Global Warming and Climate Change: Impact on Arthropod Biodiversity, Pest Management, and Food Security

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Abstract

Global warming and climate change will trigger major changes in diversity and abundance of arthropods, geographical distribution of insect pests, population dynamics, insect biotypes, herbivore plant interactions, activity and abundance of natural enemies, species extinction, and efficacy of crop protection technologies. Changes in geographical range and insect abundance will increase the extent of crop losses, and thus, will have a major bearing on crop production and food security. Distribution of insect pests will also be influenced by changes in the cropping patterns triggered by climate change. Major insect pests such as cereal stem borers (*Chilo, Sesamia*, and *Scirpophaga*), the pod borers (*Helicoverpa*, *Maruca*, and *Spodoptera*), aphids, and white flies may move to temperate regions, leading to greater damage in cereals, grain legumes, vegetables, and fruit crops. Global warming will also reduce the effectiveness of host plant resistance, transgenic plants, natural enemies, biopesticides, and synthetic chemicals for pest management. Therefore, there is a need to generate information on the likely effects of climate change on insect pests to develop robust technologies that will be effective in future under global warming and climate change.

Introduction

Crop plants used as a food by human beings are damaged by over 10,000 species of insects, and cause an estimated annual loss of 13.6% globally (Benedict 2003) and 23.3% in India (Dhaliwal et al. 2004). In India, the average annual losses have been estimated to be 17.5% valued at US$17.28 billion in eight major field crops (cotton, rice, maize, sugarcane, rapeseed-mustard, groundnut, pulses, coarse cereals, and wheat) (Dhaliwal et al. 2010). Losses due to insect damage are likely to increase as a result of changes in crop diversity and increased incidence of insect pests due to global warming. Current estimates of changes in climate indicate an increase in global mean annual temperatures of 1^{o}C by 2025, and 3^{o}C by the end of the next century. The date at which an equivalent doubling of CO_2 will be attained is estimated to be between 2025 and 2070, depending on the level of emission of greenhouse gasses (IPCC 1990a,b). Mean annual temperature changes between 3 and 6^{o}C are estimated to occur across Europe, with greatest increases occurring at high latitudes. Increased temperatures have drastically affected the rice production due to decrease crop duration in Philippines (10% reduction in yield in rice per 1°C rise in temperature) (Peng et al. 2004). An increase of 6^{o}C in temperature, and precipitation deficit of 300 nm reduced the maize yield by 36% in the European Union (Ciais et al. 2005).

Host-plant resistance, bio-pesticides, natural enemies, and synthetic chemicals are some of the potential options for integrated pest management. However, the relative efficacy of many of these pest control measures is likely to change as a result of global warming. Changes in precipitation are of greater importance for agriculture than temperature changes, especially in regions where lack of rainfall may be a limiting factor for crop production (Parry 1990). Global mean annual precipitation may increase as a result of intensification of the hydrological cycle (Rowntree 1990), which will cause disruption of agriculture as the cropping systems and the composition of fauna and flora will undergo a gradual change (Porter et al. 1991; Sutherst 1991). High mobility and rapid population growth will increase the extent of losses due to insect pests. Geographical distribution of insect pests confined to tropical and subtropical regions will extend to temperate regions along with a shift in the areas of production of their host plants, while distribution and relative abundance of some insect species vulnerable to high temperatures in the temperate regions may decrease as a result of global warming. These species may find suitable alternative habitats at greater latitudes. Many species may have their diapause strategies disrupted as the linkages between temperature and moisture regimes, and the daylength will be altered. Genetic variation and multi-factor inheritance of innate recognition of environmental signals may mean that many insect species will have to adapt readily to such disruption. Global warming and climate changes will result in:

- Extension of geographical range of insect pests,
- Increased over-wintering and rapid population growth,
- Changes in insect – host plant interactions,
- Increased risk of invasion by migrant pests,
- Impact on arthropod diversity and extinction of species,
- Changes in synchrony between insect pests and their crop hosts,
- Introduction of alternative hosts as green bridges, and
- Reduced effectiveness of crop protection technologies.

Climate change will also result in increased problems with insect transmitted diseases. These changes will have major implications for crop protection and food security, particularly in the developing countries, where the need to increase and sustain food production is most urgent. Long-term monitoring of population levels and insect behavior, particularly in identifiably sensitive regions, may provide some of the first indications of a biological response to climate change. In addition, it will also be important to keep ahead of undesirable pest adaptations, and therefore, it is important to carefully consider global warming and climate change for planning research and development efforts for pest management and food security in future.

Impact on global warming on arthropod diversity and extinction of species

Arthropods (insects, spiders, and mites) are the most abundant and diverse group of organisms (Kannan and James 2009; Gregory et al. 2009) (Table 1).. Arthropods are the most important and diverse component of terrestrial ecosystems and occupy a wide variety of functional niches and microhabitats (Kremen et al. 1993). We can take advantage of the terrestrial arthropod diversity as a resource for conservation and management of different eco-systems. Monitoring of terrestrial arthropods can provide early warnings of ecological changes due to climate change. Arthropods can be used as indicators of environmental change more rapidly than the vertebrates (Scherm et al. 2000; Gregory et al. 2009).For monitoring purposes, indicator assemblages should exhibit varying sensitivities to environmental changes, and exhibit diversity in life-history and ecological interactions. Realistic information on arthropod diversity must be integrated into policy planning and management practices if ecosystems are to be managed for use by future generations. Ecosystem baselines that document arthropod species assemblages in a manner comparable in space and time are key to interpretation and implementation of strategies designed to mitigate the effects of global warming and climate change on biodiversity. Main effects of climate change and pollution on arthropod communities result in decreased abundance of decomposers and predators, and increased herbivory, which may have negative consequences for structure and services of the entire ecosystems. Responses of arthropods to pollution depend on both temperature and precipitation, and ecosystem-wide adverse effects are likely to increase under predicted climate change (Zvereva and Kozlov 2010). Consequences of temperature increases of 1 to 2 °C will be comparable in magnitude to the currently seen climate change in the Antarctic region (Bokhorst et al. 2008).

Increase in rainfall in the Pampas region of Argentina will largely affect the species with poor dispersal capabilities, which will limit their ability to expand their home range. The most affected among the beetle species are the habitat specialists (Xannepuccia et al. 2009). At higher trophic levels, an indirect effect in terms of habitat loss and a reduction in prey availability has also been observed. Large-scale changes in rainfall due to climate change will have a major effect on the abundance and diversity of arthropods. Extreme climatic events such as drought are likely to decrease multi-trophic diversity and change the composition of arthropod communities, which in turn might affect the other associated taxa. In the forest eco-systems, chronic stress significantly altered community composition, and the trees growing under high stress supported 1/10th the number of arthropods compared to trees growing under more favorable conditions (Talbot Trotter et al. 2008). Increasing tree stress was also correlated with an eight to 10-fold decline in arthropod species richness and abundance. Arthropod richness and abundance on individual trees were positively correlated with the tree's radial growth during drought, suggesting that tree ring analysis could be used as a predictor of arthropod diversity (Stone et al. 2010).

Table 1. Species diversity among different groups of organisms.

Organisms	Number of species
Viruses, algae, protozoa, etc.	80,000
Bacteria	4,000
Fungi	72,000
Plants	270,000
Animals: Invertebrates (insects)	1,360,000
Animals: Vertebrates	48,500
Total	1,834,500

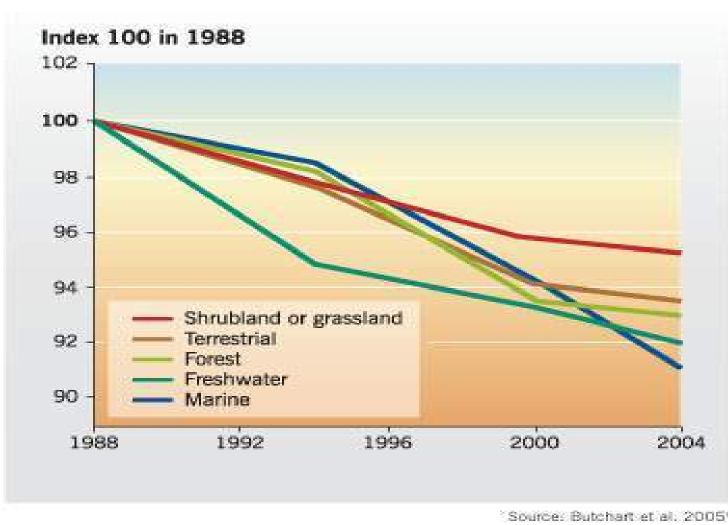

Fig. 1. Threatened species: Rate of species extinction in different eco-systems (Butchart et al. 2005).

Speciation takes between 100 and 1,000,000 years, providing between 10 and 10,000 new species per annum. Nearly 99.9% of all species that ever existed have become extinct. We are now living through the sixth extinction spasm, which is largely driven by human activities. The relative abundance of different insect species may change rapidly due to climate change, and the species unable to withstand the stresses may be lost in the near future (Jump and Penuelas 2005; Thomas et al. 2004). The current extinction rates are 100 to 1,000 times greater than what has happened earlier, and nearly 45 to 275 species are becoming extinct everyday (Fig. 1).

Impact of climate change on geographic distribution and population dynamics of insect pests

Climate change will have am major effect on geographic distribution of insect pests, and low temperatures are often more important than high temperatures in determining geographical distribution of insect pests (Hill 1987). Increasing temperatures may result in a greater ability to overwinter in insect species limited by low temperatures at higher latitudes, extending their geographical range (EPA 1989; Hill and Dymock 1989; Elphinstone and Toth 2008), and sudden outbreaks of insect pests can wipe out certain crop species, and also encourage the invasion by exotic species (Kannan and James 2009). Spatial shifts in distribution of crops under changing climatic conditions will also influence the distribution of insect pests in a geographical region (Parry and Carter 1989). Some plant species may be unable to follow the climate change, resulting in extinction of species that are specific to particular hosts (Thomas et al. 2004). However, whether or not an insect pest would move with a crop into a new habitat will depend on other environmental conditions such as the presence of overwintering sites, soil type, and moisture, e.g., populations of the corn earworm, *Heliothis zea* (Boddie) in the North America might move to higher latitudes/altitudes, leading to greater damage in maize and other crops (EPA 1989). For all the insect species, higher temperatures, below the species upper threshold limit, will result in faster development and rapid increase in pest populations as the time to reproductive maturity will be reduced considerably. In addition to the direct effects of temperature changes on development rates, improvement in food quality due to abiotic stress may result in dramatic increases in growth of some insect species (White 1984), while the growth of certain insect pests may be adversely affected (Maffei et al. 2007). Pest outbreaks are more likely to occur with stressed plants as a result of weakening of plants' defensive system, and thus, increasing the level of susceptibility to insect pests (Rhoades 1985).

Global warming will lead to earlier infestation by *H. zea* in North America (EPA 1989), and *Helicoverpa armigera* (Hub.) in North India (Sharma 2010), resulting in increased crop loss. Rising temperatures are likely to result in availability of new niches for insect pests. Temperature has a strong influence on the viability and incubation period of *H. armigera* eggs (Dhillon and Sharma 2007). Egg incubation period can be predicted based on day degrees required for egg hatching, which decreases with an increase in temperature from 10 to 27 ºC, and egg age from 0 to 3 days (Dhillon and Sharma 2007). An increase of 3°C in mean daily temperature would cause the carrot fly, *Delia radicum* (L.) to become active a month earlier than at present (Collier et al. 1991), and temperature increases of 5 to 10°C would result in completion of four generations each year, necessitating adoption of new pest control strategies. An increase of 2°C will reduce the generation turnover of the bird cherry aphid, *Rhopalosiphum padi* (L.) by varying levels, depending on the changes in mean temperature (Morgan 1996). An increase of 1 and 3°C in temperature will cause northward shifts in the potential distribution of the European corn borer, *Ostrinia nubilalis* (Hub.) up to 1,220 km, with an additional generation in nearly all regions where it is currently known to occur (Porter et al. 1991).

Overwintering of insect pests will increase as a result of climate change, producing larger spring populations as a base for a build-up in numbers in the following season. These may be vulnerable to parasitoids and predators if the latter also overwinter more readily. Diamond back moth, *Plutella xylostella* L. overwintered in Alberta in 1994 (Dosdall 1994), and if overwintering becomes common, the status of this insect as a pest in North America will increase dramatically. There may also be increased dispersal of airborne insect species in response to atmospheric disturbances. Many insects such as

Helicoverpa spp. are migratory, and therefore, may be well adapted to exploit new opportunities by moving rapidly into new areas as a result of climate change (Sharma 2005).

Effect of global warming on species diversity its influence on pest management

Biodiversity plays an important role in abundance of insect pests and their natural enemies (Alteiri 1994; Sharma and Waliyar 2003). There is a need to increase functional diversity in agro-ecosystems vulnerable to climate change to improve system resilience, and decrease the extent of losses due to insect pests (Newton et al. 2009). However, changes in cropping patterns as a result of climate change will drastically affect the balance between insect pests and their natural enemies. Since climate change will lead to a shift in cultivation of crops in non-traditional areas and crop rotations, this may influence the prevalence and importance of specific pests (Maiorano et al. 2008). System diversity can be exploited to enhance the resilience of agro-eco-systems, improve resource utilization, and stabilize yields to cope with the effects of global warming and climate change on food security (Sharma and Waliyar 2003; Newton et al. 2009).

Effect of climate change on expression of resistance to insect pests

Host plant resistance to insects is one of the most environmental friendly components of pest management. However, climate change may alter the interactions between the insect pests and their host plants (Bale et al. 2002; Sharma et al. 2010). Global warming may also change the flowering times in temperate regions, leading to ecological consequences such as introduction of new insect pests, and attaining of a pest status by non-pest insects (Parmesan and Yohe 2003: Fitter and Fitter 2002: Willis et al. 2008). However, many plant species in tropical regions have the capability to withstand the phenological changes as a result of climate change (Corlett and LaFrankie 1998). Global warming may result on breakdown of resistance to certain insect pests. Sorghum varieties exhibiting rresistance to sorghum midge, *Stenodiplosis sorghicola* (Coq.) in India become susceptible to this pest under high humidity and moderate temperatures near the Equator in Kenya (Sharma et al. 1999). There will be increased impact on insect pests which benefit from reduced host defenses as a result of the stress caused by the lack of adaptation to sub-optimal climatic conditions. Chemical composition of some plant species changes in direct response to biotic and abiotic stresses as a result, their tissues less suitable for growth and survival of insect pests (Sharma 2002). However, problems with new insect pests will occur if climatic changes favor the introduction of insect susceptible cultivars or crops. The introduction of new crops and cultivars to take advantage of the new environmental conditions is one of the adaptive methods suggested as a possible response to climate change (Parry and Carter 1989).

Insect - host plant interactions will change in response to the effects of CO_2 on nutritional quality and secondary metabolites of the host plants. Increased levels of CO_2 will enhance plant growth, but may also increase the damage caused by some phytophagous insects (Gregory et al. 2009). In the enriched CO_2 atmosphere expected in the next century, many species of herbivorous insects will confront less nutritious host plants that may induce both lengthened larval developmental times and greater mortality (Coviella and Trumble 1999). The effects of increased atmospheric CO_2 on herbivory will not only be species-specific, but also specific to each insect-plant system. Although increased CO_2 tends to enhance plant growth rates, the larger effects of drought stress will probably result in slower plant growth (Coley and Markham 1998). In atmospheres experimentally enriched with CO_2, the nutritional quality of leaves declined substantially due to dilution of nitrogen by 10 to 30% (Coley and Markham 1998). Increased CO_2 may also cause a slight decrease in nitrogen-based defenses (e.g., alkaloids) and a slight increase in carbon-based defenses (e.g., tannins). Acidification of water bodies by carbonic acid (due to high CO_2) will also affect the floral and faunal diversity (Gore 2006). Lower foliar nitrogen content due to CO_2 causes an increase in food consumption by the herbivores up to 40%, while unusually severe drought increases the damage by insect species such as spotted stem borer, *Chilo partellus* in sorghum (Sharma et al. 2005). Endophytes, which play an important role in conferring tolerance to both abiotic and biotic stresses in grasses, may also undergo a change in response to disturbance in the soil due to climate change (Newton et al. 2009).

Effect of climate change on effectiveness of transgenic crops for pest management

Environmental factors such as soil moisture, soil fertility, and temperature have strong influence on the expression of *Bacillus thuringiensis* (*Bt*) toxin proteins deployed in transgenic plants (Sachs et al. 1998). Cotton bollworm, *Heliothis virescens* (F.) destroyed *Bt*-transgenic cottons due to high temperatures in Texas, USA (Kaiser, 1996). Similarly, *H. armigera* and *H. punctigera* (Wallen.) destroyed the *Bt*-transgenic cotton in the second half of the growing season in Australia because of reduced production of *Bt* toxins (Hilder and Boulter 1999). Cry1Ac levels in transgenic plants decrease with the plant age, resulting in greater susceptibility of the crop to insect pests during the later stages of crop growth (Sachs et al. 1998; Greenplate et al. 2000; Adamczyk et al. 2001; Kranthi et al. 2005). Possible causes for the failure of insect control in transgenic crops may be due to inadequate production of the toxin protein, effect of environment on transgene expression, *Bt*-resistant insect populations, and development of resistance due to inadequate management (Sharma and Ortiz 2000). It is therefore important to understand the effects of climate change on the efficacy of transgenic plants for pest management.

Effect of global warming on the activity and abundance of natural enemies

Relationships between insect pests and their natural enemies will change as a result of global warming, resulting in both increases and decreases in the status of individual pest species. Changes in temperature will also alter the timing of diurnal activity patterns of different groups of insects (Young, 1982), and changes in interspecific interactions could also alter the effectiveness of natural enemies for pest management (Hill and Dymock 1989). Quantifying the effect of climate change on the activity and effectiveness of natural enemies for pest management will be a major concern in future pest management programs. The majority of insects are benign to agro-ecosystems, and there is considerable evidence to suggest that this is due to population control through interspecific interactions among insect pests and their natural enemies – pathogens, parasites, and predators (Price 1987). Oriental armyworm, *Mythimna separata* (Walk.) populations increase during extended periods of drought (which is detrimental to the natural enemies), followed by heavy rainfall because of the adverse effects of drought on the activity and abundance of the natural enemies of this pest (Sharma et al. 2002). Aphid abundance increases with an increase in CO_2 and temperature, however, the parasitism rates remain unchanged in elevated CO_2. Temperatures up to 25°C will enhance the control of aphids by coccinellids (Freier and Triltsch 1996). Temperature not only affects the rate of insect development, but also has a profound effect on fecundity and sex ratio of parasitoids (Dhillon and Sharma, 2008, 2009). The interactions between insect pests and their natural enemies need to be studied carefully to devise appropriate methods for using natural enemies in pest management.

Effect of climate change on the effectiveness of biopesticides and synthetic insecticides

There will be an increase in variability in insect damage as a result of climate change. Higher temperatures will make dry seasons drier, and conversely, may increase the amount and intensity of rainfall, making wet seasons wetter than at present. Natural plant products, entomopathogenic viruses, fungi, bacteria, and nematodes, and synthetic pesticides are highly sensitive to the environment. Increase in temperatures and UV radiation, and a decrease in relative humidity may render many of these control tactics to be less effective, and such an effect will be more pronounced on natural plant products and the biopesticides (Isman 1997). Rapid dissipation of insecticide residues due to increases in temperature and precipitation will require more frequent application of insecticides. Therefore, there is a need to develop appropriate strategies for pest management that will be effective under situations of global warming in future.

Climate change and pest management: The challenge ahead

The relationship between crop protection costs and the resulting benefits will change as a result of global warming and climate change. This will have a major bearing on economic thresholds, as greater variability in climate will result in variable impact of pest damage on crop yields. Increased temperatures and UV radiation, and low relative humidity may render many of these control tactics to be less effective, and therefore, there is a need to:

- Predict and map trends of potential changes in geographical distribution, and study how climatic changes will affect development, incidence, and population dynamics of insect pests.
- Understand the influence of global warming and climate change on species diversity and cropping patterns, and their influence on the abundance of insect pests and their natural enemies.
- Understand the changes in expression of resistance to insect pests, and identify stable sources of resistance, and pyramid the resistance genes in commercial cultivars.
- Study the effect of global warming on the efficacy of transgenic crops in pest management.
- Assess the efficacy of various pest management technologies under diverse environmental conditions, and develop appropriate strategies for pest management to mitigate the effects of climate change.

Conclusions

Global warming and climate change will have serious consequences on diversity and abundance of arthropods, and the extent of losses due to insect pests, which will impact both crop production and food security. Prediction of changes in geographical distribution and population dynamics of insect pests will be useful to adapt the pest management strategies to mitigate the adverse effects of climate change on crop production. Pest outbreaks might occur more frequently, particularly during extended periods of drought, followed by heavy rainfall. Some of the components of pest management such as host plant resistance, biopesticides, natural enemies, and synthetic chemicals will be rendered less effective as a result of increase in temperatures and UV radiation, and decrease in relative humidity. Climate change will also alter the interactions between the insect pests and their host plants. As result, some of the cultivars that are resistant to insect pests, may exhibit susceptible reaction under global warming. Adverse effects of climate change on the activity and effectiveness of natural enemies will be a major concern in future pest management programs. Rate of insect multiplication might increase with an increase in CO_2 and temperature. Therefore, there is a need to have a concerted look at the likely effects of climate change on crop protection, and devise appropriate measures to mitigate the effects of climate change on food security.

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