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REVIEW ARTICLE

Potential impact of climate change on honeybees (*Apis* spp.) and their pollination services

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ABSTRACT: Honeybees are the major pollinators of about 73 per cent of the world's cultivated crops. Being ectothermic, the temperature of their surroundings determines the activity of bees and hence climate change, characterized by elevated temperatures, could drastically impact their biology, behavior and distribution. Indirectly, climate change affects bees through their floral resources and natural enemies. Differential response of insects and plants to changed temperature could create temporal (phenological) and spatial (distributional) mismatches with severe demographic consequences for the species involved. Asynchrony may affect plant by reduced insect visitation and pollen deposition, while bees experience reduced food availability. Systematic studies to quantify the effects, adverse or otherwise, of climate change are very few. Being involved in a project to understand the impact of climate change on plant-pollinator interactions, we made an effort to compile and review the available literature in this critical but relatively untapped area of pollinator ecology.

Keywords: *Apis* spp., bees, climate change, pollination, temperature

Many food crops, barring cereals, are entomophilous in nature and rely on insects for pollination. Approximately 73 per cent of the world's cultivated crops are pollinated by bees, 19 per cent by flies, 6.5 per cent by bats, 5 per cent by wasps, 5 per cent by beetles, 4 per cent by birds, and 4 per cent by butterflies and moths (Abrol, 2009). The pollinators in turn benefit by obtaining floral resources such as nectar, pollen or both. This mutualism has evolved over centuries and been helping both natural terrestrial ecosystems as well as man-made agro-ecosystems. Pollinators such as bees, birds and bats affect 35 percent of the world's crop production, increasing outputs of 87 of the leading food crops worldwide (FAO, 2009). The total economic value of crop pollination worldwide has been estimated at €156 billion annually (Gallai *et al.*, 2009). The area covered by pollinator-dependent crops has increased by more than 300 per cent during the past 50 years (Aizen and Harder 2009). In the recent years, there has been a concern about declines in both wild and domesticated pollinators, especially honeybees. A large proportion of horticultural crops is potentially vulnerable to declines in honeybee and other pollinator insects (Table 1). Climate change, an emerging global phenomenon, with a potential to affect every component of agricultural ecosystems, is reported to impact bees at various levels, including their pollination efficiency. This paper reviews the available literature related to the 'push and pull' responses of honeybees and their floral hosts to the changing climate.

Bees are declining

Honeybees (Hymenoptera: Apidae: *Apis*), primarily credited as honey producers, are major pollinators of several plant species. Bees of the genus *Apis* are distributed throughout the world in highly diverse climates and currently, there are only seven recognised species of honey bees with a total of 44 subspecies, though historically, from six to eleven species have been recognized (Engel, 1999). The distribution of these species is highly uneven. Among them, *Apis mellifera*, with its origin in Africa, has been introduced to different continents while the other species have remained in Asia, which is the most likely the birthplace of the *Apis* genus (Arias and Sheppard, 2006). In case of *Apis cerana*, four subspecies are recognised, although there may be several more because of its wide range of geographical distribution while the genetic diversity of *A. mellifera* has been organised into 24 subspecies (Verma, 1992). This pattern of development of ecotypes signifies the impact of regional climate and geographic conditions on the evolution and in turn their inherent ability to adapt to local environments. India is fortunate to have all four major honeybee species *viz*., *A. cerana, A. dorsata, A. florea* and *A. mellifera* (an introduced one). They have become an integral part of Indian agriculture and rural economy both as pollinators and honey producers. In recent times, there has been a growing concern about declines in the natural populations of honeybees. Among different factors responsible for bee decline are habitat loss and fragmentation, chemical intensive agriculture, invasive species and climate change (Potts *et al.*, 2010). Climate change is thought to be one of major threats to pollination services (Hegland *et al*., 2009; Schweiger *et al*., 2010). Climate change could destabilise relationships between flowers and pollinators, and pollinators will need to be protected to ensure that they continue their pollination function, which is so important for the economy and for the ecological balance. The "pollination crisis" that is evident in declines of honeybees and native bees worldwide is due to disruption of critical balance between the two mutually interacting organisms (Table 2). Anthropogenic climate change is widely expected to drive species extinct by hampering individual survival and reproduction, by reducing the amount and accessibility of suitable habitat, or by eliminating other organisms that are essential to the species in question. Changes in habitats and climates have resulted in substantial reductions in biodiversity and evidence has been accumulating that insect biodiversity is at risk as well (Abrol, 2009).

Climate change and honeybees

Climate change is a global phenomenon and transcends geographical boundaries. Industrialization and deforestation leading to depletion of ozone layer and increased carbon dioxide concentration in the atmosphere seem to be the major factors driving this process. Global climate change is defined as a 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 the distribution of events around that average (e.g., more or fewer extreme weather events). The Intergovernmental Panel on Climate Change (IPCC) reports an approximate

Table 1. Economic impacts of insect pollination on major food crops and their rate of vulnerability to pollinator loss – World scenario (Gallai *et al.*, 2009)

Crop group	Total Production Economic Value in 10^9€ (EV)	Insect Pollination Economic Value in 10^9€ (IPEV)	Rate of Vulnerability (%) (IPEV/EV)
Fruits	219	50.6	23.1
Vegetables	418	50.9	12.2
Nuts	13	4.2	31.0
Stimulants	19	7.0	39.0
Oilseeds	240	39.0	16.3
Roots and Tubers	98	0.0	0.0
Spices	7	0.2	2.7
Cereals	312	0.0	0.0
Pulses	24	1.0	4.3

Table 2. Population decline of honeybees : World scenario (Source: Gallai *et al.*, 2009)

Country	Decline (%)	Duration
Germany	57	Last 15 yrs
UK	61	Last 10 yrs
USA	>50	Last 20 yrs
Poland	>35	Last 15 yrs
India	>40	Last 25 yrs
Brazil	>53	Last 15 yrs
Netherland	58-65	Last 25 yrs
China	>50	Last 20 yrs

temperature increase ranging from 1.1-6.4^{0}C by the end of this century. The IPCC documented the increased global temperatures, a decrease in snow and ice cover, and changed frequency and intensity of precipitation as the major consequences of climate change (IPCC, 2007). However, increased temperature is thought to be the most important effect of climate change with respect to plant-pollinator interactions (Kjohl *et al.*, 2011). The possible responses of species to climate change are adaptation to the new environment, migration to another suitable area and extinction. The first response is unlikely since expected climate change occurs too rapidly for populations to adapt by genetic change. With increase in temperatures many species move towards poles and higher altitudes. Tropical pollinators may respond to different temperature cues than pollinator species at higher latitudes (Coope, 1995).

Climate change can influence honey bees at different levels. It can have a direct influence on their behaviour and physiology. It can also alter the quality of the floral environment and increase or reduce colony harvesting capacity and development (Le Conte and Navajas, 2008) and can influence the development cycle. It is known that each race of honey bees has its own rate of development. Any sort of climate change or movement of a race of honey bees from one geographical region to an alien one is therefore bound to have measurable consequences. The effect of climate change on insects depend upon their thermal tolerance and plasticity to temperature changes. There is an urgent need to investigate the differences in thermal tolerance among *Apis* species and sub-species. Environmental cues controlling the phenology of bees include maximum daily temperature, number of degree days (number of days with a mean temperature above a certain threshold) and day length. Bees being ectothermic, require elevated body temperature for flying. The temperature of their surroundings determines their foraging activity (Willmer and Stone, 2004; Reddy *et al.*, 2012b). The high surface to volume ratio of small bees leads to rapid absorption of heat at high ambient temperatures. All bees with body weight above 35mg (*Apis*, *Bombus*, *Xylocopa* and *Megachile*) are capable of endothermic heating (Bishop and Ambruster, 1999). Behavioural responses of bees to avoid extreme temperatures could significantly impacts pollination services. The time taken for thermoregulation at higher temperatures comes at the cost of foraging. With increase in temperatures, the efficiency of pollen removal and deposition will change and pollinators are at risk of over heating especially in regions where ambient temperatures are high and climatic conditions are stable. The honey bee's capacity to accumulate energy reserves and to manage the colony's development exerts significant adaptive pressure. For example, in the spring, when the weather becomes more mild, the queen starts to lay eggs and the colony develops and increases the size of the worker population. A cold wave lasting several weeks may occur during which the honey bees are unable to move out for foraging. The large size of the honey bee population causes such a rapid depletion of stores that the colony can die of starvation.

Expected mismatches of honeybees and plants

Climate influences flower development and nectar and pollen production, which are directly linked with colonies' foraging activity and development (Winston, 1987). Bees must build up sufficient honey stores to enable them to survive the winter. A major effect of climate change on honey bees stems from changes in the distribution of the flower species (Thuiller *et al.*, 2005) on which the bees depend for food. An excessively dry climate, which reduces pollen production and impoverishes its nutritional quality, would adversely affect bees of that habitat (Stockstad, 2007). A pollen diet is very important for rearing the future workers. Pollen shortage induced by autumn drought will have the effect of depriving bees in winter, weakening their immune system and making them more susceptible to pathogens, and shortening their lifespan. Tropical climates may evolve towards more distinct seasons with dry periods. In this case, Asian honey bees would need to rapidly step up their honey-harvesting strategy to build up sufficient stores to survive dearth periods. Or else they could develop a migration strategy, as in case of *Apis dorsata*, which readily migrates in response to seasons, flowering patterns or disruption. They abandon their nests and can fly distances of up to 200 km to escape starvation or predators. After leaving their nests unoccupied for several months, the same honey bee colony returns (Mattila and Otis, 2006).

Effective crop pollination is heavily dependent on biological timing, of both the crop and its pollinators. Crops such as mangoes, litchi, coffee etc., have periods of mass blooming over relatively short periods, requiring a tremendous peak in pollinators. Climate change may have profound impacts on the timing of these events. The extreme weather events that will accompany global warming may have severe impacts on pollinators already stressed from climatic change. Insects and plants react differently to changed temperature, creating temporal (phenological) and spatial (distributional) mismatches with severe demographic consequences for the species involved. Mismatches may affect plant by reduced insect visitation and pollen deposition, while pollinators experience reduced food availability. Memmot *et al.* (2007) simulated the effect of increasing temperatures on a highly resolved plant pollinator network. They found that shifts in phenology reduced the floral resources available for 17 to 50 percent of the pollinator species. A temporal mismatch can be detrimental to both plants and pollinators. Temperature can induce different responses in plants and pollinators. For example, increased spring temperatures may postpone plant flowering time while pollinators might be unaffected. Even if plants and pollinators do respond to the same temperature cues, the strength of the response might differ (Hegland *et al.*, 2009). Williams *et al.* (2007) found a relationship between climatic niche and declines in British bumblebees, whereas Dormann *et al.* (2008) projected general declines in future bee species richness in Europe.

In our studies conducted at Bangalore, it was observed that bee activity varied significantly during different hours of the day as well as different months of the year in relation to maximum temperature. The pattern of diurnal variations indicated a peak of activity between 8-00 AM and 11-00 AM (Fig. 2). The number of out going bees as well as the number of pollen collectors has declined with increase in temperature but showed a significant positive correlation with relative humidity (Reddy *et al.*, 2012a). Temperature driven shift

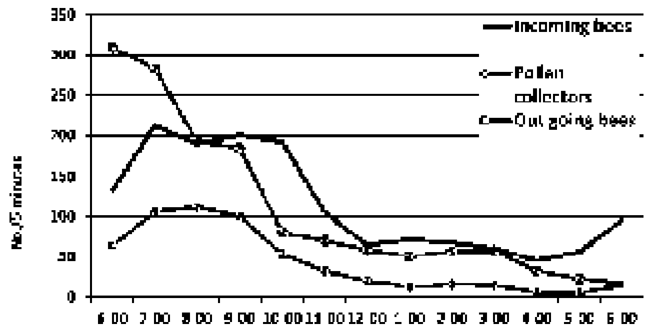

Fig. 2 : Diurnal variations in the activity of honey bee, *Apis cerana*

in foraging behavior was also observed in case of little bee, *A. florae* in mango where a decline in activity was noticed at temperatures beyond 32°C (Fig. 3) (Reddy *et al.*, 2012a). These findings give an ample indication of the vulnerability of honeybees to changes in temperatures.

Elevated CO_2 and bees

The direct effects of elevated atmospheric carbon dioxide concentrations on honeybees and their plant hosts are difficult to predict. Indirectly, elevated atmospheric CO_2 is expected to modify ratios of carbon and nitrogen in plant tissues, possibly leading to changes in nectar composition (Rusterholz and Erhardt, 1998). How this might affect communities of pollinators is uncertain. Furthermore, increasing concentrations of CO_2 in the atmosphere will probably lead to changes in plant community structure, particularly in the proportions of C_3 and C_4 plants in a given habitat (Bazzaz, 1998). It is

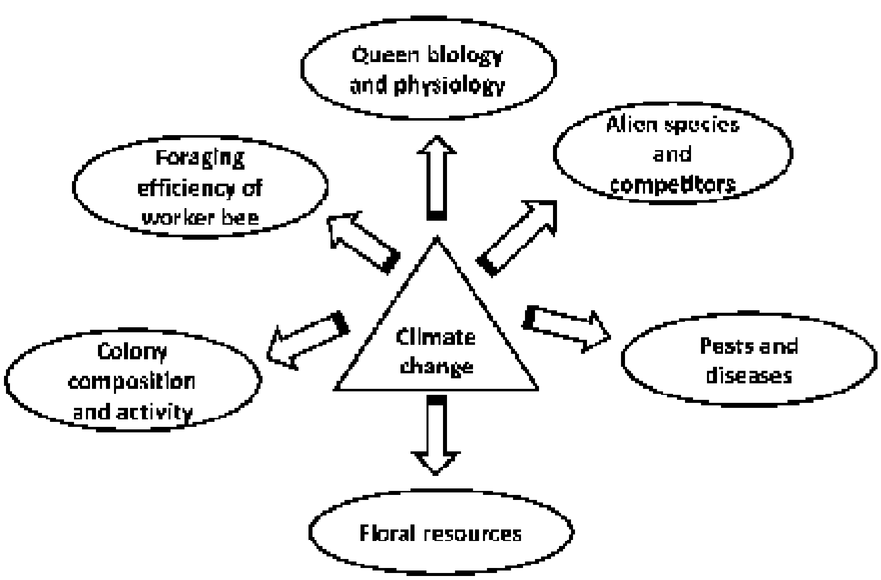

Fig. 1. Multilevel impacts of climate change on honeybees

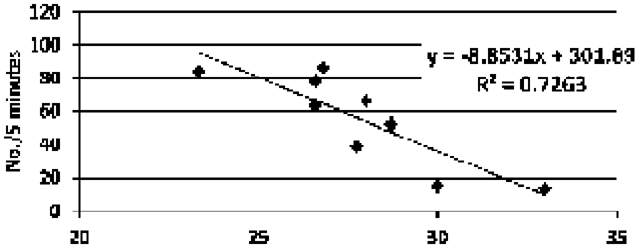

Fig. 3 : Effect of maximum temperature on the bees going out for foraging

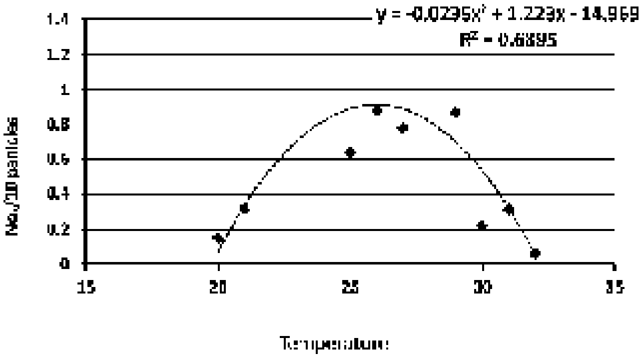

Fig. 4 : Foraging activity of Apis florea in relation to temperature on mango

too early to say whether these effects will influence the status of a particular pollinator species.

Climate change could affect bees through their natural enemies

Honeybees are susceptible to several pathogens, parasites and certain specific pests and predators. Changing climate scenario may have profound effects in the spread and virulence of these diseases and parasites. These pathogens tend to have different haplotypes of varying virulence. Climate change can encourage the transfer of these haplotypes to honey bee populations (Le Conte and Navajas, 2008). Climate change induced movements of honey bees of different species and races would, bring them into contact with pathogens with which they have never co-evolved. The case of *Varroa destructor* and *Apis mellifera* can be one such example. In the span of a few decades, two extremely homogeneous haplotypes of this parasite were sufficient to invade virtually the entire *A. mellifera* distribution range (Solignec *et al.,* 2005).

Possible measures to mitigate climate change effects (FAO, 2009)

Giving consideration to the season long resources needed by bees, both before and after crop flowering

Ensuring connectivity of natural habitats in farming areas, so that bees can more easily disperse and make needed range shifts in response to changing climates.

Providing more non-crop flowering resources in fields, such as cover crops, strip crops or hedgerows.

Stock improvement to minimise desertion especially in case of *A. cerana*

CONCLUSION

The consequences of climate change are of recent realization and hence the effect of this global phenomenon on bee activity and their interaction with crop plants need to be understood before formulating specific mitigation strategies. Though concern has been raised about the potential negative impact of climate change, there is paucity of scientific literature on how exactly pollinators are going to be affected, especially in crop plants. There is a lack of knowledge on temperature sensitivity of crop plants and their pollinators especially in the tropics where the diversity of entomophilous crops is expected to be highest. *Apis mellifera* has shown great adaptive capacity, as it is found almost everywhere in the world and in highly diverse climates and it will be able to use its genetic variability (Cornuet and Louveaux, 1981) to adapt to climate change. In contrast, the Asian species have remained in Asia, which might indicate lesser adaptability to different environments and fragility in the face of climate change. Human assistance in the form of beekeeping, therefore, is essential to conserve various ecotypes of the two domesticated species viz., *A. cerana* and *A. mellifera*. There is a need of more studies to enhance our knowledge on the basic ecology of crop pollination under climate change.

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