Climate Change and the Pollination Crisis: A Call to Action

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ABSTRACT

Pollinators play an important role in the reproduction of cross-pollinating plants. Anthropogenic activities such as industrialization and intensive agricultural practices linked to greenhouse gas emissions are among the factors responsible for climate change. Climate change results in adverse rises in temperature, water stress and increases intensity of frost, which lead to abnormalities in the floral biology of flowering plants. This, in turn, affects the pollinators' health and reproduction, leading to a decrease in pollination.

INTRODUCTION

Plants reproduce both sexually and asexually. Due to their immobility, they depend entirely on external agents such as wind, water, and animals (including insects) for pollination, particularly for cross-pollination. It is estimated that animals, especially insects, facilitate pollination in over 80% of flowering plants and around 75% of food crops (FAO, 2025). Therefore, pollinators play an indirect yet vital role in plant survival. However, in recent decades, climate change shown to impact both floral and pollination biology, posing a threat to pollinator populations. Given the crucial role of pollinators in ecosystems and agriculture, this article addresses the effects of climate change on pollinator decline and discusses potential strategies for their conservation.

Climate Change

Weather refers to the atmospheric conditions, such as humidity, temperature, rainfall, and wind speed, at a specific location and time. In contrast, climate represents the average

weather patterns recorded over at least 30 years in a particular region. When evaluating climate, any substantial and long-term alterations in these weather parameters are referred to as climate change.

Factors Contributing to Climate Change

Climate change is driven by both natural phenomena and human activities. Before industrialization, the natural factors such as volcanic eruptions, shifts in the Earth's orbit and axial tilt, solar radiation, and changes in the planet's reflectivity were the primary causes of climate variability. However, in recent decades, human-induced (anthropogenic) activities, especially the emission of greenhouse gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), have become significant contributors to climate change. Major sources of CO_2 emissions include the combustion of fossil fuels such as coal, oil, and natural gas, as well as deforestation and industrial operations like steel and cement manufacturing. Methane emissions primarily originate from flooded rice crops, livestock digestion, and poor manure management practices. Nitrous oxide is released from coal-powered plants, vehicles, industrial activities, and livestock farming.

Examples of Climate Change

As of 2024, the Earth's average temperature is 1.47°C higher than the pre-industrial baseline (1850-1900) (NASA, 2024). The concentration of atmospheric carbon dioxide has shown a consistent upward trend over the decades. In the 1960s, it increased at an average rate of 0.8 parts per million (ppm) per year. This rate doubled to 1.6 ppm annually in the 1980s, slightly declined to 1.5 ppm in the 1990s, and then surged to 2.6 ppm per year between 2015 and 2024 (NOAA, 2024).

Effect of Climate Change on the Floral Biology of Flowering Plants

1. **Sex ratio:** Climate change can have significant adverse effects on plant reproductive development. Elevated temperatures and water stress, such as drought, tend to promote the formation of more staminate (male) flowers. In contrast, cooler temperatures and excessive rainfall are associated with an increase in pistillate (female) flower production. This is because pistillate flowers, which involve the development of ovaries and ovules, require more water compared to staminate flowers.

2. **Pedicel:** Increased temperatures and drought conditions lead to a reduction in the length of the flower stalk (pedicel) in both staminate and pistillate flowers. Consequently, this decreases the visibility and accessibility of flowers to pollinators.

3. **Initiation of flowering:** Elevated temperatures can trigger earlier flowering, while reduced rainfall may cause earlier or delays in floral initiation, leading to deviations from the typical flowering schedule.

4. **Floral bud:** Elevated temperatures, along with increased frost intensity and frequency, can harm flower buds, resulting in floral bud abortion. Frost damage occurs when ice crystals form within the tissues of floral buds, disrupting their development and leading to abortion.

5. **Longevity of the flower:** Elevated temperatures accelerate biological processes such as respiration, ethylene production, and senescence, ultimately shortening the lifespan of flowers.

6. **Petals:** High temperatures and ozone layer depletion can alter UV-absorbing pigments in petals, such as flavonoids,

chalcones, and anthocyanins. Although these changes are not visible to the human eye, they are detectable by honey bees and other pollinators.

7. **Pollen:** Rising temperatures and water stress impair photosynthesis and cause abnormal lipid accumulation in pollen grains, leading to reduced pollen germination, decreased pollen tube growth, and lower pollen viability.

8. **Nectar:** Elevated temperatures and water stress lead to a decline in both the quantity of nectar and its sugar concentration.

9. **Ovule and ovary:** High temperatures can decrease stigma receptivity and reduce the number of ovules formed per ovary. Moreover, temperatures exceeding the optimal range can increase the rate of ovule abortion.

10. **Anther dehiscence:** Elevated temperatures and heat stress can cause abnormalities in meiosis, microspore formation, and anther locule development. These disruptions may delay anther filament elongation, preventing the anthers from opening and releasing pollen, ultimately leading to suppressed anther dehiscence.

Impact of Climate Change on Pollination Biology

The adverse effects of climate change reduce both the quantity and quality of food resources available to pollinators, such as nectar and pollen. This decline negatively impacts their growth, development, and reproductive capacity. Climate change can cause shifts in flowering time, either advancing or delaying it, often resulting in a mismatch with the period when pollinators are active. This lack of synchrony between pollen availability and pollinator presence leads to inadequate pollination. Pollen grains are sticky due to the presence of an oily substance called pollenkitt, which is composed of lipids, glycoproteins, and carotenoids. These components contribute to the pollen's stickiness, colour, and odour. However, elevated temperatures resulting from climate change can alter both the quantity and quality of pollenkitt, thereby reducing the efficiency with which pollinators can collect and transport pollen.

Floral scents are composed of volatile organic compounds (VOCs), which play a crucial role in attracting pollinators. However, adverse climate conditions such as elevated temperatures, drought, water stress, and frost can alter both the quantity and composition of VOCs, making it more difficult for pollinators to detect or be attracted to flowers. A significant number of pollinator species, including approximately 70% to 75% of wild bee species, construct their nests underground (Neumann *et al.,* 2024). Climate change-induced water stress and drought can alter soil structure, leading to the formation of compacted hard pans. These hardened soil layers hinder the ability of ground-nesting pollinators to excavate nests, ultimately contributing to a decline in pollinator diversity. In certain cases, adverse climatic conditions resulting from climate change may create favourable environments for the successful establishment of invasive species. These invasive species can outcompete native pollinators, potentially leading to their extinction, as explained by Gause's competitive exclusion principle. Furthermore, such climatic changes may also support the survival, proliferation, and spread of pollinator pathogens, increasing the risk of disease outbreaks and contributing to pollinator mortality.

CONCLUSION

Globally, all nations need to raise public awareness about the adverse effects of climate change and promote the adoption of renewable

energy sources such as wind, water, and solar power through supportive policies and subsidies. In agriculture, practices like alternate wetting and drying in paddy fields, efficient management of livestock diets and manure, and the proper use of nitrogen-based fertilizers can help reduce methane (CH_4) and nitrous oxide (N_2O) emissions. Several countries, including India, China, Italy, and the United Nations, have already begun implementing natural farming as a strategy to mitigate climate change. Going forward, more countries need to adopt and expand such sustainable practices to effectively address the climate crisis. Additionally, in the future, many more correlation studies, such as what is the impact of every alteration in weather parameters like temperature on the floral biological parameters and what is that effect on pollinators' behaviours, need to be studied.

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