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1. Impact of Climate Change on Insect Pests

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Abstract:

Climate change has emerged as a pivotal force reshaping ecosystem and impacting various interactions, notably those involving insect pests. As the temperature rise, insects respond by altering their developmental rates, leading to shifts in phenology and geographic ranges. Changes in precipitation patterns influence pest distribution and abundance, driving novel interactions with host plants and predators. Climate change-induced shifts in temperature and precipitation patterns are amplifying plant stress, creating favourable conditions for increased pest populations. Additionally, evolving weather patterns impact insect population dynamics, potentially exacerbating pest outbreaks. The behavioural shifts of insect pests, brought about by climate change, can disrupt pest management strategies.

However, these changes also prompt opportunities for innovative mitigation approaches. Natural selection pressures arising from changing environments drive pest adaptation and evolution, impacting pest-induced alterations in speciation and genetic makeup can lead to the emergence of new pest biotypes. Mitigation and management strategies in the face of changing pest dynamics require a climate-smart approach. By embracing climate-smart agricultural practices and innovative pest control methods, stakeholders can navigate the challenges posed by changing pest dynamics in rapidly warming world.

Keywords:

Climate change, Insect, Pest, Adaptation, Weather, Temperature, Evolution

1.1 Introduction:

Climate change stands as a major worldwide dilemma in our era, carrying extensive repercussions for both ecosystems and human communities. The rapid rise in greenhouse gas emissions, primarily driven by human activities, has led to unprecedented changes in temperature, precipitation patterns, and overall climatic conditions worldwide. These changes occurring within the earth's climate system have significant effects on a range of ecological mechanisms, including the relationships between insects and their surroundings.

The climate plays a vital role in shaping the features and arrangements of both controlled and natural systems, encompassing aspects such as water resources and hydrology, cryology, marine and freshwater ecosystems, terrestrial ecosystems, forestry, and agriculture (Grimm et al., 2013; Peñuelas et al., 2018; Poff et al., 2002).

Numerous studies have highlighted the critical role of climate in shaping the distribution and behaviour of insect pests. Climate variables, such as temperature, humidity, and rainfall, directly influence the life cycle, reproductive rate, and geographic ranges of insects (T. Jaworski & Hilszczański, 2013). Moreover, climate-related changes in host plant phenology and quality can significantly affect the abundance, distribution and survival of insect pests (Peace, 2020). Consequently, alterations in climate conditions can disrupt the delicate balance between insects, their natural enemies, and the plants they rely upon.

As the global climate continues to increase, these complex interactions are likely to be further disrupted, leading to substantial consequences for pest management strategies and agricultural productivity. Rising temperatures can accelerate insect development rates, resulting in shorter generation times and increased pest population (Harvey & Dong, 2023). Also, changing precipitation patterns may favour the proliferation of certain pest species by providing favourable conditions for their reproduction and survival.

The impact of climate change on insect pests extends beyond agriculture and has implications for ecosystem dynamics also. Insects plays a crucial role as pollinators, decomposers, and prey for other organisms. Changes in the abundance, distribution and phenology of insect pests can disrupt various ecological interactions and have cascading effects on other species and ecosystem balance (Buckley, 2022). In this chapter we have discussed the impact of climate change on insect pests. Specifically, we delve into the effects of rising temperatures, shifting precipitation patterns, and evolving weather phenomena on the behaviour, adaptation, and evolution of these pests. Moreover, we scrutinize the intricate interplay between changing climatic conditions and insect pest's genetic makeup, speciation, and overall population dynamics.

1.2 Temperature Changes and Insect Pest Distribution:

Human activities since the industrial revolution have led to the emission of carbon dioxide and other greenhouse gases into the atmosphere, resulting in alterations to the earth's climate. The temperature is being affected more and more by the use of fossil fuels, cutting down of forests, and farming of livestock. Insect distribution can be affected significantly by temperature change. The distribution of insect pests can be affected in several ways by temperature change.

With rising temperatures, there's a potential for insect pests to enlarge their geographical distribution and inhabit regions they couldn't previously thrive in (Battisti & Larsson, 2023). Increasing temperature can enable pests to colonize new areas, causing damage to previously unaffected crops or ecosystems (Pureswaran et al., 2018). The temperature of insects is controlled by the external environment, which means they are ectothermic organisms (Abram et al., 2017). The metabolic rate of these animals can be accelerated by higher temperatures consequently, the population in affected areas can increase and pest pressure will increase (Skendžić, Zovko, Živković, et al., 2021). Insects life cycles can be disrupted and their seasonal patterns altered by changes in temperature (Harvey, 2020). Warmer winter may allow increased overwintering survival and earlier emergence in the spring. This can lead to larger growing season for pests and increased damage to crop or vegetation (Bale et al., 2002). Insects typically have lost plants or specific ecosystem they rely on for survival. With temperature change, the availability and suitability of these host plants may shift. This can lead to change in insect pest distribution as they search for new resources or adapt to different plant species (Skendžić, Zovko, Živković, et al., 2021).

Temperature change not only affects insects' pests but also their natural enemies, such as predators and parasitoids (Jactel et al., 2019). Warmer temperature may favour the development and reproduction of certain insect pests, while negatively impacting the survival or effectiveness of their natural enemies. This can disrupt the natural control of pest populations and potentially lead to increased pest damage (Harvey et al., 2020). Overall, temperature change can have complex and varies effect on insect pest distribution. It is important to closely monitor these changes and understand their implications for managing insect pests in agricultural and natural ecosystem.

1.2.1 Changes in Precipitation Patterns and Insect Pest Abundance:

The majority of scientists in the world concur that global warming has impacted rainfall patterns. Changes are being made in the quantity, distribution, and timing of precipitation events, such as rain, snow, and sleet. The number of precipitation events tends to be less frequent, but their intensity tends to be higher. Changes in precipitation patterns can also significantly impact insect pest abundance. Precipitation patterns can have an impact on the exact conditions that insects need to develop and reproduce. Precipitation changes, such as more frequent or strong rainfall events or protracted droughts, might change the number of pest breeding sites that are available. An increase in mosquito numbers might result from excessive rain creating standing water that makes it easier for mosquitoes to spawn (Filho et al., 2019). Insects depend on host plants for survival and sustenance, and precipitation patterns can have an impact on both their number and health. Both the development and quality of host plants can be impacted by changes in rainfall since these changes can modify the amount of moisture and nutrients in the soil. This may alter how many and how suitable host plants are for pests, thereby affecting pest populations.

Changes in precipitation patterns can also affect the population and behavior of natural enemies such as parasitoids and predators (Eigenbrode et al., 2015). This disruption in natural enemy population can result in increased pest abundance and damage. Insect pest can rely on wind or water for dispersal to new areas. Shifts in precipitations pattern can affect these dispersal mechanisms and potentially influence the spread and distribution of pests. For example: heavy rainfall can assist windborne spread of certain pests, enable them to colonize new locations (Skendžić, Zovko, Pajač Živković, et al., 2021). Insects have evolved to respond to specific environment cues, including precipitation pattern. Alteration in timing and amount of rainfall can disrupt insect behavior and life cycles. For instance increased or prolonges period of rainfall can lead to delay in emergence, mating or oviposition, affecting the population dynamics and abundance of insect pests (Nayak et al., 2020).

1.2.2 Extreme Weather Events and Their Influence on Insect Pests:

Extreme weather events such as hurricanes, floods, droughts, heat waves and severe storm can have significant impact on insect pests. These events can either increase or decrease the population size and distribution, depending on the specific conditions and adaptability of pest species (Skendžić, Zovko, Živković, et al., 2021). Extreme weather events can disrupt the life cycle of insect pest by affecting their breeding, development and survival. For example: flooding can wash away insect's eggs or larvae, reducing their population (Shrestha, 2019). Similarly heat waves can accelerate the growth and reproduction of pests, leading to population blooms. Extreme weather events can alter the geographic distribution of insect's pests. Warmer temperature and change in precipitation pattern can expand the range of pests, causing damage to crops, forests and ecosystems. Certain extreme weather events such as drought can weaken the natural defense of plants against pests. Plants stressed by drought conditions become more vulnerable to insect infestation, as they may reduce ability to tolerate pest feeding. This can lead to increased pest outbreak and damage to crops (War et al., 2016)

Mosquitoes and ticks, and other insects, serves as vectors for a range of illnesses, including malaria, dengue fever, and lyme disease (Baylis, 2017). Extreme weather events that create favorable conditions for these vectors, like high temperature and heavy rainfall, can lead to increasing the risk of malaria and other mosquito borne disease(Anand et al., 2014). Extreme weather events can also affect the effectiveness of pest control measure. Heavy rainfall can wash away insecticides, reducing their efficacy while strong winds can disperse beneficial insects that help control pest populations. Moreover, extreme weather events may limit access to affected areas, hampering pest management efforts and increasing the risk of pest outbreak.

1.2.3 Changes in Insect Pest Behaviour and Activity Patterns:

Climate change can have significant impact on insect pest behaviour and activity patterns. Climate change can alter the suitable habitat for insects. As temperature increase, pest may expand their geographic range and invade new areas. For example there are certain pests that were previously limited to warm tropical region may now be able to survive and thrive in more temperate regions due to milder winters (Keutgen, 2023).

Warmer temperature and longer growing season can result in extended breeding season for insects. This allows them to produce more generations per year, leading to larger populations and increased damage to crops, causing economic losses. Climate change can disrupt the timing of life cycle events. Such as emergence, migration and hibernation, for many insects. Warmer temperature can cause insects to emerge earlier in the spring, leading to mismatch with the availability of their food source or pollinators. This can have negative consequences for both the insects and the plant they interact with (Id & Holzschuh, 2019).

Insects may modify their behavior and activity pattern in response to climate change. For example: Some pests may exhibit increased feeding rates or adapt to warmer temperature by changing their daily activity schedules. These changes can have implications for crop damage, disease transmission, and ecosystem functioning. Climate change can create more favorable conditions for insect pest, allowing their population to grow their population rapidly and cause outbreaks. Higher temperatures and increased humidity can accelerate their growth and reproduction rates. Additionally, warmer winter may not provide adequate cold period to suppress pest population, leading to increased survival and expanding range. The relationships between insect pests and the plants they feed on can be influenced by climate change (Jactel et al., 2019). Pests may respond differently to change in temperature, precipitation and atmospheric carbon dioxide level, which can impact their feeding behavior, reproduction, and host plants selections. Such changes can have cascading effects on plant health, crop yields, and ecosystem dynamics.

1.2.4 Adaptation and Evolution of Insect Pests in Response to Climate Change:

Insect pests have the ability to adapt and evolve in response to climate change. Insect pest can exhibit phenotypic plasticity, which refer to their ability to adjust their characteristics and behavior in response to environmental cues. Change in temperature, precipitation and other climate factors can trigger plastic response in insect pests, such as altered feeding behavior, reproduction rates and development time.This phenotypic plasticity allows pests to exploit new resources and survive in changing conditions. Overtime insect pest can undergo genetic adaptation to cope with changing environments (Armin, 2010). Individual with genetic variations that confer better survival and reproduction success in the new climate conditions are more likely to pass on their genes to future generations. This can lead to the development of populations with traits that are better suited to the changing climate. Insect pest have short generation times and high reproductive rates, which can facilitate rapid evolution. This allows them to respond quickly to selective pressure imposed by climate change.

Pest may evolve to have different environmental threshold in response to changing temperature pattern, enabling them to synchronized their life cycles with the availability of host plants or favorable conditions. Climate change can create suitable environment for insect pest in regions that were previously unfavorable. Pests may rapidly expand their ranges and colonize new areas where they are not previously present. This range expansion can involve the evolution of traits that enable pests to survive and reproduce in the noble environments, such as adaptation to different temperature regimes or host plant species. Insect pest can also evolve in response to the response of their host plants to climate change. A pest's selective pressure can be affected by changes in plant phenology. Due to climate change, pests may evolve mechanisms for overcoming plant defenses or exploiting novel host plant species. Although insect pests are capable of adapting and evolving, they can be influenced by a number of other factors besides climate change, such as available habitat, interactions with other organisms, and the speed and magnitude of climate change. Furthermore, this evolutionary response can have both positive and negative implications for agriculture, ecosystem, and human health, and must be carefully managed and monitored.

A. Speciation and Genetic Alterations:

Insect pests can also undergo speciation, which is the formation of new species, due the impact of climate change. Speciation can also occur when population of insect pest become isolated from one another and diverge genetically, resulting in the development of distinct species. Changing in climate and habitat availability can cause insect pest to come into contact with other related species that may not have previously encountered. Hybridization, the interbreeding between different species, can occur as a result of these encounters. in some areas, hybrid individual may exhibit higher fitness in the new environmental conditions, leading to the establishment of hybrid population that can evolve into new species.

Climate change can lead to genetic alterations in insect pest through various mechanisms. Climate change can impose new selective pressure on insect pests favoring individuals with specific genetic mutation that enable them to cope with changing conditions. Climate change can alter the distribution and migration pattern of insect pest. As populations move and encounter new environments gene flow can occur between different populations.

These genetic variations may contribute to adaptations and allow pest to persist and thrive in the face of changing climatic conditions. Insects have the ability dynamically adjust their genetic response to environmental changes through epigenetic modifications and change in gene expression (Villagra & Frías-Lasserre, 2020). This flexibility in gene regulations allow insect pest to rapidly respond to climate change and adjust their phenotypes, such as altering their environment rate to tolerance to extreme temperatures, without necessary undergoing genetic mutations.Genetic introgression: hybridization events can occur, resulting in genetic introgression where gene from one species is incorporated into the gene pool of another species. These introgressed genes may bring new adaptive trait or enhance genetic diversity, potentially influence the evolutionary trajectory of pest populations.

B. Plant Stress and Economic Loss:

Agriculture is essential to supplying the world's expanding food demand, but it faces ongoing biotic and abiotic stress factors. Among these, drought stress stands out as a serious risk to agricultural productivity and causes financial losses in the agricultural sector (Ahluwalia et al., 2021). Farmers' and forest managers' financial losses are exacerbated by the combined effect of biotic and abiotic stress factors, which offers additional difficulties for forestry and agriculture (Fahad et al., 2017; Teshome et al., 2020). The production of crops is consistently impacted by several factors, such as limited land sizes, inadequate mechanization, and the existence of diverse abiotic and biotic stresses (Dev, 2012). Apart from the challenges discussed earlier, different crops encounter diverse types of biotic and abiotic pressures. Biotic stress is any stress brought on by living things like bacteria, fungus, viruses, insects, and other creatures of the night. Even after being exposed multiple times, the plant does not develop a resilient defence against biotic stress. This is why pre- and post-harvest losses are primarily caused by biotic stress (Lal et al., 2023). Abiotic stress refers to problems like oxidative stress, metal toxicity, high soil salinity, and drought. These stresses possess the capability to cause lasting damage to a plant, leading to hindered growth, disrupted metabolic processes, reduced productivity, and alterations in genetic patterns that lead to mutations in progeny (Zaidi et al., 2014). One such abiotic stress that significantly lowers agricultural yield each year is drought stress. Drought conditions are brought on by a lack of water due to a decrease in rainfall and an increase in the frequency of dry spells. Often, in addition to its negative consequences, drought is accompanied with salt, heat, and disease invasion (Hossain et al., 2016). Plants undergo various physiological and structural alterations due to stress, encompassing reduced rates of transpiration and photosynthesis, adaptations in osmotic balance, inhibited growth of roots and shoots, elevated production of reactive oxygen species, modifications in stress-related signalling pathways, and accelerated senescence (Heim, 2002).

C. Crop Losses and Economic Impacts:

Crop losses have a substantial financial impact on agriculture and food security. Reductions in yield are caused by a variety of events, such as weed infestations and floods, which costs farmers and the agricultural industry money. Natural disasters like floods pose a serious threat to world agriculture. According to a study to evaluate the effects of floods on crop production, floods significantly reduce the yield of important crops. According to the study, global average yield losses over return periods longer than 10 years were predicted to be around 4% for soy, 3% for rice, 2% for wheat, and 1% for maize. Between 1982 and 2016, these losses led to a total output loss of 5.5 billion dollars in the United States. Following droughts as the second-worst agricultural calamity, floods cost the developing countries $21 billion in lost crops and livestock between 2008 and 2018. To increase the agricultural system's flood resilience and guarantee food security, effective management of flood hazards is essential (Kim et al., 2023).

Weeds are infamous for lowering yields and having serious economic effects on agriculture. An Indian study calculated the production and monetary losses brought on by weeds in important field crops. For crops like soybean (50–76%) and groundnut (45-71%), potential yield losses were shown to be significant. Rice incurred the highest real economic damages, amounting to $4420 million, trailed by wheat at $3376 million, and soybean $1559 million. The actual economic damage caused by weeds in India's ten main crops was calculated to be at USD 11 billion. Achieving sustainable agricultural goals requires lowering exposure and vulnerability to weeds, which is a crucial component of crop productivity (Gharde et al., 2018).

1.2.5 Economic Consequences of Climate- Induced Insect Pest Outbreaks:

The interplay between plants, pathogens, pests, and the environment holds significant importance in the occurrence of plant diseases and pest infestations. In addition, bark beetle outbreaks frequently accompany other biotic and abiotic forest disturbances. As a result of worldwide climate change and related natural disruptions, there has been a noticeable rise in the negative impacts and losses caused by insect infestations in recent times (Ivantsova et al., 2019).

Pathogens, insect pests, temperature extremes, and nutrient deficits are just a few of the biotic and abiotic stress factors that together cause significant output losses in both agriculture and forestry (Ayres & Lombardero, 2000; Weed et al., 2013). Studies have indicated that abiotic stresses including temperature extremes, drought, and nutrient deficits can cause production losses ranging from 51% to 82% whereas biotic stresses like pests, diseases, and weeds can result in yield losses ranging from 17.2% to 30.0% in important food crops. Similar to this, large biotic and abiotic pressures in forestry have had an impact on important forest regions, leading to a drop in the world's forest area (Teshome et al., 2020). More than half of the country's area is covered by forests, and disturbances like wildfires and pest outbreaks pose a serious threat to their ecosystems from an economic standpoint, including a loss in the commodities and services they supply. The extent of forest land impacted by pests that consume conifer trees has been rapidly increasing. It went from 353.3 thousand hectares in 2005 to 1117.7 thousand hectares in 2017, even though there was a 14-year period of reduction in the overall forest area affected by pests. The total amount of forest impacted by wildfires is also on the rise; from 2010 to 2017, it increased by more than 67%. Many countries in the boreal zone have seen similar developments.

It is obvious that outbreaks of insect pests could end up being the main factor restricting the forest economy. Despite a recent decline in the annual rate of forest loss (d'Annunzio et al., 2015; Keenan et al., 2015) and an increase in planted forest area (Payn et al., 2015), the global forest area is predicted to continue decreasing. According to Keenan et al. (2015), the worldwide forest area declined from 4.12 billion hectares to 3.99 billion ha between 1990 and 2015, whereas the area of planted forests expanded from 167.5 million ha to 277.9 million ha over the same time period. According to d'Annunzio et al. (2015), the world's forest acreage will continue to shrink during the next ten years, but at a slower rate. However, Song et al. (2018) discovered that between 1982 and 2016, the overall area of global tree covers increased.

Rising temperatures have also been linked to higher infestations of Picea abies by *Ips typographus* in Europe (Marini et al., 2017; Mezei et al., 2017) as well as increased spruce budworm (*Choristoneura spp.*) outbreaks in North America (De Grandpré et al., 2019). This is consistent with how rising temperatures affect insects' ability to reproduce and survive (Pureswaran et al., 2018). If warming does not coincide with key stages of an insect's life cycle, such as overwintering, it may have no impact on pest outbreaks. In this regard, Gazol et al. (2019) shown that only warmer winters had an impact on the outbreak of the pine processionary moth, *Thaumetopoea pityocampa*. These data suggest that, although rising temperatures may lead to an increase in insect outbreaks, this may not always be the case.

A. Ecological Consequences and Biodiversity Loss:

Ecological disruptions of forests brought on by insect pests pose a severe threat to both the wellbeing of humans and other natural ecosystems. Deforestation, shifting cultivation, and wildfire continue to be the key factors contributing to the decline in the worldwide forest area (Curtis et al., 2018). Although biotic and abiotic pressures appear to have a minimal direct impact on such forest losses (Curtis et al., 2018), their indirect effects should not be understated. As an example, instances of forest fires often coincide with tree mortality triggered by infestations of insect pests, periods of extreme heat, and prolonged droughts. These factors lead to substantial losses in the tree population (Brando et al., 2014; Klein et al., 2019; Talucci & Krawchuk, 2019; Xie et al., 2020). The incidence of biotic and abiotic pressures can vary regionally and across time, which emphasizes the significance of these elements. For instance, 32% of tree mortality in the Western United States was attributed to pests, compared to 18% loss from fire (Berner et al., 2017). Another research revealed that the primary factors behind disruptions in northern hemisphere forests are biological disturbances, such as diseases and insect pests (Kautz et al., 2017).

Diminished product quality and the influence of combined biotic and abiotic stresses on the survival and growth of forest trees can both lead to a decline in the supply of essential services and subsequently lead to a decrease in direct earnings (Aukema et al., 2011). It has been suggested—although it is debatable—that climate change promotes tree growth and subsequently forest production (Reyer et al., 2017; Ruiz-Pérez & Vico, 2020; Torzhkov et al., 2019). Even if there might be an increase, the effect of harsh weather on the spread of pathogens and pests would result in significant losses and could even cancel out any improvement in output (Reyer et al., 2017)**.** The interference with the cultural and regulatory roles of trees, coupled with a rice in tree mortality and damage to their upper branches and foliage due to a combination of living organism related and environmental stresses, could negatively impact the overall human welfare (Reid, 2005). According to Donovan et al. (2013) and Jones (2019), both rising temperatures brought on by the loss of canopy shade and increased forest densities have been linked to increased respiratory disease-related human health issues (Donovan et al., 2013; Jones, 2019). Massive tree mortality may also have an effect on the micro- and macrofaunal variety as well as the floral diversity of the forest ecosystem. For instance, the emerald ash borer's (*Agrilus planipennis*) huge ash (*Fraxinus spp*.) mortality induced a canopy gap and a buildup of woody debris, which have an impact on the activity and diversity of forest invertebrates. Massive tree mortality may also result in a drop in lichen populations, which could result in local extinction (Jönsson & Thor, 2012).

Quantifying the monetary value of the diverse damage caused by living organisms and environmental factors is a complex task. Nevertheless, efforts have been undertaken to estimate the financial impacts from different perspectives. The financial loss brought on by tree death and slower growth serves as a clear indication of these effects. In spite of the unfavourable ecological effects brought on by the related increase in harvest frequency, dead trees, especially mature ones, might still have economic worth through "salvage logging". Projected economic losses resulting from anticipated tree mortality were used to illustrate the potential harm caused by both biotic and abiotic stresses (Ochuodho et al., 2012; Soliman et al., 2012), comparisons of the cost of protection to the possible loss, and revenue loss due to downgraded products (Costanza et al., 2019). Estimates of governmental, household, and property value losses linked to tree mortality have also been made (Reid, 2005). A more comprehensive evaluation took into account economic damages stemming from production, conservation efforts, tourism, and carbon stoage (Notaro et al., 2009). Future research should take these elements into account while conducting their assessments, as losses like tree mortality are mostly caused by the interaction of biotic and abiotic pressures. Furthermore, as economic analysis is crucial for decision-makers and forest managers, it is vital to methodically analyses the data, which is typically available in technical reports.

1.2.6 Impact of Insect Pest on Native Flora and Fauna:

Insects play a vital role in ecosystems as pollinators, decomposers, and prey for other species. However, some insect pests can harm local plants and animals, upsetting the ecological balance and causing serious problems for biodiversity and ecosystem health. This article examines how insect pests affect native plants and animals, including current findings and authoritative statements about how bug populations will be exacerbated by climate change.

The increase in global surface temperature has various impacts on insects, leading to changes in their physical attributes, actions, life-cycle timing, geographical range, and relationships with other species. Additionally, the difficulties faced by insects are made worse by extreme occurrences like heat and cold spells, fires, droughts, and floods, which are occurring more frequently as a result of climate change (Harvey et al., 2023). Because it can have a domino impact on ecosystem services like pollination, nitrogen cycling, and pest control, the loss of insect populations is a serious concern.

Habitat or vegetation management is a part of conservation biological control, a practice meant to increase the effectiveness of natural enemies in eradicating pests. Recent years have seen an increase in interest in the utilization of native plants for biological conservation. These plants give natural enemies, including predatory insects, vital floral resources that support their population and increase their ability to reduce pest populations.

Although this strategy has promise, there are still questions regarding the mechanics underpinning it, how it affects pest populations, and how much it will cost to use it. The transferability and widespread implementation of this conservation technique in different agricultural systems and regions will be made possible by including these features into study (Zaviezo & Muñoz, 2023).

Developing efficient pest management solutions requires an understanding of the link between insect pest density and survival. According to studies, the survival rate of some mosquito species, such as Aedes larvae, declines when larval population rises. Controlling larval density may not necessarily result in fewer adults because the survival-density connection varies greatly in the wild. According to field research, there are rare circumstances when larval management may even lead to an increase in adult output. This variation demonstrates the difficulty in controlling insect pest populations and the requirement for site-specific strategies(Li et al., 2023).

Insect pests' influence on local flora and fauna as well as the fall in insect populations call for immediate attention. Implementing sustainable farming practices, cutting greenhouse gas emissions, and protecting natural habitats are essential steps in improving ecological resilience and minimizing the negative consequences of climate change on insect populations. Additionally, more research and creative approaches, including conservation biological control using native plants, show promise in conserving the fragile ecosystem balance and the priceless services that insects give in the natural world.

A. Mitigation and Management Strategies:

Mitigation and management strategies for integrated pest management approaches involve a combination of techniques aimed at effectively controlling pest while minimizing potential harm to humans, the environment, and non-target organisms. Emphasizing preventive measures such as proper sanitation, crop rotation, and regular monitoring of pest populations can help reduce the need of chemical interventions. Encouraging the natural enemies, such as beneficial insects or microbial agents, to suppress pest populations is an important tactic in IPM. This can be done through conservation, augmentations or introduction of these natural enemies (Saeed Ben Youssef, 2023).

Modifying cultural practices, such as planting resistant crop varieties, selecting appropriate planting dates, or implementing proper irrigation and fertilization techniques, can help reduce pest susceptibility and increase overall crop health. Implementing physical barriers, like screen, nets or fences, can prevent pest from accessing crops or structure, providing an effective non-chemical mean of pest control.

If necessary, the use of chemical pesticides is integrated into IPM. Regular monitoring and scouting for pests allow early detection and intervention only, when necessary, based on predetermined actions thresholds. Educating farmers, pest control professionals, and the wider community about the principles and benefits of IPM approach is crucial for successful implementation.

B. Climate-Smart Agriculture and Pest Management:

Climate smart agriculture aims to address the challenges posed by climate change while ensuring sustainable food production. Pest management is the critical component of CSA, as changing climate condition can have a significant impact on pest dynamics and the spread of invasive species. Implementing IPM principles with CSA can help farmer effectively manage pest while minimizing environmental impact. Natural enemies, crop rotation, and cultural practices can suppress pests and reduce the need for chemical pesticides.

Climate change can lead to shift in pest population and their distribution. Selecting and breeding crop varieties that are more resilent to pests and climate change stressors can help minimize the pest damage. Early warning system: developing and implementing early warning system can help farmers anticipate and respond to emerging pest threats.

These systems can use climate data, pest population monitoring, and predictive modeling to alert farmer to potential outbreaks and guide timely interventions. Ecosystem based approach: adopting ecosystem-based approaches, such as promoting biodiversity and conserving natural habitats, can provide natural pest control services. Healthy and diverse ecosystem support beneficial organisms that help suppress pests.

Crop diversification integrating diverse crop into farming system can help reduce pest pressure. By planting a variety of crops, pests are less likely to build up large populations that can cause significant damage (C. C. Jaworski et al., 2023). Improved irrigation and water management proper irrigation and water management practices can minimize conditions that promote pest development, such as waterlogged or overly or overly dry soils. This can help reduce the incidence of water related pests and diseases.

Capacity building and knowledge sharing providing farmers with training, information's, and resources on climate-smart pest's management practices is crucial. Capacity building programs can help farmers understand the impact of pest dynamics and learn about effective pest management techniques. By integrating pest management strategies into climate change agriculture practices, farmers can reduce pest pressure, minimize reliance on chemical pesticides, and enhance the resilience and productivity of their farming systems in the face of climate change (Heeb et al., 2019).

1.3 Conclusion:

The intricate interplay between rising temperatures, altered precipitation patterns, and shifting weather dynamics has not only influenced the behaviour and distribution of insect pests but has also triggered cascading effects on plant stress, adaptation, and even evolution. The evidence presented underscores the urgency of recognizing climate change as a significant driver of insect pest dynamics. The alterations in insect behaviour, such as shifts in migration patterns, feeding habits, and reproductive cycles, have far-reaching consequences for agricultural ecosystems, biodiversity, and human livelihoods. The increased frequency of extreme weather events further exacerbates these impacts, leading to unpredictable pest outbreaks and economic losses in agricultural sectors. Effective pest management strategies must account for evolving behaviour and distribution of insect pests, while also considering the resilience of plant species. Collaborative efforts between researchers, policymakers, and agricultural stakeholders are essential to develop adaptive strategies that mitigate the negative impacts of climate change on insect pests and ensure global food security. By fostering a deeper comprehension of these dynamics, we can pave the way for innovative solutions that safeguard our agricultural systems, preserve biodiversity, and ultimately contribute to a more sustainable and resilient future.

1.4 References:

1. Abram, P. K., Boivin, G., Moiroux, J., & Brodeur, J. (2017). Behavioural effects of temperature on ectothermic animals: Unifying thermal physiology and behavioural plasticity. *Biological Reviews*, *92*(4), 1859–1876.
2. Ahluwalia, O., Singh, P. C., & Bhatia, R. (2021). A review on drought stress in plants: Implications, mitigation and the role of plant growth promoting rhizobacteria. *Resources, Environment and Sustainability*, *5*(August), 100032. https://doi.org/10.1016/j.resenv.2021.100032
3. Anand, T., Ingle, G., Kumar, R., Saini, V., & Meena, G. (2014). Knowledge and use of personal protective measures against mosquito borne diseases in a resettlement colony of Delhi. *Annals of Medical and Health Sciences Research*, *4*(2), 227. https://doi.org/10.4103/2141-9248.129048
4. Armin, P. (2010). *Phenotypic plasticity and diversity in insects*. 593–603. https://doi.org/10.1098/rstb.2009.0263
5. Aukema, J. E., Leung, B., Kovacs, K., Chivers, C., Britton, K. O., Englin, J., Frankel, S. J., Haight, R. G., Holmes, T. P., Liebhold, A. M., McCullough, D. G., & von Holle, B. (2011). Economic impacts of Non-Native forest insects in the continental United States. *PLoS ONE*, *6*(9), 1–7. https://doi.org/10.1371/journal.pone.0024587
6. Ayres, M. P., & Lombardero, M. J. (2000). Assessing the consequences of global change for forest disturbance from herbivores and pathogens. *Science of the Total Environment*, *262*(3), 263–286. https://doi.org/10.1016/S0048-9697(00)00528-3
7. Bale, J. S., Masters, G. J., Hodkinson, I. D., Awmack, C., Bezemer, T. M., Brown, V. K., Butterfield, J., Buse, A., Coulson, J. C., & Farrar, J. (2002). Herbivory in global climate change research: Direct effects of rising temperature on insect herbivores. *Global Change Biology*, *8*(1), 1–16.
8. Battisti, A., & Larsson, S. (2023). Climate Change and Forest Insect Pests. In *Forest Entomology and Pathology: Volume 1: Entomology* (pp. 773–787). Springer.

9. Baylis, M. (2017). Potential impact of climate change on emerging vector-borne and other infections in the UK. *Environmental Health*, *16*(1), 45–51.
10. Berner, L. T., Law, B. E., Meddens, A. J. H., & Hicke, J. A. (2017). Tree mortality from fires, bark beetles, and timber harvest during a hot and dry decade in the western United States (2003-2012). *Environmental Research Letters*, *12*(6). https://doi.org/10.1088/1748-9326/aa6f94
11. Brando, P. M., Balch, J. K., Nepstad, D. C., Morton, D. C., Putz, F. E., Coe, M. T., Silvério, D., Macedo, M. N., Davidson, E. A., Nóbrega, C. C., Alencar, A., & Soares-Filho, B. S. (2014). Abrupt increases in Amazonian tree mortality due to drought-fire interactions. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(17), 6347–6352. https://doi.org/10.1073/pnas.1305499111
12. Buckley, L. B. (2022). Temperature-sensitive development shapes insect phenological responses to climate change. *Current Opinion in Insect Science*, *52*, 100897.
13. Costanza, K. K. L., Crandall, M. S., Rice, R. W., Livingston, W. H., Munck, I. A., & Lombard, K. (2019). Economic implications of a native tree disease, caliciopsis canker, on the white pine (Pinus strobus) lumber industry in the northeastern United States. *Canadian Journal of Forest Research*, *49*(5), 521–530. https://doi.org/10.1139/cjfr-2018-0380
14. Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., & Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science*, *361*(6407), 1108–1111. https://doi.org/10.1126/science.aau3445
15. Dev, M. S. (2012). *Small farmers in India: Challenges and Opportunities. Indira Gandhi Institute of Development Research, Mumbai*. *January 2012*.
16. Donovan, G. H., Butry, D. T., Michael, Y. L., Prestemon, J. P., Liebhold, A. M., Gatziolis, D., & Mao, M. Y. (2013). The relationship between trees and human health: Evidence from the spread of the emerald ash borer. *American Journal of Preventive Medicine*, *44*(2), 139–145. https://doi.org/10.1016/j.amepre.2012.09.066
17. Eigenbrode, S. D., Davis, T. S., & Crowder, D. W. (2015). Climate change and biological control in agricultural systems: Principles and examples from North America. In *Climate change and insect pests* (pp. 119–135). CABI Wallingford UK.
18. Fahad, S., Bajwa, A. A., Nazir, U., Anjum, S. A., Farooq, A., Zohaib, A., Sadia, S., Nasim, W., Adkins, S., Saud, S., Ihsan, M. Z., Alharby, H., Wu, C., Wang, D., & Huang, J. (2017). Crop production under drought and heat stress: Plant responses and management options. *Frontiers in Plant Science*, *8*(June), 1–16. https://doi.org/10.3389/fpls.2017.01147
19. Filho, W. L., Scheday, S., Boenecke, J., Gogoi, A., Maharaj, A., & Korovou, S. (2019). Climate change, health and mosquito-borne diseases: Trends and implications to the pacific region. *International Journal of Environmental Research and Public Health*, *16*(24), 5114.
20. Gharde, Y., Singh, P. K., Dubey, R. P., & Gupta, P. K. (2018). Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection*, *107*(December 2017), 12–18. https://doi.org/10.1016/j.cropro.2018.01.007
21. Grimm, N. B., Chapin III, F. S., Bierwagen, B., Gonzalez, P., Groffman, P. M., Luo, Y., Melton, F., Nadelhoffer, K., Pairis, A., & Raymond, P. A. (2013). The impacts of climate change on ecosystem structure and function. *Frontiers in Ecology and the Environment*, *11*(9), 474–482.
22. Harvey, J. A. (2020). *Climate change-mediated temperature extremes and insects: From outbreaks to breakdowns*. *September*, 6685–6701.

https://doi.org/10.1111/gcb.15377

23. Harvey, J. A., & Dong, Y. (2023). Climate Change, Extreme Temperatures and Sex-Related Responses in Spiders. *Biology*, *12*(4), 615.
24. Harvey, J. A., Heinen, R., Gols, R., & Thakur, M. P. (2020). Climate change-mediated temperature extremes and insects: From outbreaks to breakdowns. *Global Change Biology*, *26*(12), 6685–6701.
25. Harvey, J. A., Tougeron, K., Gols, R., Heinen, R., Abarca, M., Abram, P. K., Basset, Y., Berg, M., Boggs, C., Brodeur, J., Cardoso, P., de Boer, J. G., De Snoo, G. R., Deacon, C., Dell, J. E., Desneux, N., Dillon, M. E., Duffy, G. A., Dyer, L. A., … Chown, S. L. (2023). Scientists' warning on climate change and insects. *Ecological Monographs*, *93*(1), 1–37. https://doi.org/10.1002/ecm.1553
26. Heeb, L., Jenner, E., & Cock, M. J. W. (2019). Climate - smart pest management: Building resilience of farms and landscapes to changing pest threats. *Journal of Pest Science*, *92*(3), 951–969. https://doi.org/10.1007/s10340-019-01083-y
27. Heim, R. R. (2002). A review of twentieth-century drought indices used in the United States. *Bulletin of the American Meteorological Society*, *83*(8), 1149–1165. https://doi.org/10.1175/1520-0477(2002)083<1149:AROTDI>2.3.CO;2
28. Hossain, M. A., Wani, S. H., Bhattacharjee, S., Burritl, D. J., & Tran, L. S. P. (2016). Drought stress tolerance in plants, vol 1: Physiology and biochemistry. *Drought Stress Tolerance in Plants, Vol 1: Physiology and Biochemistry*, *1*, 1–526. https://doi.org/10.1007/978-3-319-28899-4
29. Id, S. K., & Holzschuh, A. (2019). *Warmer temperatures advance flowering in a spring plant more strongly than emergence of two solitary spring bee species*. 1–15. https://doi.org/10.5061/dryad.5tq5dn6.Funding
30. Ivantsova, E. D., Pyzhev, A. I., & Zander, E. V. (2019). Economic consequences of insect pests outbreaks in boreal forests: A literature review. *Journal of Siberian Federal University - Humanities and Social Sciences*, *12*(4), 627–642. https://doi.org/10.17516/1997–1370–0417
31. Jactel, H., Koricheva, J., & Castagneyrol, B. (2019). Responses of forest insect pests to climate change: Not so simple. *Current Opinion in Insect Science*, *35*, 103–108.
32. Jaworski, C. C., Thomine, E., Rusch, A., Lavoir, A., Wang, S., & Desneux, N. (2023). Crop diversi fi cation to promote arthropod pest management: A review. *Agriculture Communications*, *1*(1), 100004. https://doi.org/10.1016/j.agrcom.2023.100004
33. Jaworski, T., & Hilszczański, J. (2013). *The effect of temperature and humidity changes on insects development their impact on forest ecosystems in the context of expected climate change*.
34. Jones, B. A. (2019). Tree Shade, Temperature, and Human Health: Evidence from Invasive Species-induced Deforestation. *Ecological Economics*, *156*(July 2018), 12–23. https://doi.org/10.1016/j.ecolecon.2018.09.006
35. Jönsson, M. T., & Thor, G. (2012). Estimating Coextinction Risks from Epidemic Tree Death: Affiliate Lichen Communities among Diseased Host Tree Populations of Fraxinus excelsior. *PLoS ONE*, *7*(9). https://doi.org/10.1371/journal.pone.0045701
36. Kautz, M., Meddens, A. J. H., Hall, R. J., & Arneth, A. (2017). Biotic disturbances in Northern Hemisphere forests – a synthesis of recent data, uncertainties and implications for forest monitoring and modelling. *Global Ecology and Biogeography*, *26*(5), 533–552. https://doi.org/10.1111/geb.12558
37. Keutgen, A. J. (2023). Climate change: Challenges and limitations in agriculture. *IOP Conference Series: Earth and Environmental Science*, *1183*(1), 12069.

38. Kim, W., Iizumi, T., Hosokawa, N., Tanoue, M., & Hirabayashi, Y. (2023). Flood impacts on global crop production: Advances and limitations. *Environmental Research Letters*, *18*(5). https://doi.org/10.1088/1748-9326/accd85
39. Klein, T., Cahanovitc, R., Sprintsin, M., Herr, N., & Schiller, G. (2019). A nation-wide analysis of tree mortality under climate change: Forest loss and its causes in Israel 1948–2017. *Forest Ecology and Management*, *432*(August 2018), 840–849. https://doi.org/10.1016/j.foreco.2018.10.020
40. Lal, M. K., Tiwari, R. K., Altaf, M. A., Kumar, A., & Kumar, R. (2023). Editorial: Abiotic and biotic stress in horticultural crops: Insight into recent advances in the underlying tolerance mechanism. *Frontiers in Plant Science*, *14*(May), 1–6. https://doi.org/10.3389/fpls.2023.1212982
41. Li, X., Ye, Z., Chen, J., Zhu, J., Han, D., Wang, J., Li, L., Fu, Y., & Zhang, F. (2023). Influence of Temperature, Photoperiod, and Supplementary Nutrition on the Development and Reproduction of Scutellista caerulea Fonscolombe (Hymenoptera: Pteromalidae). *Insects*, *14*(1), 1–14. https://doi.org/10.3390/insects14010082
42. Nayak, S. B., Rao, K. S., & Ramalakshmi, V. (2020). Impact of climate change on insect pests and their natural enemies. *Int. J. Ecol. Environ. Sci*, *2*, 579–584.
43. Notaro, S., Paletto, A., & Raffaelli, R. (2009). Economic impact of forest damage in an alpine environment. *Acta Silvatica et Lignaria Hungarica*, *5*(January), 131–143.
44. Ochuodho, T. O., Lantz, V. A., Lloyd-Smith, P., & Benitez, P. (2012). Regional economic impacts of climate change and adaptation in Canadian forests: A CGE modeling analysis. *Forest Policy and Economics*, *25*, 100–112. https://doi.org/10.1016/j.forpol.2012.08.007
45. Peace, N. (2020). Impact of climate change on insects, pest, diseases and animal biodiversity. *International Journal of Environmental Sciences & Natural Resources*, *23*(5), 151–153.
46. Peñuelas, J., Sardans, J., Filella, I., Estiarte, M., Llusià, J., Ogaya, R., Carnicer, J., Bartrons, M., Rivas-Ubach, A., & Grau, O. (2018). Assessment of the impacts of climate change on Mediterranean terrestrial ecosystems based on data from field experiments and long-term monitored field gradients in Catalonia. *Environmental and Experimental Botany*, *152*, 49–59.
47. Poff, N., Brinson, M. M., & Day, J. (2002). Aquatic ecosystems and global climate change. *Pew Center on Global Climate Change, Arlington, VA*, *44*, 1–36.
48. Pureswaran, D. S., Roques, A., & Battisti, A. (2018). Forest insects and climate change. *Current Forestry Reports*, *4*, 35–50.
49. Reid, W. V. (2005). Ecosystems and human well-being: A report on the conceptual framework working group of the Millenium Ecosystem Assessment. In *Ecosystems* (Vol. 5, Issue 281).
50. Reyer, C. P. O., Bathgate, S., Blennow, K., Borges, J. G., Bugmann, H., Delzon, S., Faias, S. P., Garcia-Gonzalo, J., Gardiner, B., Gonzalez-Olabarria, J. R., Gracia, C., Hernández, J. G., Kellomäki, S., Kramer, K., Lexer, M. J., Lindner, M., Van Der Maaten, E., Maroschek, M., Muys, B., … Hanewinkel, M. (2017). Are forest disturbances amplifying or canceling out climate change-induced productivity changes in European forests? *Environmental Research Letters*, *12*(3). https://doi.org/10.1088/1748-9326/aa5ef1
51. Ruiz-Pérez, G., & Vico, G. (2020). Effects of Temperature and Water Availability on Northern European Boreal Forests. *Frontiers in Forests and Global Change*, *3*(April), 1–18. https://doi.org/10.3389/ffgc.2020.00034

52. Saeed Ben Youssef, A. (2023). Modern trends for the application of biological control and modern technologies in agricultural projects. *International Journal of Modern Agriculture and Environment*.
53. Shrestha, S. (2019). *Effects of Climate Change in Agricultural Insect Pest*. *3*(12), 74–80. https://doi.org/10.31080/ASAG.2019.03.0727
54. Skendžić, S., Zovko, M., Pajač Živković, I., Lešić, V., & Lemić, D. (2021). Effect of climate change on introduced and native agricultural invasive insect pests in Europe. *Insects*, *12*(11), 985.
55. Skendžić, S., Zovko, M., Živković, I. P., Lešić, V., & Lemić, D. (2021). The impact of climate change on agricultural insect pests. *Insects*, *12*(5), 440.
56. Soliman, T., Mourits, M. C. M., van der Werf, W., Hengeveld, G. M., Robinet, C., & Lansink, A. G. J. M. O. (2012). Framework for Modelling Economic Impacts of Invasive Species, Applied to Pine Wood Nematode in Europe. *PLoS ONE*, *7*(9), 1–12. https://doi.org/10.1371/journal.pone.0045505
57. Talucci, A. C., & Krawchuk, M. A. (2019). Dead forests burning: The influence of beetle outbreaks on fire severity and legacy structure in sub-boreal forests. *Ecosphere*, *10*(5). https://doi.org/10.1002/ecs2.2744
58. Teshome, D. T., Zharare, G. E., & Naidoo, S. (2020). The Threat of the Combined Effect of Biotic and Abiotic Stress Factors in Forestry Under a Changing Climate. *Frontiers in Plant Science*, *11*(November). https://doi.org/10.3389/fpls.2020.601009
59. Torzhkov, I. O., Kushnir, E. A., Konstantinov, A. V., Koroleva, T. S., Efimov, S. V., & Shkolnik, I. M. (2019). The economic consequences of future climate change in the forest sector of Russia. *IOP Conference Series: Earth and Environmental Science*, *226*(1). https://doi.org/10.1088/1755-1315/226/1/012032
60. Villagra, C., & Frías-Lasserre, D. (2020). Epigenetic molecular mechanisms in insects. *Neotropical Entomology*, *49*(5), 615–642.
61. War, A. R., Taggar, G. K., War, M. Y., & Hussain, B. (2016). Impact of climate change on insect pests, plant chemical ecology, tritrophic interactions and food production. *International Journal of Clinical and Biological Sciences*, *1*(02), 16–29.
62. Weed, A. S., Ayres, M. P., & Hicke, J. A. (2013). Consequences of climate change for biotic disturbances in North American forests. *Ecological Monographs*, *83*(4), 441–470. https://doi.org/10.1890/13-0160.1
63. Xie, H., Fawcett, J. E., & Wang, G. G. (2020). Fuel dynamics and its implication to fire behavior in loblolly pine-dominated stands after southern pine beetle outbreak. *Forest Ecology and Management*, *466*(864), 1–32. https://doi.org/10.1016/j.foreco.2020.118130
64. Zaidi, N. W., Dar, M. H., Singh, S., & Singh, U. S. (2014). Trichoderma Species as Abiotic Stress Relievers in Plants. In *Biotechnology and Biology of Trichoderma*. Elsevier. https://doi.org/10.1016/B978-0-444-59576-8.00038-2
65. Zaviezo, T., & Muñoz, A. E. (2023). Conservation biological control of arthropod pests using native plants. *Current Opinion in Insect Science*, *56*, 101022. https://doi.org/10.1016/j.cois.2023.101022