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Impact of Climate Change and Global Warming on Crop Pollinators and their Mitigation Strategies: A Review

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ABSTRACT

Climate change and global warming are of great concern to agriculture worldwide and are among the most debated and discussed issues in today's civilization. Climate change at the global level is leading to increased habitat loss, geographical shifts and increased extinction rates of biodiversity. The production of some crops like fruits and vegetables is dependent upon pollination by crop pollinators: bee and non-bee pollinators. Animal-based pollination puts up to 30% of global food production and bee-pollinated crops contribute to approximately one-third of the total human dietary supply. Nearly 75 percent of the world's food plants show increased fruit or seed set with insect visitation. The economic value of these services is estimated to be around 153 billion dollars per annum. If there is an increase in the average global temperature by 1.5-2.5°C, then approximately 20-30 percent of the known species will be threatened which may lead to mass extinction. As a result, there is a serious risk of economic losses as well as challenges to human food security. Only 11 of the 20,000-30,000 species of bee are managed by farmers. Pollination by honeybees and wild bees significantly increased yield quantity and quality averaging up to 62%, while exclusion of pollinators caused an average yield gap of 37% in cotton and 59% in sesame. In India, studies carried out by the International Centre for Integrated Mountain Development revealed that apple productivity has declined as a result of inadequate pollination.

Key words: Bee, Climate change, Food security, Global warming, Mitigation strategies, Pollinators.

Pollination is necessary not only for sustaining the present yield levels but also to increase quantity and improve the quality of the produce in many crops (Fig 1). Insect pollinators play an indispensable role in the success of agroecosystems (Abrol, 2012). To compare the visitation and efficiency of crop-pollinating bees and non-bees at a global scale, we review the literature published from 1950 to 2018 concerning the visitors and pollinators of 105 global food crops that are known to benefit from animal pollinators (Roubik, 1995). Of the 105 animal-pollinated crops, significant proportions are visited by both bee and non-bee taxa, with a total gross domestic product (GDP) value of US$780.8 billion. The estimated proportion of flowering plants pollinated by animals, including wild bees exceeds 85% worldwide and a total of 87 world-leading food crops are dependent on animal pollination which represents 35% of global food production (Klein *et al.,* 2007; Ollerton *et al.,* 2011).

Climate change is a global threat to the food and nutritional security of the world. As greenhouse gas emissions in the atmosphere are increasing, the temperature is also rising due to the greenhouse effect (Shukla *et al.,* 2023). The average global temperature is increasing continuously and is forecasted to rise by 2°C until 2100 (Fig 2). This would cause considerable economic losses at the international level (Inouye *et al.,* 2000) and (Khan and Jadaun, 2023). Animal pollination can potentially impact food security since many crops rely on pollinators to produce fruits and seeds (Hung *et al.,* 2018). However, the effects of projected climate change on crop pollinators and, therefore, on crop production are still unclear, especially for wild pollinators and aggregate community responses (Abrol and Abrol, 2012). More than one-third of food crops depend on commercial bees for pollination at an international level, but over 30% of domesticated honey bee colonies die out each year due to poor nutrition, pathogens, exposure to pesticides and transportation stress (Miranda *et al.,* 2019).

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Impact of pollinators on fruits and vegetables

Insects and other animal pollinators play a vital role in the production of crops for food, fiber, edible oils, pharmaceuticals and other goods. More than 1,300 different plant species are grown around the world for food, beverages, pharmaceuticals, condiments, spices and even textiles. Animals pollinate over three-fourths of these (Delaplane *et al.,* 2000). Pollinators are directly responsible for more than one out of every three bites of food or liquids we consume. Pollinators such as bees, birds and bats affect more than one-third (35%) of global crop productivity (Minachilis *et al.,* 2021). These enhance the outputs of 87 of the world's chief food crops as well as numerous plant-derived medicines**.** Hay crops grown from bee-pollinated seeds occupy around 40 million acres (alfalfa, clovers, lespedezas). Approximately 6 million acres are allocated to the production of fruits, vegetables and nuts, the majority of which are insect-pollinated (Ollerton, (2017). These plants account for around 15% of the human diet. In 2005, Insect-pollinated crops provided $20 billion directly and the value of agricultural crop production ascribable to honey bee pollination was $14.6 billion in the United States in 2000. In 2008, the entire economic value of insect pollination of Chinese fruits and vegetables was 52.2 billion US dollars, accounting for 25.5% of the total production value of China's forty-four crops. This is almost 13% of the province's overall annual crop value. Commercially raised bumblebees are the major pollinators in greenhouses and the crops they pollinate contribute around $502 million to the economy of Ontario each year. pollinators in

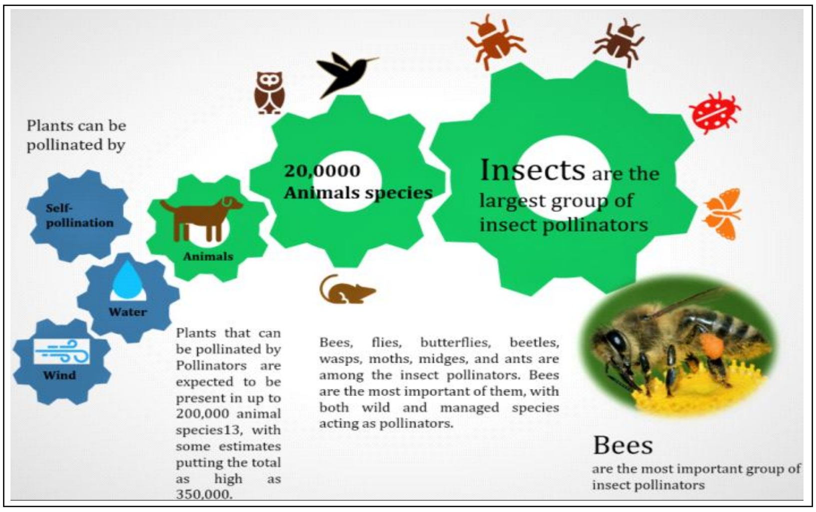


Fig 1: Contribution of Animal Pollinators to crop pollination.

Fig 2: Impact of Global warming on the environment according to WHO Report.

greenhouses and the crops they pollinate contribute around $502 million to the economy of Ontario each year.

Significance of beekeeping in agricultural and rural development

The value of enhanced production from honeybee pollination services alone is approximately 15-20 times more than the value of all hive goods combined (Sain and Nain, 2017). Pollination by honey bees enhances the quality of products as well. The potential benefits of bee pollination in terms of increased crop production range from 5% to 33150%. The following crops have seen an improvement in yield due to bee pollination (Anonymous, 2017) (Graph 1).

Pollinators play a pivotal role in the pollination of many wild plants and agricultural species (Southwick and Southwick, 1992). Many fruit crops, such as apple, blueberries, blackberries, cherries, cranberries, raspberries and strawberries and vegetables like coriander, cucumber, radish, turnip/rutabaga, globe artichoke and asparagus, brinjal, tomato, bitter gourd, ridge gourd, watermelon, pumpkin *etc.* (Table 1). Require an insect pollinator to ensure pollination. Having an ample number of pollinators enhances the quantitative and qualitative features of a wide range of fruit crops. The current research discusses the importance of native and managed pollinators in the production of fruit crops. Honeybee pollination may improve the qualitative and quantitative characteristics of various fruit harvests depending on the variety and conditions at the site.

Decline of pollinators

In 1967, pesticides injured or caused the death of 500,000 colonies in the United States, with 70,000 in Arizona and 76,000 in California (Abrol, 2012). Deaths in California were significantly higher in 1968, with 83,000 colonies lost. The commercial bee colonies' count in the United States has plummeted from 5.9 million in the late 1940s to 2.7 million in 1995. According to FAO estimates, the decrease of pollinators would have an impact on the main three crop categories: fruits and vegetables and edible oilseed crops (Parry *et. al.,* 2022). Losses for fruits and vegetables amount to $50 billion each (Giannin *et al.,* 2017), followed by edible oilseed crops with a loss of $39 billion. A decrease in the number of pollinators could have a wide-ranging impact on different parts of the earth. Intriguingly, those regions that depend on pollination for nutrition were also those with a high prevalence of malnutrition and poverty (Potts *et al.,* 2010).

Causes of or reasons for the decline

Threats to pollinators and the benefits they provide are thought to be increasing all over the world and they are mostly man-made (Kearns *et al.* 1998; Cane 2001). Pollinator declines have been documented in numerous parts of the world (Williams 1986; Rasmont 1988; Westrich 1989; Corbet *et al.* 1991; Osborne *et al.* 1991; Day 1991; Williams 1996; Pekkarinen *et al.* 1987; Luig and Maavara 1998) and the primary causes of pollinator loss can be classified as follows:

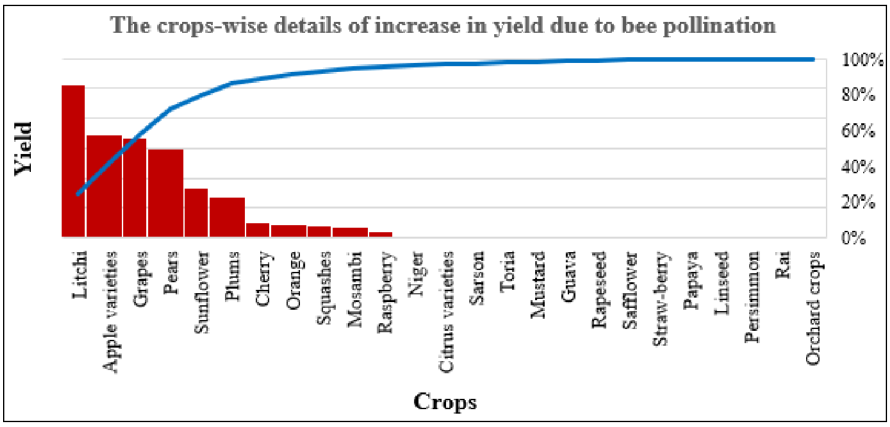
1. Land malpractices (for example, habitat loss due to mechanical destruction, fragmentation, fire, overgrazing and recreation) (Sathish *et al.,* 2024).
2. Pests and diseases.
3. Competition between Man and the different plant species.
4. Global warming.

Effect of pesticides on pollinators

Bees are affected in one or more ways, including stomach poisons, contact materials and fumigants. Arsenicals are common stomach poisons (Champaneri, Patel, 2022). While pyrethrum is a common contact insecticide Neonicotinoids (*e.g*., imidacloprid) and fipronil are more toxic and persistent than the bulk of organophosphorus (e.g., malathion), carbamates (*e.g*., carbofuran) and pyrethroids (*e.g*., cypermethrin) insecticides. Botanicals like the potential acute toxicity and sub lethal effects of Citronella oil, eucalyptus oil, garlic extract, neem oil and rotenone effects bees (Ostiguy *et al.,* 2019).

Bee pollinators vs. climate change

Climate change may be a major reason for decline in the bee population. It has heavily affected crop pollination in



Graph 1: The crops-wise increase in yield due to bee pollination.

Table 1: Influence of pollinators on fruits and vegetables.

Crops	Bee pollinators	Non-bee pollinators	Others way	References
Mango	Honeybees	Flies		Rader *et al.,* 2020 and Klein *et al.* (2007) and Das *et al.,* 2018 and (Heard, 1999) (Raina *et al.,* 2023)
Apple	Bees			
Anola	-		Winds	
Strawberry	*Bombus lucorum*	Beetles		
Vanilla	-	Birds		
Papaya	-	Butterflies		
Mango	-	Flies		
Banana	Honeybees	Bats		
Guava.	Guava, wasps			
Litchi	European honey bee	House flies		
Pomegranate	Bees			
Papaya	-	Moth		
Cocoa	-	Flies		
Cashew	*A. mellifera*	Ants and Butterfly		
Passionfruit	*A. mellifera* (honey bee)			
Custard apple	Honeybees			
Sapota	-	Thrips		
Ber	*Apis* spp.			
Fig	-	Wasps		
Cherries and plums	Honeybees			
Avocado	The honey bees	Hover flies		
Tomato	Honey bees, Wild bees, Halictid bees, Bumble bees, Wild solitary bees.			
Watermelon	Honey Bees,			
Pumpkin and squash	Honey bee and wild bees	Cucumber beetles, scarab beetles, flies and moths		
Muskmelon	Honey bees	Ants and thrips.		
Cole crops	Honey bees and wild bees	flies.		
Carrot	Bees.	Flies		
Bitter gourd	Small bees			
Beet	Honey bees, solitary bees	Thrips, syrphid fly		
Coriander, Cucumber, Radish and Asparagas	Honey bees.			
Brinjal	Bumble bees, carpenter bees and honey bees.			
Lettuce	Honey bee, flies, wild bees	Butterflies.		
Okra	Honey bees and bumble bees.			
Onion	Flies, honey bees, small halictid bees	Drone flies. syrphid flies,		
Peppers	Honey bees and other bees.			
Parsnip	Honey bee, other bees, beetles	Dung flies.		
Beans	*Apisdorsata spp., A. florea,Trigona* spp. and bumble bees.			
Field beans	Honey bee and short toungue. bumble bee and carpenter bee			
Cowpea	Bumble bees.			
Lima bean	Honey bee, bumble bee.	thrips.		

many agricultural areas. Historical records reveal that beehives fluctuate every 7 or 8 years, influenced by weather and crop output. Climate change is thought to be the worst calamity that we would face in the future. It would be very detrimental in terms of habitat loss, ecosystem destruction and biodiversity loss (Settele *et al.,* 2016) and (Abrol and Abrol, 2012).

According to the Intergovernmental Panel on Climate Change's 2007 Assessment Report, global average temperatures in 2100 will be between 1.8°C and 4.0°C higher than the 1980-2000 average. Based on observed rates of ice flow from Greenland and Antarctica, sea levels are expected to raise 0.18/0.59 meters by 2100. Extreme weather phenomena, such as drought and flooding, are also anticipated to become more common and intense (Fig 3).

Pollinator population decline and its effects

Pollinator loss may enhance the susceptibility of some plant species to extinction, while results in non-agricultural settings are difficult to determine. Because of the impact on honey pastures, bee colonies are heavily influenced by frequent extreme temperature and rainfall circumstances (drought period, exceptionally intense precipitation, especially during August). As honey pastures decline, so will overwintering and, eventually, the death of the bee colony. Reduced bee populations in the environment resulted in less effective pollination of native plant species as well as a 30% decrease in crop production, particularly for oleaginous plants. Climate change has an influence on native pollinators in agroecosystems, particularly bumble bees and solitary bees and their decline is linked to plant species extinction (Luig and Maavara, 1998).

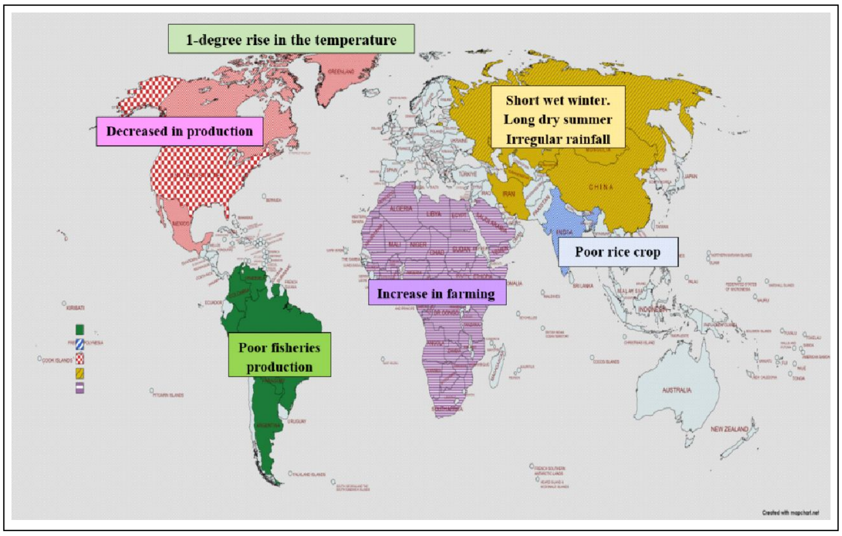


Fig 3: Impact of climate change on world environment.

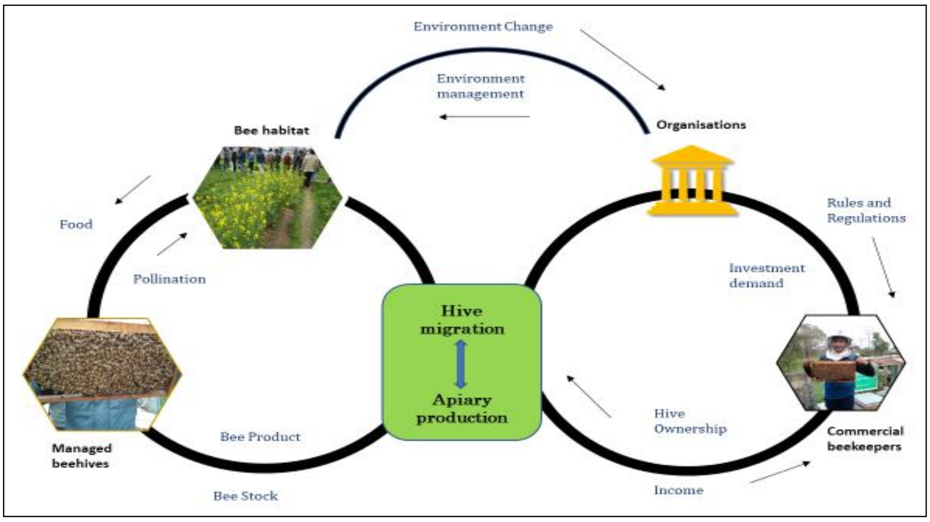


Fig 4: Conceptual diagram of the beekeeping industry's social-ecological system.

Climate change and the diversity of butterfly species

Climate change could be one of the most serious threats to pollinator biodiversity. According to Kerr (2001), the human effect on climate is unexpectedly ubiquitous. Continental precipitation losses in industrialised countries, for example, can be ascribed to an increase in atmospheric particle matter, which impairs raindrop nucleation (Rosenfeld 2000). On North America's Atlantic coast, industrial aerosols influence storm timing and frequency (Balling and Cerveny 1998). Regional variations in species distributions recorded in Europe and North America provide compelling evidence that climate change is already having an impact on pollinator taxa (Rodder *et al.,* 2021) (Table 2).

The direct effects of rising CO_2 levels in the atmosphere on pollinators and their mutualistic plant hosts are equally difficult to anticipate (Hill, 2021). Indirectly, increased atmospheric CO_2 is projected to alter carbon and nitrogen ratios in plant tissues (Bazzaz, 1998; Bazzaz and Sombroek 1996), perhaps resulting to changes in herbivory patterns by creatures such as butterfly larvae (Rusterholz and Erhardt, 1998). It's unclear how this will influence pollinator communities. Furthermore, rising CO_2 levels in the atmosphere are likely to alter plant community structure, notably the proportions of C3 and C4 plants in a given environment.

Climate change hinders flower pollination timing

Pollination timing could be thrown off by global warming, causing major problems for both plants and pollinators. Changes in the timing of flowering in high altitudes will be one of the most pernicious effects of global warming, potentially leading to diminished reproductive success and extinction (Inouye and Wielgolaski 2003; Wielgolaski and Inouye 2003). According to Inouye *et al.,* (2003), global warming could affect pollination time in alpine habitats, with major consequences for both plants and pollinators.

Climate change on phenology

The time of phenological processes like blossoming is frequently linked to environmental variables like temperature. Changing conditions are thus predicted to cause changes in life cycle events, which have been documented for many plant species. Climate change is influencing the timing and intensity of seasons, hence influencing phenology. Spring is arriving early by about 1.2 days each decade across the whole northern hemisphere. Across Europe, for example, the growing season increased by 10.8 days between 1960 and 1999 (6 days earlier spring, 4.8 days longer summer). The IPCC estimated in 2007 that more than 89% (25,810) of the changes observed in physical and biological systems are in the direction expected as a result of climate change, based on a review of more than 29,000 observational data series.

Bees and flowers are both disappearing

According to research led by the University of Leeds and published in science, the diversity of bees and the flowers they pollinate has fallen dramatically in the United Kingdom and the Netherlands over the last 25 years. The study is the first to show a broad reduction in bee diversity. Concerns concerning the loss of pollination services have been raised for years, but most data has been limited to a few critical species or a few focal areas. Biesmeijer *et al.* (2006) gathered biodiversity records for 100 sites and discovered that bee diversity has decreased in about 80% of them. In the United Kingdom, many bee species are dwindling or have become extinct.

Mitigation strategies

Make an environment with availability of forage through habitat management

Many species' distributions are changing as a result of climate change. Agricultural genetic resources that aid crop adaptation to climate change are being sought. Pollinators, on the other hand, will mostly adapt by limiting or increasing their ranges in response to new climatic trends. Thus, the possibility of crops losing critical pollinating species, or mismatches in crop and pollinator ranges, is a genuine threat. Such repercussions have already been felt in India's seed sector (Daniels *et al.,* 2020).

Table 2: Impact of Climate change on non-bee pollinators.

Non-Bee pollinators	Effect due to climate change.	References
Wasps	1. Population of fig wasps and their life span is declining steadily. 2. Pollination of figs is slowing down, causing a decline in the population of fig trees.	Jevanandam *et al.,* 2013
Birds	1. Breeding patterns are changes in birds. 2. Migration occurs due to lack of food.	Carey, 2009
Butterfly and Moth	1. Changes in abundance. 2. Changes in range, distribution, or area 3. Changes in phenology	Rusterholz and Erhardt, 1998
Flies	1. Decrease fly longevity, fecundity, pupal weights and pupal mortality.	Shrestha, 2019
Ant	1. Affect ant communities by altering foraging behaviour 2. Affect ant colonies, populations and communities.	Parr and Bishop, 2022

Use biodiversity-friendly agroecosystem strategies, beekeeping, colony management skills and ecotourism in key areas

This diagram depicts (Fig 4). The Tier 1 components of the social-ecological system framework, include bee habitat (resource system), managed hives (resource unit), organizations (governance system) and commercialization. Beekeepers (actors), hive migration (interactions) and apiary productivity are all featured in this film (Patel *et al.,* 2020).

Modern genomics methods

The Earth BioGenome Project (EBP) is an ambitious international endeavour to sequence the genomes of over 2 million identified eukaryotic species. Beenome is one of many efforts linked with the EBP. Eukaryotes are distinguished from other life forms by the presence of nuclei and other organelles in their cells. All plants, fungi and animals, including bees, are included in this domain.

The national bee board (NBB) and its function

The primary goal of NBB is to promote scientific beekeeping in the country in order to boost crop productivity through pollination support and the production of honey and other beehive products in order to increase farmers'/beekeepers' income. NBB is one of MIDH's National Level Agencies (NLAs).

Currently, the main focus of NBB is to establish at least one Integrated Beekeeping Development Centre (IBDC)/ Centre of Excellence (CoE) in beekeeping in each state.

Beekeeping industry in india

Currently, over 30 lakh bee colonies in India produce 94500 metric tonnes of honey (2016-17 estimated), including honey from wild honey bees and employ approximately 3.00 lakh people. India is one of the countries that export honey. Germany, the United States, the United Kingdom, Japan, France, Italy and Spain are among the key markets for Indian honey.

World beekeeping scenario

Honey is a valuable natural health commodity that is produced all over the world. A total of 14-15 lakh metric tonnes are generated globally. 15 countries in the world contribute 90% of global output. China, the United States, Mexico, Argentina, Ukraine, Turkey, Russia and India are major honey producers.

Possibilities and opportunities

India has enormous beekeeping potential. The diversity of flora and fauna opens up new avenues for the development of the beekeeping sector. The National Commission on Agriculture estimated that approximately 150 million bee colonies would be required to pollinate the country's 12 key agricultural crops. Currently, 200 million bee colonies are needed to boost yield, which will employ 215 lakh people, create 10 million tonnes of honey and increase crop production.

CONCLUSION

Climate change will have an impact on the various pollinating species, influencing their importance as crop pollinators; however, climate change is also likely to alter pollinator lifecycles, distributions and interactions with pests and diseases, as well as the timing and quantity of nectar and pollen produced by crop plants. Despite this, a fundamental objective should be to increase pollinator species variety to enhance pollination activity under changing and extremely unpredictable climatic circumstances. This necessitates a focus on realistic management solutions aimed at a variety of species that have already been identified as essential pollinators.

Conflict of interest

All authors declared that there is no conflict of interest.

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