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CLIMATE CHANGE AND MISMATCHED PHENOLOGY: CONSEQUENCES FOR POLLINATOR-PLANT INTERACTIONS

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Abstract

As a result of its effect on phenological events, which refers to the seasonal timing of life cycle activities in plants and pollinators, climate change has emerged as a significant factor that contributes to ecological disturbance. The purpose of this study is to investigate the effects of phenological mismatches that are caused by climate change. These mismatches gradually desynchronise the interdependent timing of blooming in plants and the activity periods of the pollinators that are responsible for those flowers. These kinds of incompatibilities can result in decreased pollination efficiency, decreased reproductive success for plants, and population losses in both plant and pollinator species. We present a synthesis of the most recent research that focusses on case studies from a wide range of ecosystems. These case studies investigate the processes that are responsible for phenological changes, including temperature sensitivity, changed precipitation patterns, and photoperiodic responses. A comprehensive analysis is performed on the cascading ecological repercussions, which include changes in the makeup of communities, disruptions to mutualistic networks, and risks to biodiversity. In addition, we address various adaptive tactics and mitigation techniques to strengthen the resilience of ecosystems, with a particular emphasis on the significance of integrated monitoring and modelling activities. It is necessary to get an understanding of these mismatches and find solutions to them in order to preserve pollination services, provide food security, and contribute to the sustainability of ecosystems in a climate that is changing quickly.

Keywords: *Climate, Mismatched, Phenology, Pollinator-Plant*

Introduction

As a result of climate change, ecosystems all over the world are undergoing a transformation in terms of their structure and function, which is having a significant impact on the timing of biological occurrences, which is a topic of study known as phenology. Phenological changes, which include alterations in the time of blooming, leaf-out, migration, and insect emergence, are among the most sensitive biological markers of climatic variability. Phenological changes include adjustments in the timing of these events. In recent decades, there have been visible modifications in the phenology of both plants and animals as a result of rising global temperatures, changing patterns of precipitation, and an increased frequency of extreme weather events. The problem known as phenological mismatch is caused by the fact that these adjustments do not necessarily occur in step with one another across species types. Interdependent species, such as blooming plants and the pollinators that pollinate them, can generate phenological mismatches when they react differently to the cues provided by the environment. As an illustration, plants may start flowering sooner as a result of warmer temperatures, yet the major pollinators of the plant might not modify their emergence or activity time at the same pace. This disconnection has the potential to have harmful effects on the environment. Any temporal misalignment may result in diminished plant reproductive success and decreased pollinator survival. This is due to the fact that many blooming plants are dependent on particular pollinators for effective reproduction, and pollinators are dependent on floral resources for nourishment. The global reduction of pollinator numbers, which is already being driven by habitat loss, pesticide usage, illness, and invasive species, is a particularly troubling phenomenon, and these mismatches only serve to exacerbate the problem. There is a possibility that climate-induced changes in the synchronisation between plants and pollinators might worsen these reductions, so further endangering biodiversity and ecological services. In agricultural systems, where crop yields frequently depend largely on efficient pollination, the implications extend beyond natural ecosystems and go beyond the scope of natural ecosystems. Therefore, gaining a knowledge of the dynamics of phenological mismatches is not only a worry for the environment, but it is also an issue of ensuring the stability of the economy and the sustainability of food supplies. Under the effect of climate change, the purpose of this research is to investigate the factors that cause phenological mismatches in pollinator-plant interactions as well as the repercussions of these mismatches. The first thing that we do is investigate the climatic elements that have an effect on phenological changes and the reactions that are distinctive to each species. Next, we conduct an investigation into the reported mismatches that exist in a variety of habitats, and then we proceed to analyse the ecological and evolutionary ramifications of these mismatches. In the final part of this article, we will cover various techniques for climate change adaptation and mitigation. These strategies include ecological forecasting, conservation planning, and the creation of agricultural systems that are climate-dependent. We hope that by including different points of view, we will be able to emphasise how important it is to solve phenological mismatches in order to protect biodiversity and make sure that ecological networks are resilient in a world that is warming.

Objective

1. To Find out how pollinators and flowering plants are affected by the shifting timing of biological processes caused by climate change.**.**
2. To Examine how these incongruities have altered ecosystem services, agricultural output, and biodiversity from an evolutionary and ecological perspective.
3. To Analyse the effects of climate change on the Sarus Crane's mating and migration habits, paying special attention to how it is altering their habitat and the food supplies available to them.

Phenological Shifts and Climate Drivers

It has been proven by a great number of studies that phenology is extremely sensitive to fluctuations in temperature, particularly in locations that are classified as temperate. Both Parmesan and Yohe (2003) and Root et al. (2003) discovered that within all taxonomic groups, there is a growing body of data indicating that biological processes like blooming and insect emergence are accelerating as a result of rising global temperatures. The findings of Menzel et al. (2006), who conducted an analysis of long-term phenological records across Europe, demonstrated that the frequency of blooming and leafing events in plants has increased by an average of 2.5 days every decade. On the other hand, different species have varying degrees of sensitivity to climatic signals, which leads to asynchronous changes among organisms that interact with one another (Thackeray et al., 2016).

Mismatches in Pollinator-Plant Interactions

Phenological mismatch is a phenomena that has been seen in a number of well-known pollinator-plant systems. For instance, Burkle et al. (2013) examined historical and present plant-pollinator interactions and discovered that there was a fifty percent decrease in the number of species interactions that occurred over a period of one hundred twenty years in a subalpine meadow located in the Rocky Mountains of the United States. In a similar vein, Kudo and Ida (2013) observed that early snowmelt brought on by climate change accelerated the flowering period of Caltha scaposa in Japan. However, the appearance of its pollinators stayed the same, which resulted in a decrease in seed output. The significance of these findings lies in the fact that they highlight the vulnerability of specialised pollinators and plants that have tight phenological windows.

Ecological and Evolutionary Consequences

According to Memott et al. (2007), phenological mismatches can lead to a reduction in the reproductive success of plants, a drop in the fitness of pollinators, and a disruption and disruption of ecological networks. It is possible for population losses, local extinctions, and alterations in community composition to occur as a result of decreasing temporal overlap between mutualistic partners (Forrest, 2015). When compared to specialists, generalist species have the capacity to adapt more quickly, which might result in biotic homogenisation. Generalist species have a wider range of temporal niches. According to Visser and Gienapp (2019), evolutionary responses, such as improved phenological flexibility or selection for novel mutualisms, continue to be unknown and are bound by generation time and genetic variety.

Implications for Agriculture and Food Security

Beyond the realm of natural ecosystems, the ramifications extend to the realm of agriculture. The pollination of crops by insects is extremely important for the growth of almonds, apples, and blueberries, among other crops. Both Rader et al. (2016) and Potts et al. (2010) conducted research that suggests that asynchronous blooming and pollinator activity may result in decreased yields and economic losses. Farmers are already seeing variable crop production in certain locations, which may be attributed to the fluctuation of the climate and the modifications made to the availability of pollinators.

Mitigation and Adaptation Strategies

For the purpose of mitigating the effects of phenological mismatches, the most recent research has placed an emphasis on the necessity of proactive conservation efforts. A study conducted by Bartomeus and colleagues (2011) highlights the significance of habitat connectivity in facilitating the migration and variety of pollinators. Additionally significant is the incorporation of phenological data into ecological models and the planning of conservation efforts. According to Tang et al. (2016), the capacity to monitor and anticipate mismatches is being improved by the use of tools like as remote sensing, citizen science platforms (such as iNaturalist and Nature's Notebook), and phenological databases.

The Impact of Global Warming on Pollinators and Flowering Plants?

Phenology

Numerous species react to shifts in temperature by modifying their activity and metabolism in response to the change. Therefore, increases in temperature that are caused by human activity have the potential to have an effect on the phenology of both plants and pollinators. A significant amount of information on the magnitude and direction of the phenological responses to rising temperatures was not known until very recently. In point of fact, it had not been demonstrated whether or not natural communities experienced any phenological adjustments as a result of climate change. On the other hand, throughout the course of the past ten years, there has been a growing interest in phenological reactions to climate warming (Rosenzweig et al. 2008), and a significant portion of the information learnt about the consequences of climate warming comes from phenological research. It is common practice in temperate environments to use the beginning of blossoming as a measurement of the coming of spring. It would appear that a great number of plants have responded to rising temperatures by blossoming sooner during the course of the past 20–50 years (Fitter & Fitter 2002; Figure 1). 78% of the time series that were studied throughout Europe revealed evidence of such a tendency, which is in agreement with the data from

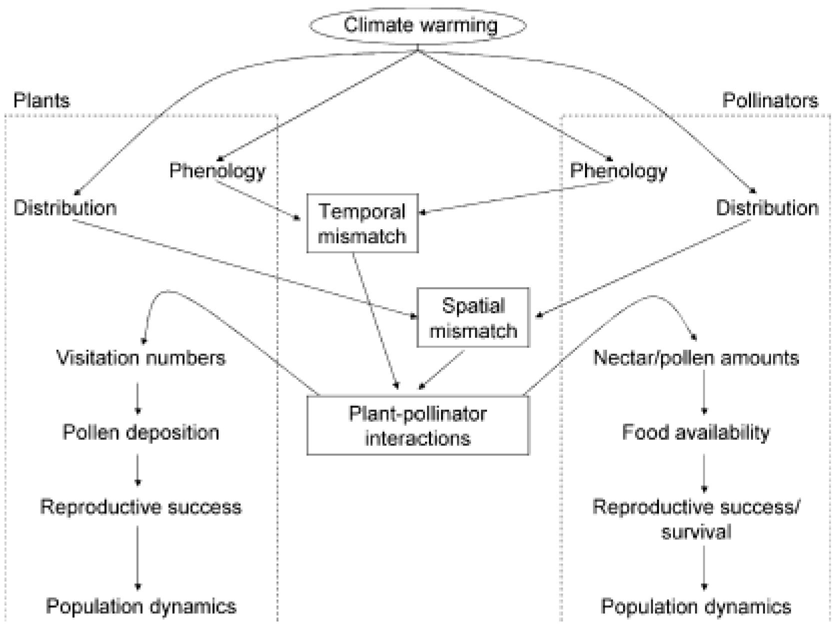

Figure 1 This framework illustrates the potential effects of climate change on plant and pollinator phenology and distribution, as well as the potential resulting temporal and geographical mismatches in plant-pollinator interactions. The lower half of the panels illustrate the projected demographic changes among the mutualistic partners and the factors that will influence them.

sparks et al. (2000) found that other regions of the northern hemisphere was affected. In general, plants that are pollinated by insects respond more strongly to increasing heat than plants that are pollinated by wind. Species that blossom early in the season tend to be the most responsive, which is an indicator that these species have phenologies that are sensitive to temperature. The commencement of flowering appears to be connected with the mean temperature in the month of blooming or the months before to flowering, according to Sparks et al. (2000) and Menzel et al. (2006). This is the general consensus among researchers. Other factors, however, may co-vary with temperature and have a significant role in the patterns that have been found (for more information, see Future Research). In the majority of instances, the responses of blooming onset to increasing temperatures were linear, which may be significant for the interactions that plants have with pollinators. Sparks et al. (2000) discovered significant linearity within the observed range of temperature variations for 24 of 25 British plant species, 23 of which flowered earlier with increased temperatures This is despite the fact that it is obvious that such linear responses cannot continue indefinitely under any circumstances. It is essential to have a comprehensive understanding of the implications of climate change, and the generalisations of species reactions that were discussed before are essential. However, we would like to emphasise that there is a possibility that certain species would not blossom sooner as a result of higher temperatures (for example, 22% of the species that were included in Menzel et al. (2006)). Other possible signals for blooming initiation include photoperiodicity, precipitation, soil humidity, and snow melt, as well as specific combinations of these cues (for example, Lambercht et al. 2007; see also Future Research). blooming can also be triggered by a combination of variables.

Mismatches Between Plants And Pollinators

The occurrence of mismatches

Time (phenological) and space (distributional) mismatches can alter the availability of mutualistic partners, which in turn can disturb plant-pollinator interactions (Fig. 1). When the initial mutualistic partners encounter less habitat sharing, whether in terms of time or distance, it can cause a partial or total decoupling of their trophic relationships, which is known as mismatch. The potential effects of climate change on a finely tuned network of plant pollinators were modelled by Memmott et al. (2007). Between seventeen percent and fifty percent of pollinator species had their food supplies interrupted by temporal mismatch, according to their research. The exact percentage depends on the phenological changes used. They demonstrated that specialised pollinators will likely be the ones to go without food plants due to phenological fluctuations, but that generalist pollinators may also face severe dietary restrictions. Due of pollinators' inability to keep tabs on all of their ancestral hosts, many plant-pollinator associations may become uncoupled as a result of phenological response variability due to climate change. Novel plant-pollinator interactions may evolve as a result of phenological decoupling, as many pollinators visit plants fairly opportunistically. searched for signs of a mismatch between the mutualistic partners by analysing the phenological responses of plants and pollinators to rising temperatures in the Iberian Peninsula. Apis mellifera and Pieris rapae were discovered to have an activity period that was later than their preferred forage species, which meant that they were out of sync with when their primary plant supplies were available. This finding is in line with the phenologies of herbivorous insects, which advance at a faster rate than those of plants, in response to climatic change and the availability of food plants. On the other hand, although bumble bee-pollinated plants experienced a decline in seed-set due to mild spring temperatures, early-flowering plants in Japan accelerated their blossoming during this time. As a result, species and locations may exhibit distinct direct temperature responses and pollination mismatch occurrence rates.

While there is little evidence of regional mismatches in temporal decoupling in ecological interactions generally, no publications have indicated climate-driven spatial mismatches in pollination interactions. Despite this, a study by Devoto et al. (2007) examined the effects of climate-driven range shifts along a rainfall gradient. The researchers discovered that few species would actually go extinct due to these shifts, and the pollination systems seemed to be quite resilient. This was true even when they assumed that pollinators couldn't adapt to different plants, and that plants relied solely on pollinators for reproduction and population persistence.

When compared to other climate change consequences, how serious is the danger of phenological mismatch?

In addition to the possibility of causing phenological mismatch, climate change may also have an effect on pollination by affecting plant and pollinator populations in other ways. Temperature increases, in particular, have the potential to have direct effects (either good or negative) on the development, survival, and reproduction of plants and animals. Alterations in precipitation and an increase in the unpredictability of the climate are other potential factors (Table 1). For some subalpine plants, for instance, dry winters are linked to low flower counts in the summer that follows (Miller-Rushing and Inouye 2009). This suggests that the plants have a limited reproductive potential and that there is a low total resource availability for flower visits in years that are warmer and drier. The early melting of snow raises the possibility that late-spring frosts may cause damage to the flower buds of some plants (Inouye 2008). This, in turn, affects the amount of seeds produced and the amount of food resources that are available throughout the year. A decrease in the population of Parnassius smintheus, an alpine butterfly, has been linked to climatic variability, which manifests itself as severe winter values of the Pacific Decadal Oscillation index. The specific processes that are responsible for this relationship are as follows:

Table 1. Various climatic impacts on plant and pollinator populations, either proven or suggested. Inclusion criteria were limited to research that demonstrated effects on either survival or reproduction. Important studies that have documented or reviewed the phenomena are included for both plants and pollinators. There is a lack of data on pollinators for some impacts.

Type of climate-change effect	Plants	Pollinators
Heat stress	reviewed by Scaven and Rafferty 2013	reviewed by Scaven and Rafferty 2013
Increased frequency of damaging frost	Augspurger 2013, Inouye 2008	Boggs and Inouye 2012
Loss of insulating snow cover	reviewed by Pauli et al. 2013	reviewed by Pauli et al. 2013
Altered precipitation	Liancourt et al. 2012, Peñuelas et al. 2004*	
Phenological mismatch	Kudo and Ida 2013, Thomson 2010	

The cause is unknown; however, it is possible that both desiccation during warm winters and cold exposure during cold winters are implicated. According to Pauli et al. (2013), the loss of insulating snow cover during warmer winters in regions of the world that are typically covered in snow exposes organisms that are overwintering not only to the risk of desiccation but also to the risk of potentially hazardous temperature fluctuations. The overwintering biology of hibernating bees and dormant plants is still largely unstudied, despite the fact that future warming is anticipated to occur disproportionately in winter (IPCC 2007). Declining snowpack may have major consequences on the overwinter survival of hibernating bees and dormant plants. Alterations in the size of the plant or pollinator population as a consequence of any of these factors are just as likely to disrupt the relationships between plants and pollinators as alterations in the phenology of the plant. It has been rather difficult to compare the ecological significance of the direct effects of climate change on plant populations to that of the shifting synchrony between plants and pollinators. This is despite the fact that some of the direct effects of climate change on plant populations have been investigated very thoroughly (Table 1). There is a possibility that this is due to the fact that the species that have been utilised to investigate the physiological effects of warming (which are often wind-pollinated grasses and trees) have not been utilised to investigate the timing of species interactions. When viewed from the point of view of pollinators, the same thing is true: the relative relevance of phenological mismatch and the physiological effects of climate change is unknown. However, this is not surprising given the dearth of evidence about the consequences of mismatch for pollinators. In the absence of any comparison, it is difficult to determine if the attention that has been devoted to phenological mismatch over the course of the past decade (Memmott et al. 2007, Hegland et al. 2009, Fabina et al. 2010) is proportionate to the ecological damage that it poses.

Conclusion

Not only is climate change causing widespread changes to ecosystems, but it is also causing disruptions to the delicate timing that regulates interactions between species, notably between pollinators and blooming plants. This review has brought to light the fact that phenological mismatches, which are caused by asynchronous responses to climatic factors, are becoming more prevalent and constitute a substantial risk to ecological stability, biodiversity, and food security. In response to climate signals such as temperature and precipitation, both plants and pollinators are demonstrating alterations in the events that occur during their life cycles. However, these changes are not always occurring in concert, which results in decreased reproductive success for plants and resource shortages for pollinators. The repercussions of such mismatches extend beyond the scope of individual species and have the potential to impact whole communities as well as the operations of ecosystems. These factors have the potential to result in the dissolution of long-standing mutualisms, a decrease in the provision of pollination services, changed relationships between species, and the possibility of extinction cascades. Because of the high degree of dependence that many crop species have on animal pollinators for both productivity and quality, agricultural systems are particularly susceptible to attack. In spite of the rising amount of information, there are still significant knowledge gaps about the long-term evolutionary significance of these mismatches and the potential of both plants and pollinators to adjust to new environments. Furthermore, many of the studies that are currently available have a geographical bias towards temperate regions, which highlights the necessity of doing more extensive study on a worldwide scale, particularly in biodiversity hotspots and tropical ecosystems that are under-represented. Investing in integrated monitoring networks, expanding phenological databases, and incorporating mismatch risks into conservation and agricultural planning are all essential steps that must be taken into consideration in order to overcome these difficulties. The enhancement of habitat connectivity, the diversification of agricultural systems, the preservation of generalist pollinators, and the promotion of climate-resilient plant species are all potential solutions. In addition, community science efforts and ecological modelling have the potential to play significant roles in monitoring changes and predicting future situations. In conclusion, in order to effectively address the ecological issue of phenological mismatches, it is necessary to use a multidisciplinary strategy that links the fields of sustainability science, ecology, conservation biology, and agriculture. In order to protect the critical ecosystem services that pollinators and plants offer for human and environmental well-being, we must first reduce the effects of climate change on interactions between pollinators and plants. This can only be accomplished by coordinated worldwide efforts.

References

[1] Bartomeus, I., Ascher, J. S., Wagner, D., Danforth, B. N., Colla, S., Kornbluth, S., & Winfree, R. (2011). Climate-associated phenological advances in bee pollinators and bee-pollinated plants. *Proceedings of the National Academy of Sciences*, 108(51), 20645–20649. https://doi.org/10.1073/pnas.1115559108

[2] Burkle, L. A., Marlin, J. C., & Knight, T. M. (2013). Plant-pollinator interactions over 120 years: Loss of species, co-occurrence, and function. *Science*, 339(6127), 1611–1615. https://doi.org/10.1126/science.1232728

[3] Forrest, J. R. (2015). Plant–pollinator interactions and phenological change: What can we learn about climate impacts from experiments and observations? *Oikos*, 124(1), 4–13. https://doi.org/10.1111/oik.01386

[4] Kudo, G., & Ida, T. Y. (2013). Early onset of spring increases the phenological mismatch between plants and pollinators. *Ecology*, 94(10), 2311–2320. https://doi.org/10.1890/12-2003.1

[5] Memmott, J., Craze, P. G., Waser, N. M., & Price, M. V. (2007). Global warming and the disruption of plant–pollinator interactions. *Ecology Letters*, 10(8), 710–717. https://doi.org/10.1111/j.1461-0248.2007.01061.x

[6] Menzel, A., Sparks, T. H., Estrella, N., Koch, E., Aasa, A., Ahas, R., … & Scheifinger, H. (2006). European phenological response to climate change matches the warming pattern. *Global Change Biology*, 12(10), 1969–1976. https://doi.org/10.1111/j.1365-2486.2006.01193.x

[7] Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, 421(6918), 37–42. https://doi.org/10.1038/nature01286

[8] Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: Trends, impacts and drivers. *Trends in Ecology & Evolution*, 25(6), 345–353. https://doi.org/10.1016/j.tree.2010.01.007

[9] Rader, R., Bartomeus, I., Garibaldi, L. A., Garratt, M. P. D., Howlett, B. G., Winfree, R., … & Woyciechowski, M. (2016). Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences*, 113(1), 146–151. https://doi.org/10.1073/pnas.1517092112

[10] Root, T. L., Price, J. T., Hall, K. R., Schneider, S. H., Rosenzweig, C., & Pounds, J. A. (2003). Fingerprints of global warming on wild animals and plants. *Nature*, 421(6918), 57–60. https://doi.org/10.1038/nature01333

[11] Tang, J., Körner, C., Muraoka, H., Piao, S., Shen, M., Thackeray, S. J., & Yang, X. (2016). Emerging opportunities and challenges in phenology: A review. *Ecological Indicators*, 61, 17–30. https://doi.org/10.1016/j.ecolind.2015.09.005

[12] Thackeray, S. J., Henrys, P. A., Hemming, D., Bell, J. R., Botham, M. S., Burthe, S., … & Wanless, S. (2016). Phenological sensitivity to climate across taxa and trophic levels. *Nature*, 535(7611), 241–245. https://doi.org/10.1038/nature18608

[13] Visser, M. E., & Gienapp, P. (2019). Evolutionary and demographic consequences of phenological mismatches. *Nature Ecology & Evolution*, 3(6), 879–885. https://doi.org/10.1038/s41559-019-0880-8

[14] Rosenzweig, C., Karoly, D., Vicarelli, M., Neofotis, P., Wu, Q., Casassa, G. et al. (2008). Attributing physical and biological impacts to anthropogenic climate change. Nature, 453, 353–357.

[15] Fitter, A.H. & Fitter, R.S.R. (2002). Rapid changes in flowering time in British plants. Science, 296, 1689–1691.

[16] Roy, D.B. & Sparks, T.H. (2000). Phenology of British butterflies and climate change. Glob. Change Biol., 6, 407–416.
[17] Menzel, A. & Fabian, P. (1999). Growing season extended in Europe. Nature, 397, 659.
[18] Memmott, J., Craze, P.G., Waser, N.M. & Price, M.V. (2007). Global warming and the disruption of plant-pollinator interactions. Ecol. Lett., 10, 710–717.
[19] Devoto, M., Zimmerman, M. & Medan, D. (2007). Robustness of plant-flower visitor webs to simulated climate change. Ecol. Aust., 17, 37–50.
[20] Miller-Rushing, A.J. & Primack, R.B. (2009). Global warming and flowering times in Thoreaus concord: a community perspective. Ecology, 89, 332–341.