slower rate of spread of their host plant species.

Phenology

Phenology is the timing of seasonal activities of plants and animals such as flowering or breeding. Since it is in many cases temperature dependent, phenology can be expected to be influenced by climate change. It is one of the easiest impacts of climate change to monitor and is by far the most documented in this regard for a wide range of organisms from plants to vertebrates. Common activities to monitor include earlier breeding or first singing of birds, earlier arrival of migrant birds, earlier appearance of butterflies, earlier choruses and spawning in amphibians and earlier shooting and flowering of plants.

Evidence of phenological changes in numerous plant and animal species as a consequence of climate change is abundant and growing. In general, spring activities have occurred progressively earlier since the 1960s and have been documented on all but one continent and in all major oceans for all well-studied marine, freshwater, and terrestrial groups.

Life cycle events are temperature-dependent, they may be expected to occur earlier and increased temperatures are likely to facilitate extended periods of activity at both ends of the season, provided there is no other constraints present. With increased temperatures, it is expected that insects will pass through their larval stages faster and become adults earlier. Therefore expected responses in insects could include an advance in the timing of larval and adult emergence and an increase in the length of the flight period. Members of the Order Lepidoptera again provide the best examples of such phenological changes. Changes in butterfly phenology have been reported from the UK where 26 of 35 species have advanced their first appearance (Roy and Sparks, 2000). First appearance for 17 species in Spain has advanced by 1-7 weeks in just 15 years (Stefanescu *et al.*, 2003). Seventy percent of 23 butterfly species in California, USA have seen an advancement of first flight date of approximately eight days per decade (Forister and Shapiro, 2003).

Changes in phenology - early adult emergence and an early arrival of migratory species - have also been noted for aphids in the UK (Zhou *et al.*, 1995; Harrington *et al.*, 2007). Gordo and Sanz (2005) investigated climate impacts on four Mediterranean insect species (a butterfly, a bee, a fly and a beetle) and noted that all species exhibited changes in their first appear-ance date over the last 50 years which was correlated with increases in spring temperature.

Impact on innate immunity

Insects present an immune system endowed with only innate immune components consisting of cellular and humoral factors. Cellmediated immunity includes phagocytosis and encapsulation, exerted by specific cell types, while humoral mediators comprise several factors among which the antimicrobial peptides (AMPs) and the components of the pro-phenoloxidase (pro-PO) cascade have been the most elucidated. It is important to observe that cellular and humoral components have not to be considered as separate elements, because several findings indicated that secreted factors are fundamental for clotting and pathogen recognition and engulfment.

The maintenance and deployment of an efficient immune response may shift away resources from other functions (such as reproduction), so that immune function results from physiological trade-offs in insects In view of its cost, the immune response is influenced therefore by both biotic and abiotic factors (such as food availability and temperature). According to these assumptions, the predicted increase in thermal stress due to global warming (Diffenbaugh *et al.*, 2005, 2007) is likely to induce cascading effects on other functions such as the immune response, thus further reducing the individual fitness and favouring the distribution and prevalence of infectious diseases (Lafferty, 2009; Travers *et al.*, 2009).

In order to verify this hypothesis, Karl *et al.*(2011) investigated in the tropical butterfly *Bicyclus anynana* the effects of temperature changes on fitness-related adult traits (such as body mass andfat content) and on phenoloxidase (PO) activity andhemocyte numbers that are two key parameters for evaluating the immune function at both cellular and humoral levels. Interestingly, results on body mass and fat content suggest that global warming couldbe beneficial, whereas haemocyte numbers and PO activity decreased at increasing temperatures (Karl *et al.,* 2011) supporting the hypothesis that immune parameters were negatively affected by globalwarming. At higher temperatures, insects may therefore increase their rate of growth andreproduction, but may become more susceptible to diseases, leading to reduced lifespan and possiblreduced fitness in the field.

Indirect impact of climate change

Changes in temperature, precipitation, atmospheric CO_2 concentrations and other climatic factors can very well alter the physiology of the host in different ways which actively affect their resistance to insect pests and herbivores.

Impact of elevated level of CO_2

Climate change is a multi-faceted phenomenon, including elevated CO_2, warmer temperatures, more severe droughts and more frequent storms (Jactel *et al.* 2019). Higher atmospheric CO_2 levels result in improved growth rates and water use efficiency of plants and trees. This increased productivity leads to lower nitrogen concentrations in trees and plants as carbon-nitrogen (C: N) ratios rise and thus reduces the nutritional value of vegetation to insects (Kopper and Lindroth, 2003; Mortsch, 2006). In response insects may increase their feeding (and consequently tree damage) in an attempt to compensate for the reduced quality and gain the necessary nitrogen (Ayres and Lombardero, 2000). In many cases the increased feeding does enable the insect to meet its nutritional needs but most often it does not and results in poor performance, reduced growth rates and increased mortality (Cannon, 1998; Harrington, Fleming and Woiwod, 2001). Such an effect, however, is not consistently observed (Holton, Lindroth and Nordheim, 2003), and increased growth due to enhanced CO_2 may in fact more than compensate for the defoliation in some cases (Kopper and Lindroth, 2003). Generally, eCO_2 causes an increase in carbohydrates, reduction in N, thus increasing C:N ratio and C-based defences that are deleterious to defoliating herbivores (Robinson *et al*., 2012 and Boullis *et al*. 2015) with notable differences among tree species and insect functional groups.

Elevated CO_2 levels can also result in changed plant structure such as increased leaf area and thickness, greater numbers of leaves, higher total leaf area per plant, and larger diameter stems and branches (Garrett *et al*., 2006). An increase in defensive chemicals may also result under such conditions (van Asch and Visser, 2007). Either of these changes to host physiology would influence palatability to insects, though the impacts on pests differ by species. For example, under increased CO_2 levels

- Castor semilooper consumes more foliage which results in more larval weight and slower development.
- Winter moth (*Operophtera brumata*) consumes more oak (*Quercus robur*) leaves due to a reduction in leaf toughness.
- Gypsy moth (*Lymantria dispar*) exhibits normal pupation weight but requires a longer time to develop as a result of an increase in tannin concentrations.

Impact on insect vectors of medical importance

Vectors require specific ecosystems for survival and reproduction. These ecosystems are influenced by a number of factors viz., temperature, precipitation, change in solar output, etc. Changes in any of these factors will affect the survival and hence the distribution of vectors. Thus global climatic changes therefore, have a considerable impact on the distribution of vector-borne diseases. A permanent change in one of the abiotic factors may lead to an alteration in the equilibrium of the ecosystem, resulting in the creation of more favourable or less favourable vector habitats. At the present limits of vector distribution, the projected increase in average temperature is likely to create more favourable conditions for the vectors, which may then breed in larger numbers and invade formerly inhospitable areas. The projected increase in global temperature, coupled with an increase in rainfall, may lead to an expansion of favourable habitats for malaria vectors, whereas reduced rainfall associated with such temperature increases may create new habitats for the phlebotomine vectors of leishmaniasis. Human lymphatic filariasis transmission may be reduced if there is a decrease in ambient relative humidity. The anticipated changes in temperature and precipitation resulting from global warming will affect vector reproduction and longevity. Hence, disease transmission that is at present seasonal may change to perennial transmission and vice-versa. In addition, changes in vectorial capacity may occur because the rate of development of the parasites and pathogens in the vector is temperature controlled. Regions at higher altitudes or latitudes may become hospitable to the vectors. Thus, disease-free highlands, such as parts of Ethiopia, Indonesia, and Kenya, may be invaded by vectors as a result of an increase in the annual temperature. In brief we can conclude that with changing climate

- The rate of digestion of blood meal increases
- Reduction in time taken for vector populations to breed (ovarian development, egg laying, etc)
- Produce smaller adults which may require multiple blood meals for reproduction.
- Increased biting behavior of the vector
- Increase the rate of transmission
- Decrease the incubation period of the pathogen

Impact on outbreak of new pests

Climate change has resulted in outbreak of many new pests in areas where they were not present previously. Some examples are:

Other promising examples are:

PEST	YEAR	CROP	AREA
Tobacco Caterpillar *Spodoptera litura*	Aug, 2008	Soybean	Vidharba, Maharashtra
Brown plant hopper *Nilaparvata lugens*	Sept, 2008	Basmati Rice	Haryana, UP and New Delhi
Cotton mealy bug *Phenacoccus solenopsis*	2006	Cotton	Gujarat
Papaya mealy bug *Paracoccus marginatus*	2008, 2009	Papaya	Tamil Nadu
Sugarcane wooly aphid *Ceratovacuna lanigerum*	2003	Sugaracane	Tamil Nadu and Maharashtra

- *Parasa bicolor* infesting rice in Manipur
- Rice hispa, *Dicladispa armigera* became the most dreadful pest in Assam, Meghalaya and Tripura
- Whorl maggot, *Hydriella philippina* and BPH *Nilaparvata lugens* became major pests.

Conclusion

Insect pests and natural enemies have been noted to respond to warming in all the expected ways, from changes in phenology and distribution to influencing community dynamics and composition. Some impacts of climate change may be beneficial in terms of protecting agriculture and forest health (e.g. increase in winter mortality of certain insect pests due to thin snow cover; slower larval development and increase in mortality during droughts), many impacts will be quite detrimental (e.g. accelerate insect development rate; range expansions of pests). Agricultural and forest communities already exist and survive across a wide range of climatic conditions, suggesting that agriculture and forests will persist under altered climatic conditions. It may be concluded that the transitions, when pests expand into new territories without the checks and balances provided by natural enemies, or encounter either a new host species or a large expanse of their natural host species, may create opportunities for significant occurrence of outbreaks, of reductions in forest growth and of tree mortality. Predicting and managing these transitions is where the challenges lie.

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