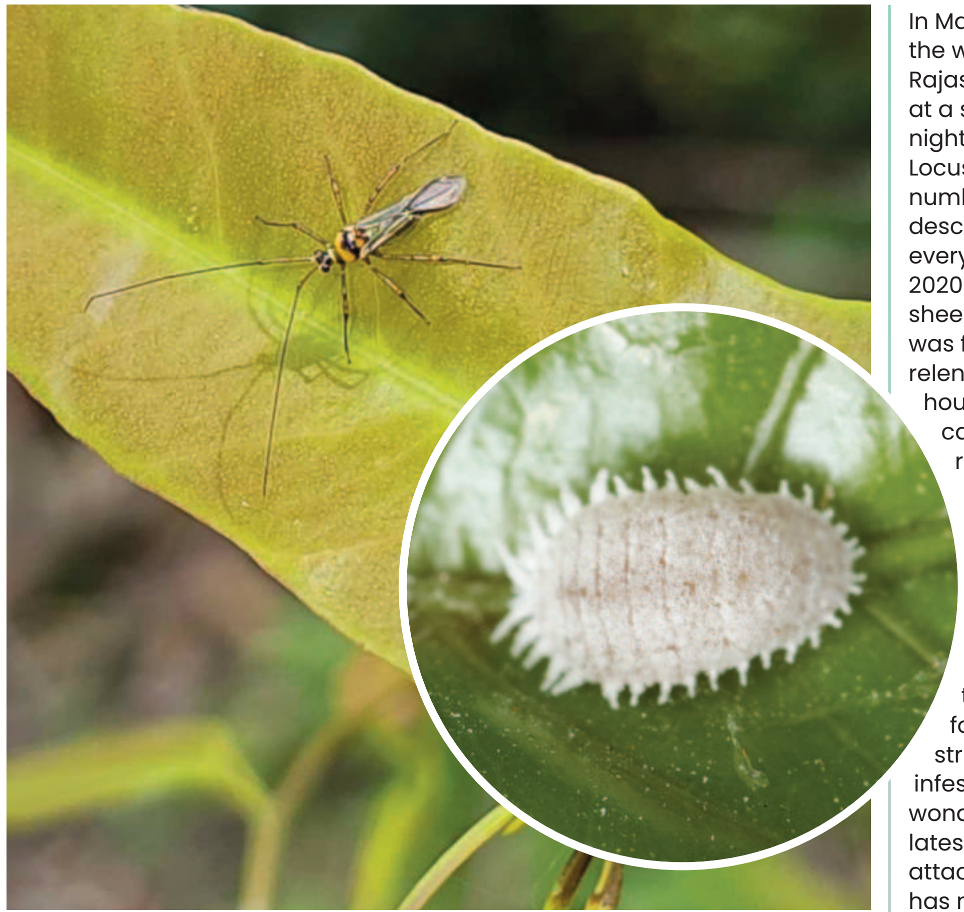

Figure 1. *Helopeltis theivora* (Tea Mosquito Bug). Photo: Dr Srikumar Kotian; Inset: *Planococcus* sp. Photo: Copyright Dr Deepak Deshpande

Climate change and insects: We don’t know enough

Much work has been done on the impacts of climate change on insects, particularly in Europe and the USA, and yet the impacts are arguably more immediately catastrophic in other regions. So, it is nice to hear from one of our Indian members on the subject. Encouraged by the RES Rep for India, Sajidha Mohammed, Femi Ezhuthupallickal Benny reports on well-known climate change concerns but from an Indian perspective. We are always delighted to hear from our overseas members. Editors.

Ezhuthupallickal Benny Femi
Insect Biosystematics and Conservation Laboratory
Ashoka Trust for Research in Ecology and the Environment (ATREE)
Bangalore, India
femi.benny@atree.org

In May 2020, as the sun rose over the western Indian state of Rajasthan, farmers looked in horror at a scene straight out of a nightmare. Swarms of Desert Locusts (*Schistocerca gregaria*), numbering in the millions, descended on their fields, devouring everything in their path (Joshi *et al.*, 2020). The sky was darkened by the sheer number of insects, and the air was filled with the sound of their relentless munching. In a matter of hours, crops that had been carefully tended for months were reduced to stubble. The locusts, driven by a combination of weather conditions and their natural migration patterns, have been wreaking havoc across India and other parts of South Asia in recent years, causing widespread damage to agriculture and threatening food security. As authorities struggle to contain the infestation, farmers are left to wonder how they will survive this latest blow to their livelihoods. An attack of the May 2020 magnitude has not happened for 26 years. What changed in these years and what triggered the attack?

As temperatures rise, weather patterns shift, and habitats are altered, insects are facing a myriad of challenges that threaten their survival. Climate change and its effect on insects are complex and multifaceted, and while we have some understanding of their causes and effects, there is still much that we don’t know. Research has shown that climate change can have a significant impact on insect populations (Ladányi and Horváth, 2010). For example, warmer temperatures can affect the timing of insect life cycles, such as hatching and pupation, which can have cascading effects on food availability and reproductive success. There are still many unanswered questions in this context. For instance, it’s not entirely clear how different insect species are affected by climate change, or how interactions between species are impacted. Also, the effects of climate change on insect populations may vary depending on the region and ecosystem. Another challenge is that insect populations are notoriously difficult to study and monitor, and many species have not been well documented. This makes it challenging to track changes in populations over time and to identify the underlying causes.

Insects are vital in most ecosystems. They are crucial in determining the species composition of any habitat. Their roles as pollinators, organic matter decomposers, soil nutrient recyclers, and food sources for diverse wildlife make them critical for ecosystem balance and global economies. However, many insect species have been declining at an alarming rate in recent years, whilst several pest species have produced outbreaks. Insects are particularly sensitive to environmental changes, and their instability is an indication of broader ecological imbalances. Scientists are still trying to understand the causes of declines and periodic outbreaks, but climate change is emerging as a leading culprit.

Impact of climate change

Insects are bearing the brunt of the profound consequences brought about by climate change. For example, the untimely birth of immature stages might result in them lacking adaptations to thrive in their novel environment (Sgrò *et al.*, 2016). In areas where winters are normally cold, warm temperatures have detrimental effects on insect diapause, mainly due to the loss of resistance to cold winter conditions.

The existence of insect species in any particular habitat is driven by patterns of temperature, relative humidity, solar radiation and wind. Changes in these abiotic factors impart direct effects on insect populations (Mukhtar *et al.*, 2022). Also, these changes indirectly affect insects by influencing the availability and abundance of food resources, natural enemies, competitors and mutualists, thereby influencing biotic interactions among species. Changes in precipitation patterns can affect the availability of resources for insects, such as nectar and pollen. Extreme weather events, such as droughts or floods, can also disrupt insect populations, alter the availability of food and habitat, and increase the spread of insect-borne diseases. As temperatures warm, insects are moving into new regions, which can disrupt the balance of ecosystems. Also, rising temperatures may allow invasive species to expand their geographic ranges and outcompete native insects for resources. This can have a ripple effect throughout the food chain.

The major and currently understood responses of insects towards climate change are range shift as well as outbreak or breakdown. The implications of these responses are yet to be completely understood.

Phenology

Phenology refers to the timing of recurring biological events in response to seasonal and climatic cues, such as temperature, precipitation and daylength. Insects are highly sensitive to phenological changes and often rely on environmental cues to synchronise their life-cycle events with optimal conditions for growth, development and reproduction. Climate change has altered these cues and disrupted the synchrony between insects and their environment, leading to changes in phenology across many species.

Earlier emergence of overwintering insects in spring is a notable example. Warmer temperatures can accelerate the development of immature stages and reduce the time spent in diapause or dormancy. As a result, many insect species are emerging earlier in the year than they did in the past, sometimes by several weeks or even months. For example, the Tea Mosquito Bug (*Helopeltis theivora*) (Fig. 1), the Citrus Mealybug (*Planococcus citri*) and the Common Fruit Fly (*Drosophila melanogaster*) emerge earlier than usual and thus have the potential for more generations per year, thereby damaging crops even more.

Earlier emergence can have cascading effects on the rest of the life cycle and interactions with other species. If the timing of emergence is not synchronised with the timing of flowering of host plants, it can reduce the availability of food and disrupt pollination services. This can have negative consequences for both the insect and the plants, as well as for the ecosystem as a whole.

In addition to earlier emergence, climate change can affect the timing of other life-cycle events, such as reproduction and migration. For example, warmer temperatures can advance the onset of egg-laying in butterflies, beetles and moths, and lead to more generations per year. This can increase the population density of some species and enhance their ability to adapt to changing conditions. On the other hand, it can also increase the risk of competition, predation and disease transmission, as well as reduce the quality of offspring. Climate change can also alter the timing of migration in some insect species, such as Monarch (*Danaus plexippus*) butterflies and dragonflies. Warmer temperatures can trigger earlier and longer migrations, as well as alter the timing of reproduction and food availability at the migration destination. This can affect the distribution and abundance of insects across different regions and ecosystems, and potentially disrupt interactions with other species.

Range shift

Range shift refers to the movement of a species’ geographic distribution towards a new location. Climate change induces shifts in temperature and precipitation patterns, leading to changes in the timing and duration of seasons (Walther *et al.*, 2002). As temperatures and precipitation patterns change, the suitable habitat for a species may shift, forcing it to move in order to remain within its preferred temperature and moisture range as well as to track its food source. Many butterfly species have shifted their ranges towards higher latitudes or altitudes in response to warming temperatures (Chandra *et al.*, 2019). For example, over the last few decades, populations of the Indian Skipper (*Spialia galba*) butterfly (Fig. 2) have shifted by as much as 2,000 meters uphill in the Himalayas. The movement of the butterfly to higher altitudes could disrupt the pollination networks that exist in these habitats, potentially leading to declines in plant populations and reduced biodiversity.

Outbreak or breakdown?

The response of insects to climate change falls within two extremes – outbreaks to breakdowns. The outbreak of Desert Locust in Rajasthan and Gujarat and Asian Citrus Psyllid (*Diaphorina citri*) (Fig. 3) in different parts of India are classic examples. Breakdowns occur when populations crash, resulting in local extinctions. The decline in insect populations has significant implications for ecosystems and human society. The increase in extreme weather

Figure 2. *Spialia galba* (Indian Skipper). Photo: Dr Jafer Palot

events, such as floods, droughts and hurricanes, can destroy habitats and disrupt migration patterns, leading to significant declines in populations.

Warmer winters can enable vulnerable insect stages to survive more readily, leading to more rapid population growth in spring and increased outbreaks in summer. For example, warmer temperatures can accelerate the development of mosquito larvae and increase the number of generations per year, leading to higher population densities and greater risk of disease transmission. However, some insect species may be negatively affected by warmer winters due to faster depletion of resources. Many insects rely on specific plants for food and shelter, but changes in weather patterns are disrupting the timing of plant growth and blooming, leaving insects without the resources they need to survive. Unpredictability of the onset of rains due to climate change affects the periodicity of insect emergence (Ayieko and Ndong'a, 2010). These effects vary from species to species, so generalised conclusions cannot be made.

We don't know enough

While the role of climate change in insect declines and outbreaks is becoming increasingly clear, there is still much we do not know. For example, scientists are still trying to understand the specific mechanisms by which climate change is impacting insect populations. The effect of climate change on insect range, population dynamics and impacts of these changes on communities and ecosystems are yet to be understood in detail. Insect responses to cope with climate change-driven stress are still understudied.

A major issue is the lack of data on insect populations in many parts of the world, including India. Despite being home to several globally significant biodiversity hotspots, such as the Western Ghats and the Eastern Himalayas, the insect biodiversity of India remains largely underexplored and understudied. While there are discussions happening on a global scale on how insects are affected by climate change, we are still at the stage of exploring and describing new species in India. The sheer number of new species being described from these regions serves as a striking example of the vast unknown insect diversity that awaits discovery and further scientific investigation (Ranjith and Priyadarsanan, 2023). The urgency to expand research efforts on the impact of climate change on insects becomes even more apparent in tropical regions. While long-term data and evidence of changes in insect populations predominantly come from Europe and North America, countries with the greatest insect biodiversity and the potential for significant agricultural implications, such as those in the tropics, remain understudied.

Although there have been some studies on insect decline in certain regions, we do not have a comprehensive understanding of the state of insect populations globally. Little is known about other impacts like the reason behind apparently random outbreaks, phenology changes *etc*. This lack of data makes it challenging in relation to fully understanding the scale of the problem and developing effective solutions.

ARTICLE

Figure 3. The Asian Citrus Psyllid (*Diaphorina citri*). Nymphs pass through five instars during their development. Photo: copyright Dr Deepak Deshpande

Hence, this article is intended as a compelling call for increased research in tropical countries, highlighting the crucial need to bridge the knowledge gap and gain a comprehensive understanding of what is happening in areas with high insect diversity, where the effects of climate change on insects may be most pronounced. By directing attention and resources toward these regions, we can better comprehend the challenges at hand and develop effective strategies to mitigate the potential impacts on both local ecosystems and global food production. This will likely involve several steps, including reducing greenhouse gas emissions, protecting and restoring habitats, and implementing sustainable farming practices.

Lastly, the 'cute and cuddly' bias is playing out in the attention given to insects and climate change studies. While many people express concern over the plight of charismatic species such as Polar Bears and whales, insects are often overlooked. However, these small creatures are essential to the health of our ecosystems and play a crucial role in pollination, decomposition and pest control. The impact of climate change on insects is therefore a matter of urgent concern. Failure to recognise this could disrupt entire food webs and damage the very foundations of our natural world. It is time for us to broaden our perspectives and take action to protect all non-pest species, regardless of their appearance, from the effects of climate change.

References

Ayieko, M.A. and Ndong'a M.F. (2010) *Journal of Cell and Animal Biology* **4**, 112–118.
Chandra, K. *et al.* (2019) *Zoological Survey of India,* 1–457.
Joshi, M.J. *et al.* (2020) *Agriculture and Food: E-Newsletter* **2**, 691–693.
Ladányi, M. and Horváth, L. (2010) *Applied Ecology and Environmental Research* **8**, 143–152.
Mukhtar, M *et al.* (2022) *Climate Change Alleviation for Sustainable Progression*. 1st edition. CRC Press, USA.
Ranjith, A., and Priyadarsanan, D.R. (2023) *Zootaxa* **5278**, 461–492.
Sgrò, C.M. *et al* (2016) *Annual Review of Entomology* **61**, 433–451.
Walther, G.R *et al* (2002) *Nature* **416**, 389–395.