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Apoorva Indrapal Singh Kataria
Department of Ecosystem & Environment Management, Indian Institute of Forest Management, Bhopal, Madhya Pradesh, India

Advait Edgaonkar
Department of Ecosystem & Environment Management, Indian Institute of Forest Management, Bhopal, Madhya Pradesh, India

Corresponding Author:
Apoorva Indrapal Singh Kataria
Department of Ecosystem & Environment Management, Indian Institute of Forest Management, Bhopal, Madhya Pradesh, India

Forest insect pollination ecosystem services and climate change: A review

Apoorva Indrapal Singh Kataria and Advait Edgaonkar

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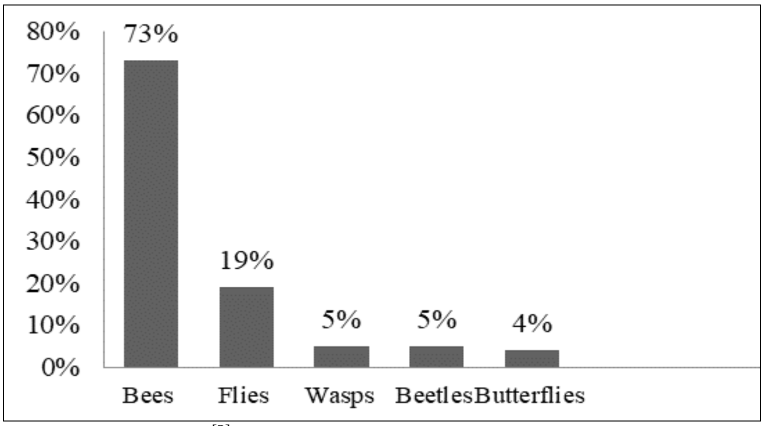
Abstract
Global warming has been predicted to cause big changes in terrestrial natural ecosystems and processes. Forests, being a part of terrestrial ecosystems, help in the regulation of biogeochemical processes and functions. Insect pollination is one function that is useful to the forest ecosystem as well as to the associated agroecosystems. Climate change is thought to be a principal factor that can influence the activities, distribution, and abundance of insect pollinators dwelling in the forest. Overall, elevated temperature level could affect the insect pollinators present in the forests. The present paper reviews the possible impact of climate change on insect pollination services provided by the forests, highlighting the importance of insect pollinators present in the forest, the dependence of linked agro-ecosystems on the forest, and various indicators of climate change with the species present in the forest. The paper finally concludes with some key recommendations for the conservation of forest insect pollination function with respect to climate change.

Keywords: Forest, pollinators, climate change, ecosystem services, agriculture

1. Introduction

Climate change has the potential to bring about pronounced shifts in insect behavior, their susceptibility to insecticides, and phenological synchrony with host plants (Pannure 2016) [48]. As per the IPCC report, temperature rise ranging from 1.1- 6.4 °C is estimated by the end of this century (Verghese *et al*. 2012) [61]. The forest forms an integral part of the biome encompassing a huge amount of biodiversity with a land cover of about 30% and an area of about 42 million km^2 in tropical, temperate, and boreal lands (Bonan 2008) [13]. Forests provide pollination as an ecosystem service of global importance providing significant economic and aesthetic benefits as well as cultural values to human society.



Source: Abrol, 2009 [2]

Fig 1: Contribution of insect groups pollinators to pollination

Insect pollinators show an astonishing taxonomic diversity in the forest ecosystem and are abundant in almost all environments across the globe. Hymenopterans with nearly 2,50,000 described species constitute the most important group of pollinators (Pannure 2016) [48].

Bees, flies, butterflies, moths, wasps, beetles, thrips, and some other insect orders encompass the majority of pollinating species (Fig.1).

Of the more than 100 crop species which provide 90% of the food supply for 146 countries, 71 are bee-pollinated (mainly by wild bees) and several others are pollinated by wasps, flies, beetles, etc. (Pannure 2016) [48]. Native bee communities provide pollination services but the amount of benefit they provide and how this varies with land management practices is not well known.

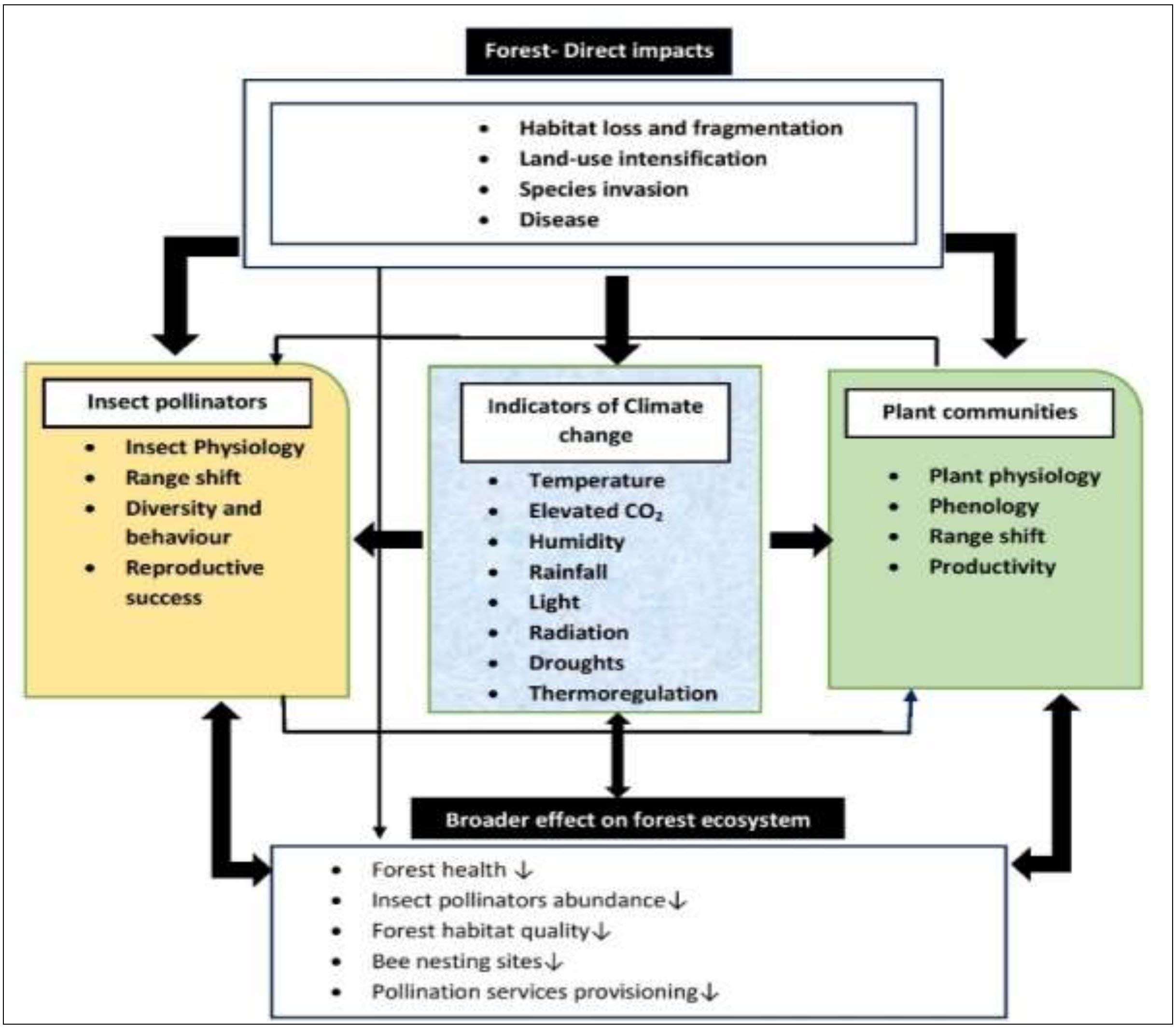


Fig 2: Conceptual framework for understanding the flow of insect pollination service in the forest ecosystem

Over 85% of described flowering plant species are dependent, to some degree, on animal pollination, with mobile foraging insects accounting for the vast majority of this activity (Kremen *et al*. 2007) [39]. This results in increased fruit quality and quantity, seed production and fertility (Albrecht *et al*. 2012; Barrett 2003; Klein *et al*. 2007) [4, 7, 37].

This review attempts to understand the role and effect of forests in providing insect pollination ecosystem services and the possible factors responsible for bringing changes in the patterns of delivering insect pollination services influenced by climate change (Fig 2).

2. Indian context

In India, 116 species of Dipterans belonging to 16 families visiting 92 plant species have been reported. The most dominant group among the flower-visiting flies was the family Syrphidae, and Asteraceae was the most favored plant family (Mitra 2010, Sima *et al*. 2012) [45, 55].

The potential effects of climate change on pollinators have been reported by farmers practicing traditional beekeeping with *Apis cerana* in the Himalayas showing the effect of temperature influencing the population sizes and swarming times of the insect pollinators (Tripathi 2011) [58]. In the Nainital district of Uttarakhand state the abundance of honeybees was significantly higher in an orchard having pollination services from apiary bees than in a control site where the pollination was dependent on available natural pollinators (Sharma 2012) [54].

The percent yield increase due to bee pollination for crops like mustard was found to be 43%, 32- 48% for sunflower, 17-19% for cotton, 93% for onion, and 44% for apple, etc. (Source: TNAU, Aggrotech portal).

3. Effects of climate change on the forest insect pollination ecosystem services

Patterns of change in most pollinator assemblages suggest a causal connection between plants and their pollinators (Biesmeijer 2006) [12]. Studies on different climate change indicators are shown in Table. 1.

In the Kodagu district, India (Boreuxa *et al*. 2012) [15], the impact of forest fragments was observed. Here the bee visits and fruit set in rain-fed and irrigated coffee agro-forests were seen affected by the forest and its size. Klein (2003) [36] found that coffee and cacao agro-forests in Sulawesi near rainforests had higher pollinator species diversity than in agro-forests situated further away, and as a consequence diversity was seen affecting the fruit-set more than abundance. Similarly in Brazil, farms near forest fragments had an increase in production up to 14.6% (De Marco & Coelho 2004) [25].

In tropical forests, the value of pollination services to agriculture is seen to increase coffee yields by 20% within 1 km of the forests, and pollination services performed by the insects improved coffee quality near the forest by reducing the frequency of "peaberries" by 27% (Ricketts 2004) [52].

4. Indicators of climate change influencing insect pollinators

Insects are cold-blooded organisms, it is estimated that a 2 °C temperature shift could have a drastic effect on their behavior, abundance, life cycles, and reproductive capabilities, which may differ depending on pollinator size, age, and sex. (Yamamura and Kiritani 1998; Verghese *et al*. 2012) [62, 61]. Night-time temperatures may also have strong effects on the pollinator communities, affecting maturity and senescence, leading to differences in the time of nectar secretion and pistil receptivity. This can have an effect on the insect pollinators' visitation durations and crop pollination (Chabert *et al*. 2018; Rohde and Pilliod 2021) [19, 53]. The metabolic rate of the insect pollinators may increase with the temperature (Willmer 1983) bringing changes in their flight activities. In honeybees, flight metabolic rate decreases with increasing temperature, and may be able to spend more time foraging when temperatures are rising. Large and dark-colored bees warm up and cool down faster than small and light-colored bees (Pereboom & Biesmeijer 2003) [49]. This results in differences in resource exploitation and might lead to shifts in pollinator assemblages with increasing temperatures (Taylor 1963) [57].

Relative humidity may affect an insect's visitation rates and nectar quality. The rate of equilibrium of nectar in the flower may also get influenced by humidity (Rohde and Pilliod 2021) [53].

The phenology of plants and their insect pollinators (bumblebees and whitefly) may be affected by the amount of light that is received. The reproductive success of bee-pollinated species is seen to be highly susceptible to seasonal changes in light in deciduous forests (Kudo 2008; Keeler *et al*. 2021) [40, 34]. There can be a possibility in some cases for rainfall being responsible for affecting the insect pollinators' abundance rates. Arnold *et al*. (2018) [5] found a positive relationship between the abundance of cocoa midge and rainfall.

Table 1: Literature showing the effect of climate change indicators on insect pollinators

Variables	Findings	References
Temperature	Effect on the abundance rate of the insect pollinators, developmental stages of plants and insects, and pollinators' efficiency. Insects are affected at spatial and temporal contexts.	Arroyo *et al*. (1994) [6]; Gordo & Jose (2006) [31]; Boyle-Makowski and Philogene (2012)
Humidity	Effect on insect visitation rates, nectar quality changes, nectar quality, etc.	Rohde and Pilliod (2021) [53]; Corbet *et al*. (1979) [22]; Corbet (1990) [21]
Light	Effect on the phenology of plants and insect pollinators.	Kudo (2008) [40]; Keeler *et al*. (2021) [34]
Rainfall	Effect on insect pollinators' abundance rates.	Arnold *et al*. (2018) [5]
Microclimate	Effect on timing of flower opening, and the exposure and receptivity of the style affecting insect pollinator's visitation rates.	Gols *et al*. (2021) [30]

Microclimate can affect small ectotherms like insects as they have limited ability to adjust under higher temperature ranges. Microclimate influences the timing of flower opening, extrusion and dehiscence, the survival and germination of pollen grains, and the exposure and receptivity of the style (Gols *et al*. 2021) [30]. The nectar quality of the flowers may be affected due to microclimate and insect visits. Microclimate inside the flower may influence the rate of equilibrium of nectar with the relative humidity of the air or the equilibrium concentration itself (Corbet *et al*. 1979) [22].

Factors affecting the phenology of insect pollinators are life cycle changes, alteration in the development rate, and availability of food resources (Bezerra *et al*. 2019 [11]; Tougeron 2019; Rohde and Pilliod 2021; Kendall *et al*. 2021) [53, 35]. Studies show a shift in the natural range of *Xylocopa* bees due to climate changes (Bartomeus *et al*. 2011; Bezerra *et al*. 2019) [11]. Climate change may alter the mutualism between plant flowering time and pollinator flight periods. There may be possibilities for phenological mismatches that contribute to the disruption of pollination of plants that flower later in the season. This could mainly influence specialist insect pollinators, though it may also reduce the generalist foragers.

In Eastern Massachusetts, New Hampshire, and South Africa the flower shape, temperature, light, and season appeared to be the most important variables influencing insect visitation rates (Boyle-Makowski and Philogene 1985 [16]; Abrahamczyk *et al*. 2011; Bezerra *et al*. 2019) [11]. Reduced foraging activity and increased disease prevalence are due to changes in weather variables like temperature, humidity, and light quality/quantity (Rafferty and Ives 2011; Kendall *et al*. 2021) [35]. The reproductive success of certain pollinators is highly susceptible to seasonal fluctuations, and can result in decreased reproductive potential and adult mortality (Kudo *et al*. 2004; Kudo 2008; Bezerra *et al*. 2019 [11]; Kendall *et al*. 2021) [40, 41, 35].

5. Loss in forest insect pollination service and effect on the agroecosystems

Klein *et al*. (2007) [37] showed that many crops do not directly rely on insect pollinators for the production of the part that is consumed, but pollinators are important for their propagation.

Annual production of pollination services estimated worldwide is $235 billion- $577 billion (in 2015 US$) which is 5-8% of market value directly linked with pollination services (Potts *et al*. 2016) [50]. As per the global surveys (Verghese *et al*. 2012) [61] on insect pollinators, the numbers of pests and diseases are more in horticultural crops than field crops, and they can affect the nutritional security of poor people under the influence of climate change.

In north-western Argentina, the diversity of flower visitors declined with decreasing forest fragment size, but the

frequency of flower visitors especially honey bee visits tended to increase (Aizen and Feinsinger 1994) [3]. Pollinator populations have declined across many regions due to habitat loss and degradation (Bezerra *et al*. 2019; Lee *et al*. 2021) [11]. Natural and restored fragments near Pondicherry, India, showed lower fruit sets due to the limitation of insect pollinators leading to low reproductive outputs (Nayak and Davidar 2010) [47].
Land-use intensification and disease have long driven pollinator losses (Bergholz *et al*. 2022) [10]. Vanbergen 2013 [60], Garibaldi *et al*. 2011) [28]. Due to climatic fluctuations, disease outbreak can occur in crops. The association between these different pressures is also likely are also likely to contribute to pollinator declines (Vanbergen 2013) [60].
Studies on biological invasions showed that invasions affected insect pollinators by decreasing visitation rates and the fruit set percentage (Kaiser-Bunbery 2011; Montero-Castano and Vila 2012) [33, 46]. Studies suggest that plant invasion may attract fewer floral visitors (Montero-Castano & Vila 2012) [46] affecting the pollination activity (Brown *et al*. 2002) [18].
Frequent use of pesticides on crops may lead to reduced foraging activity of insect pollinators (Kendall *et al*. 2021) [35]. Surveys on wild bees and butterflies show a lower species richness in the places where the use of pesticides is more (Brittain *et al*. 2010) [17]. Systemic pesticides i.e., neonicotinoids have the capacity to penetrate through plant tissue resulting in accumulation in the plant nectar and pollen. This can result in sublethal effects on insect pollinators' activity and behavior (Cresswell 2011) [23]. It could affect the brain functioning, growth, and foraging capacity of honey bees (Vanbergen 2013, Gill *et al*. 2012) [60].
Droughts can lead to modifications in floral signals and rewards which could impact the reproductive success of both plants and pollinators negatively by decreasing pollen viability, pollen tube growth, and pollen deposition effectiveness. (Fang *et al*. 2010; Vaudo *et al*. 2015; Solis-Montero and Vallejo-Marin 2017; Arnold *et al*. 2018; Descamps *et al*. 2021) [27, 46, 5, 26].
N-fixing bacteria allow the plants to produce higher-quality rewards by increasing phosphorous and micronutrients, increasing pollinator visitation. A reduction in the strength of the interaction between legumes and rhizobia can affect plant nitrogen negatively (Keeler *et al*. 2021) [34]. This can affect pollinator feeding preference due to reduced flower number, nectar, and pollen quality. This could in turn have an effect on bee fitness. Potassium is also an important micronutrient for bee reproductive success (Praz *et al*. 2008; Davis *et al* 2019; Bonoan *et al*. 2018; McAulay *et al*. 2021) [24, 14].
Fires regimes are seen to be impacting the functions of insect pollinator communities. Insect pollinator responses to fire are tied to multiple factors like fire history, plant responses, and changes in species interactions. Due to spatiotemporal and historical heterogeneity of fires and interaction of global drivers of insect pollinators change, prediction of community-level resilience of insect pollinators is often challenging (Koltz *et al*. 2018) [38].
The artificial night light is seen as a reason for reduced population sizes and changes in the community composition of insect pollinators. It can lead to disruption of visual cues and affect pollinators' behavior and populations. It could also result in affecting the plant-pollinator interaction patterns (Grubisic and Grunsven 2021; Macgregor *et al*. 2017; Van Grunsven *et al*. 2020) [32, 43, 59].

6. Conclusions
Climate change may adversely affect ecosystem functions therefore managing forests' ecosystems can prove beneficial in mitigating the adverse effects of climate change. The effects of climate change on insect pollinator species may have positive as well as negative consequences.
Out of all the climatic variables affecting insect pollinators, the temperature is found to be the most prominent factor influencing the forest ecosystem. Rise and fall in temperature levels more than the normal range could create an enormous impact on insect pollinator diversity and abundances, their phenology, and their distribution patterns. Because of fluctuation in the temperature ranges every year, there may be chances of reduced floral appearances, delayed flowering and fruiting, disease outbreaks, etc. It may also cause a shift in the pattern of insect pollinators occurrences, morphology, and their habitat range, etc. studies show that it is due to climate change that an insect pollinator species dwelling in a particular ecosystem may alter the fundamental niche habitat. It may enable survival of that species but the plants dependent on these insect pollinators may get affected adversely.
Globally and in India much research needs to be performed on insect pollinators and their effect on forests and the agroecosystem. While the attributes affecting climate change are difficult to analyze, there are still some parameters and data available, explaining the interrelationships between the climate variables affecting insect pollination service. However, the scale of dependence of plants and tree species present in the forest ecosystem on the insect pollinators is not known.
Despite knowledge of importance of insect pollinators and their role in providing the service to the agroecosystem for crop production, there is still limited data on species diversity, abundance, and community composition of insect pollinators. There is a need to carry out research on the forest floral species-specific insect pollinator. One of the major problems is the availability of baseline data. Therefore, in order to reduce the research gap, it is important that more attention be given to baseline data generation on the insect pollinators, their diversity, and abundances. This ground data gathered over years could be utilized in understanding the plant species-specific insect pollinators and comparing it with climatic events using some climatic models. Thus the impact of climate change on both plants as well as insect pollinators could be predicted.

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