

The dual crisis: Climate change simultaneously drives pollinator decline and Pest outbreaks

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Abstract

1. Insects are fundamental to global ecosystem health, providing essential services including pollination, decomposition and biological control. The global economic value of insect pollination alone is estimated at USD 235–577 billion annually, underscoring its critical role in food security and human nutrition.
2. Without pollinators one-third of flowering plants would produce no seeds. Although studies have examined climate-driven pollinator declines or pest expansions separately, these are not independent crises—yet a synthesis integrating them as linked, mutually reinforcing outcomes remains underdeveloped.
3. Here I discuss that climate change simultaneously restructures insect communities unevenly—accelerating pollinator decline while expanding agricultural pests—threatening both food security and ecological networks. I argue this dual crisis arises from climate change acting as a selective ecological filter, favouring opportunistic, r-selected pests while disadvantaging specialist, K-selected pollinators.
4. Synthesized evidence indicates that for every degree of warming, documented bee species richness has declined by approximately 25% since the 1990s, while pest-induced crop losses increase by 10%–25%. These disruptions are severe across multiple biomes but are especially concerning in tropical regions, where extreme heatwaves cause catastrophic mortality in stingless bees and monitoring remains critically sparse. I review the physiological, phenological and distributional mechanisms driving these changes, including phenological mismatches that decouple flowering from pollinator emergence.
5. To address these challenges, I advocate for a network-centric approach encompassing climate-responsive integrated pest management, landscape-scale habitat restoration and community-based monitoring. Systematic monitoring and further research into species-specific and network-level responses are essential to guide effective policy and safeguard insect biodiversity in a rapidly changing climate.

KEYWORDS

agricultural pests, climate change, conservation strategies, ecosystem services, insect biodiversity, phenological mismatch, pollinator decline

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INTRODUCTION

As the most abundant and ecologically diverse group of animals in terrestrial ecosystems, insects furnish essential services that are indispensable for the proper functioning of ecosystems and the well-being of human populations (Noriega et al., 2018; Ramos et al., 2020). Occupying a vast range of trophic niches, they underpin ecosystem stability through services such as pollination, decomposition, nutrient cycling, biological control and ecosystem engineering (Belovsky & Slade, 2000; Curran et al., 2023; Katumo et al., 2022). Among these, pollination is particularly critical: over 75% of global crops depend, at least in part, on animal pollinators (Klein et al., 2007), and insect pollination alone is estimated to contribute USD 235–577 billion annually worldwide (IPBES, 2016). Insect pollinators facilitate the reproduction of wild plants that sustain biodiversity by providing food and habitat for numerous species, thereby reinforcing ecosystem resilience and stability. Furthermore, pollinator-dependent crops are key sources of essential micronutrients—including vitamins A and C, calcium and folic acid—linking insect-mediated ecosystem services directly to global human nutrition and health (Potts et al., 2016). Despite their immense value, these insect-mediated services are now under unprecedented threat from climate change—now a dominant driver of insect population dynamics, altering physiology, phenology and species distributions worldwide (González-Tokman et al., 2020).

Although a growing body of research documents climate-driven declines of individual pollinator species and, separately, climate-driven expansions of individual pest species, an integrated framework that unites these phenomena as two sides of the same climatic coin remains underdeveloped. Specifically, existing studies have largely treated pollinator losses and pest outbreaks as independent problems, and as a result, their shared mechanistic basis, simultaneous emergence from the same climatic drivers, and interconnected consequences for biodiversity and food security have received limited systematic attention. Furthermore, research on how climate change simultaneously harms beneficial insects while benefiting harmful ones is limited—a gap with profound implications for ecosystem management and agricultural policy. To address this gap, I discuss that climate change simultaneously restructures insect communities unevenly—accelerating pollinator biodiversity decline while expanding the range and reproductive output of many agricultural pests—thereby threatening both global food security and the ecological networks that sustain it. I argue that climate change acts as a selective ecological filter, rather than a uniform stressor, disproportionately disadvantaging specialist and functionally important taxa—such as many pollinators—while favouring opportunistic, *r*-selected species with broad thermal tolerances and rapid reproduction, traits commonly associated with many insect pests. This asymmetric filtering aligns with fundamental life-history theory: *r*-selected species, which prioritize high reproductive rates and rapid population growth under disturbed conditions, are pre-adapted to climate-induced instability (Salguero-Gómez et al., 2016; Taylor et al., 2018). Among insects, species with slower, more *K*-like life histories (e.g. low fecundity, late maturity, specialized niches) are disproportionately vulnerable (Caldas, 2014). This differential filtering gives rise to a paradoxical dual crisis: the

simultaneous decline of beneficial insect populations and proliferation of pest species. This convergence of opposite ecological outcomes from a single driver represents a fundamental challenge for both biodiversity conservation and agricultural stability.

Although multiple drivers—including land-use change, pesticide use and pathogens—contribute to pollinator decline, climate change uniquely interacts with these pressures by altering physiology, phenology and species distributions, often amplifying their effects through synergistic interactions (Dicks et al., 2021; Vanbergen et al., 2013). The persistent separation of pollinator research from pest research has obscured this underlying biodiversity–food security nexus that lies at the heart of the climate–insect crisis. A notable disconnect remains between documenting climate-driven impacts and developing integrated, climate-adaptive conservation and management strategies. This review integrates these disparate threads, moving beyond a simple cataloguing of effects to develop a cohesive framework that links underlying mechanisms to ecological consequences and actionable solutions. Specifically, it addresses three pivotal questions: (1) What are the principal physiological and phenological mechanisms through which climate change restructures insect populations? (2) How do these mechanisms converge to drive the dual crisis of pollinator decline and pest proliferation? (3) What integrated conservation and management strategies can effectively mitigate these impacts while simultaneously supporting pollinator recovery and pest regulation? By explicitly linking mechanism, consequence and response, this review provides a unified framework for understanding—and addressing—the insect crisis in the Anthropocene, centred on safeguarding both the biodiversity that underpins ecosystems and the food security that sustains human populations.

MECHANISMS OF CLIMATE CHANGE IMPACTS ON INSECTS

Climate change is restructuring global ecosystems through fundamental alterations in temperature, precipitation and atmospheric composition (Chen et al., 2023; Shivanna, 2022). Insects, as poikilotherms, are critically sensitive to these changes, as their physiology, development and behaviour are governed by external conditions (González-Tokman et al., 2020; Skendžić et al., 2021). Consequently, this sensitivity manifests through four primary and interconnected pathways—physiological responses, phenological shifts, geographic range dynamics and indirect trophic interactions—which together drive the reorganization of insect populations and their ecological interactions. Crucially, these mechanisms do not operate in isolation but interact synergistically, leading to a progressive decoupling of ecological relationships that underpin ecosystem stability and insect-mediated services.

Physiological sensitivity of Poikilotherms

The poikilothermic nature of insects makes their metabolic rates, development, survival and reproduction highly dependent on ambient

temperature. Even modest warming can accelerate developmental processes, increase feeding rates and enhance dispersal activity (Bale et al., 2002). For example, metabolic rates can double with every 10°C increase (Clarke & Fraser, 2004; Gillooly et al., 2001), highlighting the nonlinear sensitivity of insect performance to temperature. Warming enhances growth and reproduction only up to an optimal threshold; beyond this point, metabolic costs rise disproportionately, thermal injury accumulates and fitness declines, resulting in reduced fecundity, impaired dispersal and increased mortality (González-Tokman et al., 2020; Harvey et al., 2023; Jamieson et al., 2012). At high temperatures, physiological stress responses—such as the production of heat shock proteins (HSPs) and biogenic amines—impose energetic trade-offs that further constrain reproduction and immunity (González-Tokman et al., 2020). Importantly, these thermal responses are species-specific, governed by distinct upper and lower tolerance limits, making some insect groups—particularly pollinators—far more vulnerable than others (Lehmann et al., 2020). Warmer overwintering conditions can increase metabolic expenditure during diapause, depleting fat reserves and producing smaller, less fit adults upon emergence (Schenk et al., 2018). As Stange and Ayres (2010) note, warming reduces the frequency of lethally cold temperatures for many insects, particularly at higher latitudes, but this benefit can be offset by loss of snow insulation or increased vulnerability to late-winter cold snaps. Together, these direct physiological effects form the mechanistic foundation upon which higher-level ecological disruptions are built, initiating the asymmetric responses that characterize insect communities under climate change.

Phenological shifts and trophic mismatches

Phenology—the timing of seasonal life-cycle events—is among the most climate-sensitive biological traits. Warmer temperatures are driving earlier emergence, flight and reproduction across many insect taxa (Burkle & Jha, 2024; Gordo & Sanz, 2005, 2006; Parmesan, 2007; Sparks et al., 2010). A global synthesis has confirmed that the relative timing of interacting species has changed significantly over recent decades, with shifts in synchrony far exceeding natural variation (Kharouba et al., 2018). However, these shifts are rarely uniform across species, leading to changes in temporal overlap and the potential for phenological mismatches (Kharouba & Wolkovich, 2020). Crucially, phenological mismatches are not universal outcomes of climate change but are highly context-dependent, with their likelihood and severity varying by species' climatic sensitivities, interaction specialization and adaptive capacity (Abarca & Spahn, 2021; Martín-Rodríguez et al., 2025; Renner & Zohner, 2018).

Most research has focused on pairwise interactions; however, species typically participate in multiple temporally structured interactions simultaneously, complicating predictions of mismatch. For example, Xie et al. (2025) examined a tri-trophic spring ephemeral system (plant, specialist pollinator, forest canopy) and found that flowering advanced faster (0.21 day/year) than pollinator emergence (0.16 day/year), leading to spatially divergent

outcomes: the pollination window lengthened in northern regions but shortened in central and coastal regions under future warming. This demonstrates that climate change can restructure multi-species temporal relationships in spatially heterogeneous ways, as interacting guilds differ in their phenological sensitivities across climatic gradients. However, the absence of universal mismatch does not preclude its occurrence in specific systems; rather, these contrasting findings highlight that phenological disruption is highly context-dependent.

A global synthesis of 340 studies found that although both plants and pollinators are advancing phenologically, clear evidence of widespread mismatch remains limited (Martín-Rodríguez et al., 2025). This apparent contradiction reflects the fact that phenological change does not consistently translate into functional disruption. In some systems, plants and pollinators have shifted their phenologies at similar rates, maintaining synchrony over time. For instance, in subalpine meadows of the Rocky Mountains, syrphid flies and their floral resources have shown parallel phenological advances, preserving temporal overlap despite differential responses to climate cues (Forrest, 2016). In contrast, other systems exhibit strong mismatches with clear fitness consequences. A 19-year study of *Corydalis ambigua* and its bumblebee pollinators demonstrated that earlier snowmelt advanced flowering more than bee emergence, reducing seed set by up to 50% (Kudo & Cooper, 2019).

Similarly, long-term monitoring of bumblebees and flowering plants in the same region revealed decreased synchrony, as plant phenology advanced more rapidly than bee activity (Pyke et al., 2016). Experimental warming studies similarly show reduced visitation rates and lower plant reproductive success when phenologies diverge (de Manincor et al., 2023). Together, these contrasting cases demonstrate that phenological shifts produce system-specific outcomes rather than uniform disruption. Adding further nuance, some systems exhibit 'hidden mismatches'. For example, in Mediterranean scrublands, plants and pollinators advanced at similar rates, yet total phenological overlap declined due to changes in the duration of flowering versus flight periods (Montes-Perez et al., 2025). This highlights that synchrony depends not only on the timing of onset but also on the length and shape of activity periods.

Beyond temporal mismatches, climate change can also generate spatial mismatches between plants and their pollinators. A recent study demonstrated that for 11 neotropical wild vanilla species, future climate conditions may expand suitable habitat for some plants by up to 140% while simultaneously contracting pollinator ranges by 21%–40% (Watteyn et al., 2025). This spatial decoupling—wherein plants track suitable climates into regions where their pollinators cannot follow—threatens plant reproduction even where plant populations persist. Such effects are particularly severe for specialized interactions, is projected to decline by 60%–90% under future scenarios. Species distribution models for Great Britain project that by 2050, climate change will create spatial mismatches between suitable areas for orchard crops and their pollinators, thereby increasing the risk of pollination deficits (Polce et al., 2014).

Drivers of divergent phenological responses

The variability in mismatch outcomes can be explained by differences in species traits and interaction structure. First, interaction specialization shapes phenological responses: specialist species often track their partners more closely but are more vulnerable when environmental cues decouple. For example, a study of two bee species in a *Clarkia* plant population showed that the specialist bee, *Hesperapis regularis*, closely tracked host-plant flowering, whereas the generalist *Lasiosglossum incompletum* did not, highlighting the greater sensitivity of specialists to disrupted synchrony (Anderson et al., 2021). Second, species differ in their ability to adjust phenology to inter-annual climate variation, a trait known as phenological sensitivity. In Mediterranean butterfly communities, species with higher phenological sensitivity exhibited more positive—or less negative—population trends than less responsive species, indicating that phenological plasticity can buffer populations against climate-driven mismatch (Colom et al., 2022). Together, specialization and phenological sensitivity provide key mechanistic explanations for why climate change produces uneven outcomes across ecological communities.

Functional consequences of phenological change

Phenological shifts can have complex and sometimes counterintuitive consequences that differ across functional groups. For insect pests, earlier emergence may either disrupt or enhance synchrony with host plants. For example, the cotton bollworm (*Helicoverpa armigera*) can emerge earlier under warming conditions, potentially reducing early-season resource availability (Ouyang et al., 2016). Conversely, in other systems, warming can increase synchrony or extend activity periods, enhancing pest performance and outbreak potential. A striking example is the spruce bark beetle (*Ips typographus*), where warmer summers allow an additional generation per year, transforming it from a secondary colonizer into a primary killer of healthy spruce stands across Europe (Jönsson et al., 2011; Marini et al., 2017). Similar temperature-driven voltinism increases occur in North American bark beetles (Bentz et al., 2010).

For pollinators, the consequences are often more negative. When phenological responses differ from those of flowering plants, pollinators may miss peak resource availability, reducing foraging success and reproductive output (Chen et al., 2009; Saikia et al., 2016). Warming can also alter voltinism, sometimes generating additional generations that cannot be completed before winter, creating developmental traps. In herbivores, increased voltinism can outpace natural enemies, weaken biological control and increase the likelihood of pest outbreaks (Jamieson et al., 2012; Mooney et al., 2023). Overall, phenological shifts reinforce ecological asymmetry by generating both winners and losers across insect communities.

Many studies of phenological mismatch rely on single time-point metrics such as first flowering or first emergence dates, which capture only the onset of activity rather than the full temporal structure of phenology. Understanding ecological consequences requires

characterizing the entire phenological distribution—including onset, peak timing and duration—and linking these to fitness outcomes (Fisogni et al., 2025). Defining an appropriate baseline for synchrony is equally challenging; without knowledge of historical interaction timing, it is difficult to determine whether observed asynchrony reflects climate-driven disruption or pre-existing ecological dynamics (Kharouba & Wolkovich, 2020; Singer & Parmesan, 2010).

Geographic range shifts

Climate-driven range shifts do not produce uniform responses across insect taxa; instead, they generate clear winners and losers. Species differ markedly in their dispersal capacity, thermal tolerance and habitat specificity, leading to divergent range dynamics. In response to warming, many insect species are migrating poleward and to higher elevations in pursuit of suitable climatic conditions (Di Marco et al., 2023; Pilotto et al., 2022; Sunde et al., 2023). Long-term data from Sweden and Finland show that butterfly species richness has increased with rising temperatures over the past 120 years, with average provincial richness increasing by 64%. However, range expansions frequently lag behind the velocity of climate change, creating a 'climatic debt' as species fail to track the pace of temperature shifts (Sunde et al., 2023). Some cold-adapted taxa benefit from warming at their northern or high-elevation range margins. Bumble bee richness increases with elevation (i.e. in colder conditions) due to their exceptional cold adaptation, allowing them to expand into previously unsuitable high-elevation habitats as temperatures warm (Sponsler et al., 2022). At the community level, warming drives fundamental taxonomic shifts: bee-dominated communities transition to fly-dominated communities between 4.9 and 5.7°C mean annual temperature, with flies dominating in colder environments (McCabe & Cobb, 2021). Similarly, syrphid flies play central network roles in polar climates, while bees dominate in tropical networks (Saunders et al., 2023). Many agricultural pests are also expanding. Some species are rapidly colonizing newly suitable regions, such as the northward spread of the beet webworm in China (Zhang et al., 2024) and temperature-driven increases in bark beetle voltinism (Robbins et al., 2022).

In stark contrast, other taxa are losing ground. For cold-adapted specialists like bumblebees, the same warming that expands high-elevation habitat simultaneously contracts their low-elevation and southern ranges. A continent-scale analysis of 66 bumblebee species across North America and Europe found that climate change—specifically the increasing frequency of summer temperatures exceeding historical maxima—is a primary driver of widespread declines, with occupancy probabilities declining by 30%–50% per decade (Soroye et al., 2020). Thus, bumblebees experience range expansion at cold margins but net declines overall due to larger contractions at warm margins. Tropical highland bees (*Fijian Homalictus*) are similarly constrained by narrow elevational ranges and habitat specificity, making them vulnerable to upward range shifts that eventually run out of suitable habitat (Dorey et al., 2020). Odonata species exhibit sensitivity linked to limited thermal tolerance traits (Rocha-Ortega et al., 2020).

This asymmetry—mobile, generalist species expanding while specialists' contract—reinforces ecological filtering and drives the dual crisis. Unlike pests that benefit from warming through increased voltinism and expanded ranges, many pollinators face physiological stress, phenological mismatch and spatial decoupling from floral resources. An additional risk is that range shifts create novel biotic encounters in both directions. As species expand into new regions, they may encounter predators, parasites and competitors to which they lack evolved defences. Conversely, resident enemies that shift their own ranges may encounter naïve host populations, potentially triggering outbreaks or disease spread. These novel interactions can increase mortality, destabilize recipient communities and amplify the ecological consequences of climate-driven redistribution (Wallingford et al., 2020). These contrasting responses demonstrate that climate change systematically reorganizes insect communities, favouring pest traits while disadvantaging pollinators. This spatial reorganization interacts with habitat destruction and biological invasions, compounding pressures on vulnerable species (Bellard et al., 2012; Fatah et al., 2023; Sundar et al., 2021).

Indirect effects and trophic interactions

Beyond direct physiological impacts, climate change exerts powerful indirect effects by altering the web of species interactions. Climate change can disrupt tri-trophic interactions; for example, the effectiveness of natural enemies like parasitoid wasps may be impaired if their development is not synchronized with that of their herbivore host, a form of trait mismatch (Abarca & Spahn, 2021; Frank, 2021; Harvey et al., 2023). Climate change can also indirectly benefit pests by reducing the efficacy of their natural enemies through multiple pathways: elevated temperatures may directly kill or impair parasitoids, altered plant volatiles may reduce enemy attraction to herbivore-infested plants and phenological decoupling may create temporal refuges for pests (Jamieson et al., 2012; Zhu et al., 2014). For pollinators, climate change can amplify the impacts of other stressors through indirect pathways: heat stress increases susceptibility to pathogens, nutritional stress from habitat loss reduces tolerance to pesticides and extreme weather events disrupt foraging behaviour (Potts et al., 2016; Vanbergen et al., 2013). Extreme heat events can decouple these relationships; for instance, warmer temperatures can reduce the efficacy of endosymbionts that protect aphids from parasitoids, or alter the production of plant volatile organic compounds (VOCs) that parasitoids use to locate hosts (González-Tokman et al., 2020). Collectively, these processes weaken ecological regulation and increase the likelihood of pest outbreaks. Thus, direct and indirect effects converge to drive the decoupling of ecological networks, destabilizing trophic interactions and reducing ecosystem resilience.

Community-level consequences and synthesis

The ecological consequences of phenological shifts extend beyond simple pairwise interactions to reshape entire communities. In a tri-

trophic system involving sycamore, aphids and parasitoids, a 20-year study showed that warmer springs advanced the phenology of all three trophic levels, but parasitoids lagged behind their aphid hosts, reducing parasitism and altering population dynamics (Abarca & Spahn, 2021). Similarly, warming can disrupt synchrony between herbivores and their natural enemies; for example, cereal leaf beetles experience fewer parasitoid attacks in warm years due to delayed host-parasite timing (Forrest, 2016). Such temporal decoupling can cascade through food webs, destabilizing predator-prey and plant-pollinator interactions and increasing the risk of herbivore outbreaks or higher trophic-level declines (DeLucia et al., 2012; Lau et al., 2023). These cascading effects illustrate that climate change operates not only through direct physiological and phenological pathways but also through emergent, network-level disruptions that alter the strength and stability of species interactions.

Beyond these direct cascading effects, the broader question arises: can biodiversity buffer against these disruptions? The role of biodiversity in buffering these effects is complex and context-dependent. While more diverse communities often exhibit greater baseline overlap among interacting species, they do not necessarily resist declines in synchrony over time. Importantly, species interactions can be more sensitive to disturbance than species richness alone (Doré et al., 2021), meaning that network-level disruptions may precede or exceed observable species losses. However, evidence suggests that buffering effects may emerge at lower diversity levels, indicating that simplified agroecosystems or degraded habitats are particularly vulnerable to phenological decoupling (Montes-Perez et al., 2025). The interplay of physiological stress, phenological shifts, range dynamics and altered species interactions creates a feedback loop of ecological disintegration (Figure 1). These processes interact synergistically, leading to the breakdown of synchronized life cycles, spatial mismatches and weakened trophic regulation. The outcome is not simply population decline but a systemic reorganization of insect communities, producing ecological winners and losers.

THE DUAL CRISIS: POLLINATOR DECLINE AND PEST PROLIFERATION

The ascent of agricultural pests

Climate change is increasingly exacerbating challenges posed by many agricultural insect pests, posing a growing threat to global food security. A study projected that global yield losses of wheat, rice and maize to insect pests will increase by 10%–25% per degree Celsius of global mean surface warming (Deutsch et al., 2018). This increase arises from two additive mechanisms: rising metabolic rates increase per-capita consumption, while warming accelerates population growth in temperate regions where current temperatures lie below thermal optima. Under a 2°C warming scenario, median increases in yield losses reach 46%, 19% and 31% for wheat, rice, and maize, respectively—equivalent to 59, 92 and 62 million metric tonnes annually. The largest increases are projected for France, the United States and China,

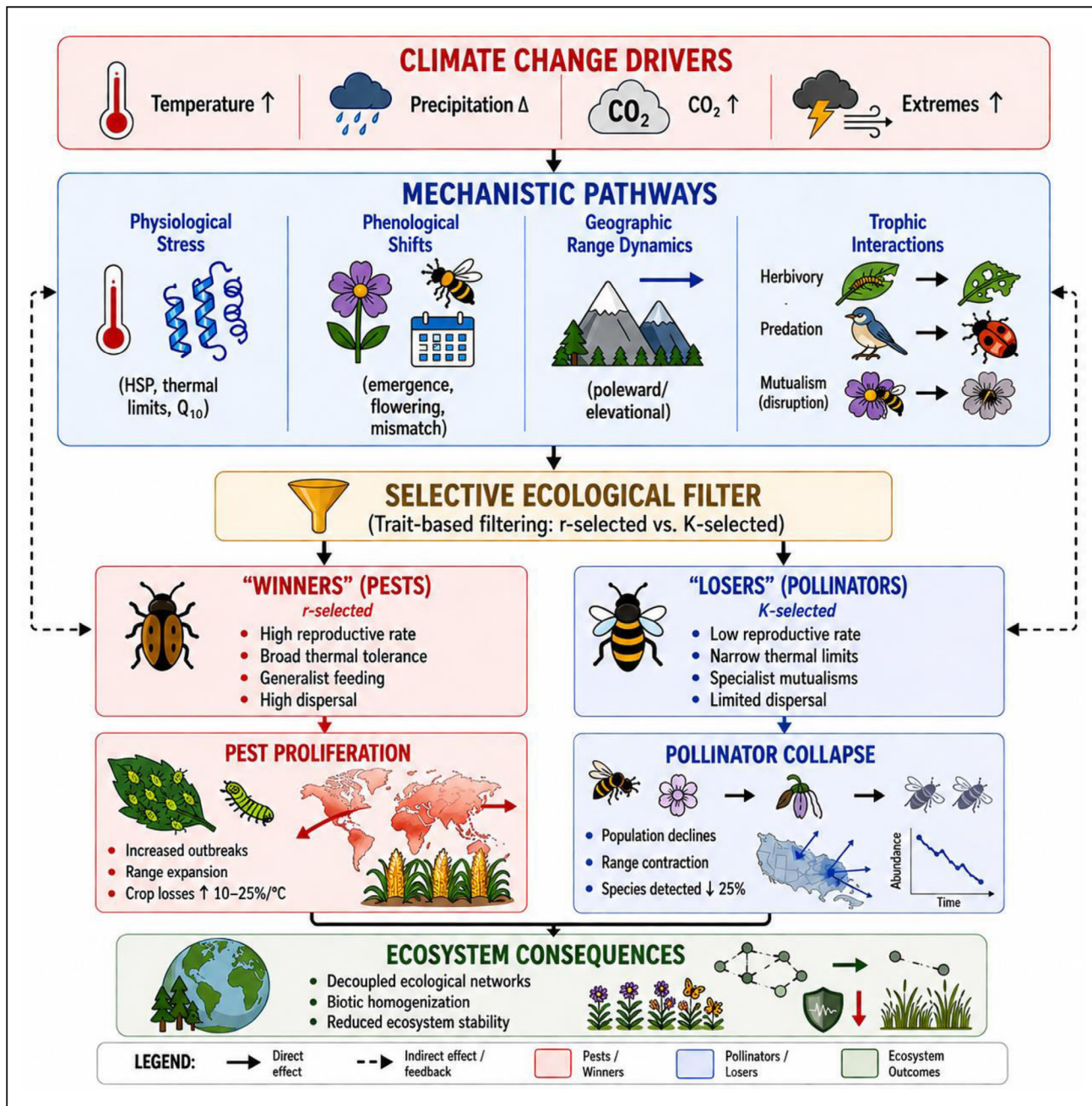


FIGURE 1 Conceptual pathways linking climate change to insect population and interaction dynamics. Climate drivers (warming, altered precipitation, elevated CO₂, extreme events) affect insects through four interacting mechanisms: physiological stress, phenological shifts, geographic range dynamics and altered trophic interactions. These direct and indirect effects disrupt temporal synchrony, spatial distributions and species relationships, leading to ecological mismatches and altered community structure. Combined effects generate feedback loops that reduce ecosystem resilience and promote the progressive decoupling of ecological interactions.

underscoring that pest proliferation is likely to intensify most strongly in major temperate agricultural systems.

Temperature-driven changes in Pest biology

Rising temperatures accelerate pest development, increase the number of generations per year (voltinism) and expand overwintering

survival, leading to larger and more damaging populations (Altermatt, 2010; Bale et al., 2002; Forrest, 2016). However, pest responses are not universal. Species already near their thermal maximum in tropical regions, such as the black armyworm (*Spodoptera exempta*), may experience range contractions under further warming (Li et al., 2024). For those that benefit, examples include increased bark beetle-induced tree mortality (Robbins et al., 2022) and temperature-driven migration shifts, such as the expansion of the

black cutworm (*Agrotis ipsilon*) in China (Zeng et al., 2020). Increases in pest populations reflect complex interactions among temperature, humidity and community dynamics (Lehmann et al., 2020; Pathania et al., 2020), meaning the net effect is not a simple linear increase but a recalibration of global agroecosystems. Climate change acts as a filter, selecting for traits such as thermal resilience, rapid reproduction and ecological generalism—thereby driving a global homogenization of pest communities and diminishing the efficacy of traditional, location-specific control methods.

Effects of elevated CO₂ on plant-herbivore interactions

Elevated atmospheric CO₂ alters plant physiology, typically reducing nitrogen content in foliage and changing the chemical composition of leaves (Barbehenn et al., 2004; Johnson et al., 2020). This decline in nutritional quality often triggers compensatory feeding in chewing herbivores, increasing plant damage (DeLucia et al., 2008; Hamilton et al., 2005; Stiling & Cornelissen, 2007; Thomson et al., 2010). For sap-sucking insects such as aphids and whiteflies, responses are more variable and species-specific (Hullé et al., 2010; Sun & Ge, 2011; Sutherst et al., 2011). This variability reflects differences in phloem composition, plant defence responses and aphid genotype (DeLucia et al., 2008; Stiling & Cornelissen, 2007). The net effect of elevated CO₂ on herbivore populations is not a simple directional trend but a complex recalibration of plant-herbivore interactions. Chewing insects generally increase consumption to compensate for lower nitrogen, while sap-feeders show context-dependent responses that can either increase or decrease abundance depending on plant species and environmental conditions (DeLucia et al., 2008; Jamieson et al., 2012). Increased aphid populations can amplify crop damage and disease transmission, whereas declines may reduce food availability for natural enemies, further releasing pest populations from top-down regulation. Moreover, the combined effects of elevated CO₂ and other climate change factors—such as warming and drought—can interact in non-additive ways, making predictions about future plant-herbivore dynamics particularly challenging (Jamieson et al., 2012).

Critically, the effects of elevated CO₂ on insect herbivores are not independent of temperature. A meta-analysis of 42 studies (encompassing 31 plant species and 7 insect herbivore species) found that while elevated CO₂ alone impairs insect performance and elevated temperature alone improves it, their combined effect is neutral—warming cancels CO₂'s negative impact (Zvereva & Kozlov, 2006). As the authors conclude, CO₂ elevation studies 'cannot be directly extrapolated' to realistic warming scenarios. Yet a synthesis of 75 meta-analyses confirmed that such interactive effects remain severely understudied (Vidal et al., 2025). These findings indicate that elevated CO₂ does not simply increase or decrease herbivore pressure uniformly. Rather, it reshapes plant-herbivore interactions in complex, species-specific ways that depend on herbivore feeding guild, plant defence responses and the broader community context.

Altered precipitation and overwintering survival

Climate change also alters pest dynamics through changes in precipitation and seasonal survival. Rainfall variability can both suppress and promote pest outbreaks, depending on timing and intensity. Heavy rains can physically suppress small-bodied pests like aphids and whiteflies, yet sequences of drought followed by rain can trigger dramatic outbreaks. For example, drought conditions reduce the effectiveness of natural enemies, enabling pests such as the Oriental armyworm (*Mythimna separata*) to proliferate when favourable conditions return (Sharma et al., 2010). Similarly, cyclonic rainfall events create optimal breeding conditions for desert locusts (*Schistocerca gregaria*) (Meynard et al., 2020). Drought stress also alters plant physiology in ways that cascade through food webs: it can reduce plant water content, increase concentrations of defensive compounds such as glucosinolates or terpenoids, and change the emission of volatile organic compounds (VOCs) that parasitoids and predators use to locate their herbivorous prey (Zhu et al., 2014). These plant-mediated changes can decouple pests from their natural enemies by reducing the detectability of herbivore-infested plants, altering the nutritional quality of herbivores for parasitoids or directly affecting parasitoid survival and development. As a result, top-down control weakens, allowing herbivore populations to escape regulation and potentially reach outbreak levels (Jamieson et al., 2012; Zhu et al., 2014).

A second critical pathway is the enhancement of overwintering survival. Warmer winters directly reduce cold-induced mortality, boosting the initial population size of pests in the spring. This has been documented in species such as the cotton bollworm (*Helicoverpa armigera*) (Reddy et al., 2015) and the diamondback moth (*Plutella xylostella*), where warming also promotes pesticide resistance and range expansion (Ma et al., 2021). This improved survival synergizes with other temperature effects; for migratory pests like the corn earworm (*Helicoverpa zea*), accelerated phenology and a prolonged growing season intensify agricultural challenges (Venugopal & Dively, 2017). The net result is a fundamental alteration of local agricultural landscapes, as pests establish in regions previously limited by cold (Hong et al., 2024). This dual process simultaneously amplifies existing pest populations and enables invasion into previously unsuitable regions, necessitating a fundamental reorientation of pest management towards predictive modelling and climate-resilient Integrated Pest Management (IPM) strategies.

The decline of pollinators

In contrast to the mechanisms that promote pest proliferation, the same climate-driven processes impose physiological, ecological and interaction-level constraints on many pollinators. As a result, many pollinators—particularly specialists and cold-adapted species—represent the vulnerable side of the dual crisis.

Physiological vulnerability and thermal stress

The vulnerability of pollinators to climate change is strongly rooted in their physiological sensitivity to temperature. Extreme heat events pose an acute and increasingly documented threat. During an unprecedented 2024 heatwave on Mexico's Yucatán Peninsula, 100% of managed *Melipona beecheii* colonies experienced brood mortality, with internal nest temperatures exceeding the thermal tolerance of immatures (34–36°C) and 69% of beekeepers experiencing colony loss (Quezada-Euán et al., 2025). Experimental evidence further shows that simulated heatwaves of just 4 days during larval development reduce survival to adulthood in bumblebees, with effects becoming severe at 38°C (Wöglér & Kurze, 2025). Similarly, experimental heatwaves disrupt bumblebee foraging not only through direct heat stress on the bees but also indirectly by reducing the nectar production of their host plants (Hemberger et al., 2023). These findings demonstrate that, unlike many pest species that thrive under warming, pollinators are often pushed beyond their thermal limits, resulting in reduced survival, impaired development and reproductive failure.

Phenological and interaction-level disruptions

Climate change disrupts not only the timing but also the mechanisms underlying plant-pollinator interactions. While phenological shifts are widespread, evidence for universal mismatch remains limited and highly species-specific (Martén-Rodríguez et al., 2025). However, even subtle shifts can reduce the effectiveness of interactions. Climate change induces earlier spring emergence in many species (Burkle & Jha, 2024; Gordo & Sanz, 2005, 2006; Parmesan, 2007; Sparks et al., 2010), which can lead to mismatched timings that reduce plant reproduction success and limit food resources for pollinators. Beyond timing, climate change alters the chemical and behavioural basis of pollination. Elevated temperatures and CO₂ levels can alter the production of floral volatiles, scrambling the signals that guide specialist pollinators to their hosts (Cruz et al., 2023; Farré-Armengol et al., 2013, 2014). Experimental studies show that warming reduces flower size, nectar production and interaction frequency, while increasing generalization in pollinator foraging (de Manincor et al., 2023). Drought conditions can further alter floral volatile profiles, affecting pollinator attraction and visitation behaviour (Burkle & Runyon, 2016; Glenny et al., 2018). These changes reduce both the quantity and quality of pollination. Phenological shifts further compound these disruptions. Even when flowering phenologies remain stable, climatic changes can alter floral traits, influencing pollinator visitation rates and pollination effectiveness (Takkis et al., 2015).

The vulnerability of pollinators to these disruptions varies with their degree of specialization. For example, specialist bees track host plants closely but are more susceptible to mismatches when cues decouple. Highly specialized mutualisms, such as fig-fig wasp interactions, are particularly vulnerable to even small temperature increases, which can reduce pollinator lifespan and destabilize entire ecological networks (Jevanandam et al., 2013). Furthermore, climate change can

disrupt mutualisms beyond direct plant-pollinator pairs; for example, warming can alter protective ant-plant mutualisms, reducing ant defence of plants against herbivores and indirectly affecting pollinator visitation through changes in plant condition and floral rewards (Magnoli et al., 2023). These processes collectively demonstrate that climate change degrades both the temporal synchrony and the chemical communication systems that underpin effective pollination. For pollinators, these physiological and phenological stresses are especially consequential because successful reproduction depends on precise synchronization with floral resources.

Geographic range shifts and spatial mismatch

Pollinators are also undergoing significant range shifts, with warm-adapted species increasing and cool-adapted species declining (Hofmann et al., 2018). However, these shifts often generate spatial mismatches between pollinators and the plants or crops that depend on them. Climate variability also influences migration patterns of species such as *Apis dorsata*, further altering pollination dynamics (Itioka et al., 2001; Nagir et al., 2016). These distributional and temporal shifts disrupt both the availability and reliability of pollination services, with consequences for plant reproduction and ecosystem stability (Carrasco et al., 2021; Richman et al., 2020). Thus, even where pollinators persist, their geographic redistribution can decouple them from the plant communities and agricultural systems they support.

Community and network instability

Beyond individual species responses, climate change destabilizes the ecological networks that sustain pollination. A 35-year study in a desert stream ecosystem showed that warming and drying conditions disrupted compensatory dynamics within macroinvertebrate communities, leading to synchronous species declines and a highly unstable community state (Wang et al., 2023). This breakdown of compensatory dynamics—where species previously responded differently to environmental variability, buffering the community—illustrates how climate change erodes ecological resilience. As these stabilizing dynamics collapse, pollination systems become more vulnerable to disturbance and less capable of maintaining consistent function. Such network-level instability represents a critical but often overlooked dimension of pollinator decline, extending beyond species loss to the loss of ecological resilience itself.

Population decline and global evidence

The global scale of pollinator decline has been quantified by Zattara and Aizen (2021), who analysed over a century of occurrence records from the Global Biodiversity Information Facility (GBIF). After the 1990s, the number of bee species reported annually declined sharply, with approximately 25% fewer species recorded between 2006 and

2015 compared to pre-1990 levels. This decline shows phylogenetic structure: long-tongued bees (Apidae, Megachilidae) exhibit steep declines from the 2000s onward, while short-tongued families (Andrenidae, Halictidae) began declining earlier. In contrast, ants (Formicidae) show no evidence of global decline, indicating that these trends reflect genuine biological patterns rather than sampling artefacts. However, the authors note important limitations: GBIF data are biased towards well-sampled regions such as North America and Europe, while data from Africa, Asia and much of South America remain sparse, introducing uncertainty into global estimates. Despite these limitations, available evidence consistently indicates widespread and taxonomically structured pollinator declines.

Functional and economic consequences

The loss of pollinators has direct and measurable economic and ecological consequences. The global economic value of insect pollination is estimated at USD 235–577 billion annually, and pollinator-dependent crops are major sources of essential micronutrients (Potts et al., 2016). Declines in pollinators therefore pose risks to both agricultural productivity and human nutrition, particularly in regions where reliance on pollinator-dependent crops is high (Dicks et al., 2021; Potts et al., 2016). At the ecological level, without animal pollinators, 33% of flowering plant species would produce no seeds, and 50% would experience an 80% or greater reduction in fertility (Rodger et al., 2021). Vulnerability is highest among trees, tropical species and plants with specialized pollination systems—groups already at elevated extinction risk. Notably, many highly pollinator-dependent species are long-lived perennials, meaning that population declines may lag behind pollinator loss, creating an extinction debt that obscures the urgency of the crisis. Thus, pollinator decline represents not only a loss of biodiversity but also a critical threat to ecosystem functioning, food security and global health.

Asymmetric responses: Why many pests thrive while many pollinators decline

The dual crisis of pollinator declines and pest proliferation is not coincidental but arises from a common underlying mechanism: climate change acts as a selective ecological filter that differentially favours species with certain life-history traits. Rather than acting as a uniform stressor, climate change reshapes insect communities by favouring species with broad environmental tolerances, high reproductive rates and flexible life histories—traits disproportionately associated with agricultural pests—while disadvantaging species that rely on narrow ecological niches and tightly synchronized interactions, such as many pollinators and natural enemies. This filtering process aligns closely with the r/K selection continuum. r-selected species, which thrive under disturbance and exhibit rapid population growth, high fecundity and early maturation, are pre-adapted to climate-induced instability, while in contrast, K-selected species, which invest in competitive ability, stable populations and delayed

reproduction, are disproportionately vulnerable to environmental change (Pianka, 1970; Reznick et al., 2002). Increasing evidence supports this framework: species with narrow thermal niches, specialized resource requirements and limited dispersal ability are consistently more vulnerable to climate-driven stress (Martén-Rodríguez et al., 2025; Neff et al., 2022), whereas generalists with high phenological plasticity and rapid population turnover are better able to track environmental variability and exploit emerging opportunities. For example, phenological sensitivity predicts population trends in Mediterranean butterflies, with more responsive species showing more stable or increasing populations (Colom et al., 2022).

Physiological and thermal constraints drive divergent responses

A key axis of asymmetry lies in species' thermal performance. For many agricultural pests, warming enhances metabolic rates and population growth, particularly in temperate regions where current temperatures are below thermal optima, leading to projected yield losses of 10%–25% per°C warming (Deutsch et al., 2018). In contrast, pollinators often operate closer to their upper thermal limits. Tropical stingless bees, *Melipona beecheii*, experience catastrophic reproductive failure when nest temperatures exceed 34–36°C (brood LT₅₀), illustrating how warming can push pollinators beyond physiological thresholds (Quezada-Euán et al., 2025). This contrast highlights a fundamental asymmetry: pests frequently benefit from warming through enhanced performance, whereas pollinators are more likely to experience thermal stress and reduced fitness.

Spatial and interaction mismatches amplify asymmetry

Climate change also drives asymmetry through spatial and interaction-level decoupling. While some plant species may expand their climatic ranges, their pollinators often cannot track these shifts. A suitable habitat for certain *Vanilla* species may expand by up to 140%, while pollinator ranges contract by 21%–40%, with overlap declining by as much as 60%–90% for specialized interactions (Watteyn et al., 2025). This creates scenarios in which plants persist or expand but fail to reproduce due to the absence of pollinators. At the same time, pest species often expand into newly suitable regions. Even where some pests (e.g. *Spodoptera exempta*) may decline in tropical regions (Li et al., 2024), many others benefit from poleward expansion and reduced climatic constraints. Thus, climate change simultaneously increases opportunities for pest expansion while constraining the ability of pollinators to maintain functional interactions.

Trait-based filtering explains community reorganization

These divergent outcomes can be traced to consistent differences in species traits. Vulnerable insect species, including many pollinators

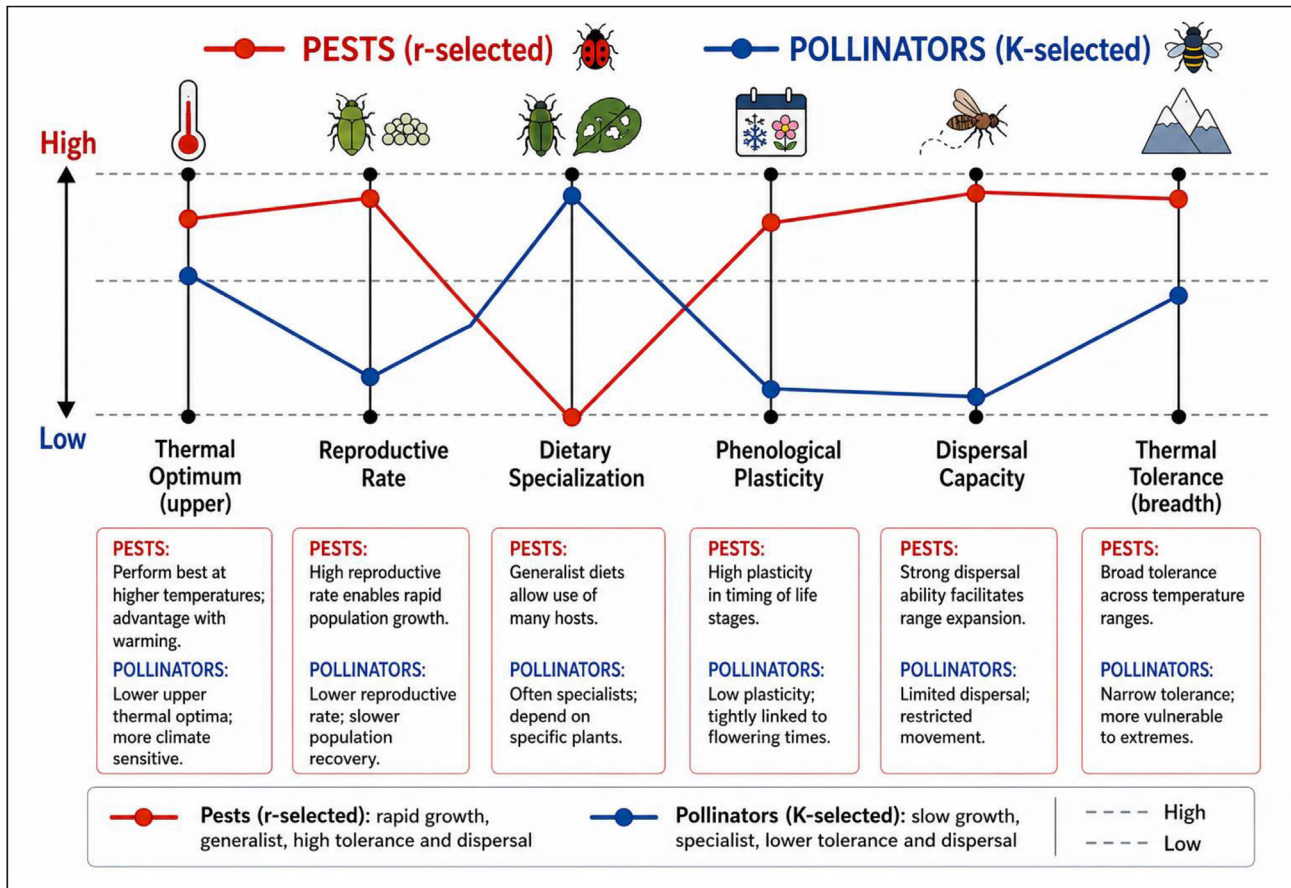


FIGURE 2 Trait-based filtering of insect communities under climate change. Climate change acts as a selective ecological filter favouring r-selected traits (high reproductive rate, broad thermal tolerance, generalist feeding, high dispersal capacity) while disadvantaging K-selected traits (low reproductive rate, narrow thermal limits, specialist mutualisms, limited dispersal). This asymmetric filtering drives pest proliferation and pollinator decline.

and ecological specialists, typically exhibit narrow thermal tolerances, high host-plant specificity, dependence on precise phenological synchrony, low reproductive rates and limited dispersal capacity (Duyck et al., 2007; García-Robledo & Baer, 2021)—a suite of K-selected traits consistent with the slow end of the fast-slow continuum (Salguero-Gómez et al., 2016) (see Figure 2). In contrast, resilient species—disproportionately represented among agricultural pests—are characterized by broad thermal tolerances, generalist feeding strategies, flexible life histories, high reproductive rates and strong dispersal capacity (Da Silva et al., 2021; Duyck et al., 2007)—classic r-selected traits. These trait differences determine how species respond to the interacting mechanisms described in, including physiological stress, phenological shifts, range dynamics and trophic disruption.

Functional consequences and biotic homogenization

The ecological consequences of this asymmetry extend to ecosystem functioning and service provision. Ecosystem functioning depends not only on species richness but also on functional diversity. A global meta-analysis of oilseed rape systems showed that functional

divergence among pollinators explains variation in crop yield beyond abundance alone (Woodcock et al., 2019). Similarly, a synthesis of 89 studies found that pollinator and natural enemy richness directly support ecosystem services, with up to 50% of the negative effects of landscape simplification mediated through biodiversity loss (Dainese et al., 2019). Experimental evidence further shows that different pollinator functional groups contribute uniquely to plant reproduction; for example, male bumblebees enhance pollen donor diversity, while abundant but less efficient taxa such as hoverflies contribute through cumulative effects (Labonté et al., 2024). These findings demonstrate that the loss of specialized or functionally distinct species cannot be compensated by increases in generalist abundance. Instead, communities undergo biotic homogenization, in which resilient generalists dominate while specialized and functionally important taxa decline (Sánchez-Bayo & Wyckhuys, 2019).

Synthesis: A predictable outcome of ecological filtering

The evidence demonstrates that the dual crisis of pollinator declines and pest proliferation is a predictable outcome of climate-driven

ecological filtering. Climate change enhances pest populations through increased metabolic rates, expanded ranges and weakened top-down control, while simultaneously constraining pollinators through physiological stress, disrupted interactions and spatial mismatches. The result is a systematic reorganization of insect communities: agricultural landscapes become increasingly dominated by thermally tolerant, generalist species, while pollinator communities undergo functional simplification and decline. This pattern is already evident in global datasets (Zattara & Aizen, 2021) and tropical empirical studies (Quezada-Euán et al., 2025), and is likely to intensify under continued warming. The tropical context is particularly concerning given severe data gaps (Boyle et al., 2025), suggesting that these changes may be underestimated and progressing undetected in biodiversity hotspots. These mechanisms demonstrate that climate change does not simply reduce insect populations but systematically reorganizes them, producing divergent outcomes across functional groups. Physiological sensitivity, phenological flexibility, dispersal capacity and trophic dependence interact to determine species resilience, while their combined effects accelerate the breakdown of ecological interactions and community stability.

TOWARDS SOLUTIONS: AN INTEGRATED MITIGATION AND CONSERVATION FRAMEWORK

Because climate change produces asymmetric outcomes—favouring pests while disadvantaging pollinators and their natural enemies—solutions must directly address this imbalance. Rather than treating pest outbreaks and pollinator decline as separate problems, an effective response requires an integrated, system-level framework that restores ecological balance across agroecosystems and natural landscapes. Addressing these impacts demands a fundamental shift from traditional IPM towards a dynamic, climate-responsive approach, as the ecological predictability underpinning conventional pest control is being systematically eroded (Fand et al., 2026). This new framework must be adaptive, predictive and focused on maintaining ecological interactions and functional diversity rather than simply suppressing pest populations.

Climate-responsive integrated Pest management

Climate-responsive IPM plays a central role in managing pest populations under changing environmental conditions. It relies on robust, real-time monitoring systems using tools ranging from remote sensing to molecular approaches to track pest populations and their natural enemies (Egan et al., 2020; Preti et al., 2021; Rizvi et al., 2021). Predictive modelling, powered by climate data, is essential for forecasting outbreaks and enabling pre-emptive rather than reactive interventions (Egan et al., 2020; Preti et al., 2021). The projections that pest-induced crop losses increase by 10%–25% per °C warming (Deutsch et al., 2018) provide a quantitative benchmark for the scale of

adaptation required, emphasizing that pest responses will vary spatially, with temperate regions experiencing both increased metabolic rates and population growth, while tropical regions may show metabolic increases partially offset by population declines. At the farm level, this translates into adaptive cultural practices such as adjusting planting schedules and selecting climate-resilient crop varieties (Skendžić et al., 2021; Subedi et al., 2023), alongside strategic habitat diversification to support natural enemy communities and strengthen ecological regulation. The recognition that some pests, such as *Spodoptera exempta*, may decline in certain regions (Li et al., 2024) further highlights the need for region-specific management strategies. At the same time, direct control methods must be recalibrated for climate variability, including optimizing biopesticides and carefully timing chemical applications to minimize resistance evolution and non-target effects (Skendžić et al., 2021; Subedi et al., 2023). Ultimately, climate-responsive IPM functions as a continuous learning system integrating monitoring, prediction and adaptive response, and its success depends on bridging the science-policy-practice gap through education, decision-support tools and economic incentives (Figure 3).

Landscape-scale conservation and restoration

Complementing farm-level interventions, landscape-scale conservation and restoration are essential to rebuild the ecological networks that sustain pollinators and natural enemies. Effective strategies include protecting intact ecosystems and restoring degraded habitats to create climate-resilient ecological networks (Eickermann et al., 2023), supported by reforestation, wildlife corridors and agri-environment schemes that incorporate flower-rich margins and native grasslands into agricultural landscapes (Curran et al., 2023; Duffus et al., 2023; Farfán-Beltrán et al., 2022; Shuey, 2013). Central to this approach is the concept of ecological infrastructure, consisting of networks of semi-natural habitat patches embedded within agricultural landscapes that provide nesting and floral resources within pollinator foraging ranges (approximately 500 m to 1 km) and enhance connectivity through features such as hedgerows and road verges (Dicks et al., 2021; Potts et al., 2016).

Conservation must also prioritize maintaining functional diversity and ecological interactions, as species interactions are often more sensitive to disturbance than species richness alone (Doré et al., 2021), and up to 50% of the negative effects of landscape simplification are mediated through biodiversity loss (Dainese et al., 2019). Climate-driven spatial mismatches—such as those identified by Watteyn et al., 2025), where plant ranges expand while pollinator ranges contract—underscore the need for interaction-aware conservation planning that ensures co-occurrence of mutually dependent species and facilitates coordinated range shifts. Effective conservation is inherently context-dependent, ranging from protecting Arctic ecosystems for specialized taxa (Chowdhury et al., 2023; Lange et al., 2023) to creating urban greenspaces that serve as native plant refuges (Duffus et al., 2023). Importantly, community engagement is critical: successful monitoring can be achieved through partnerships

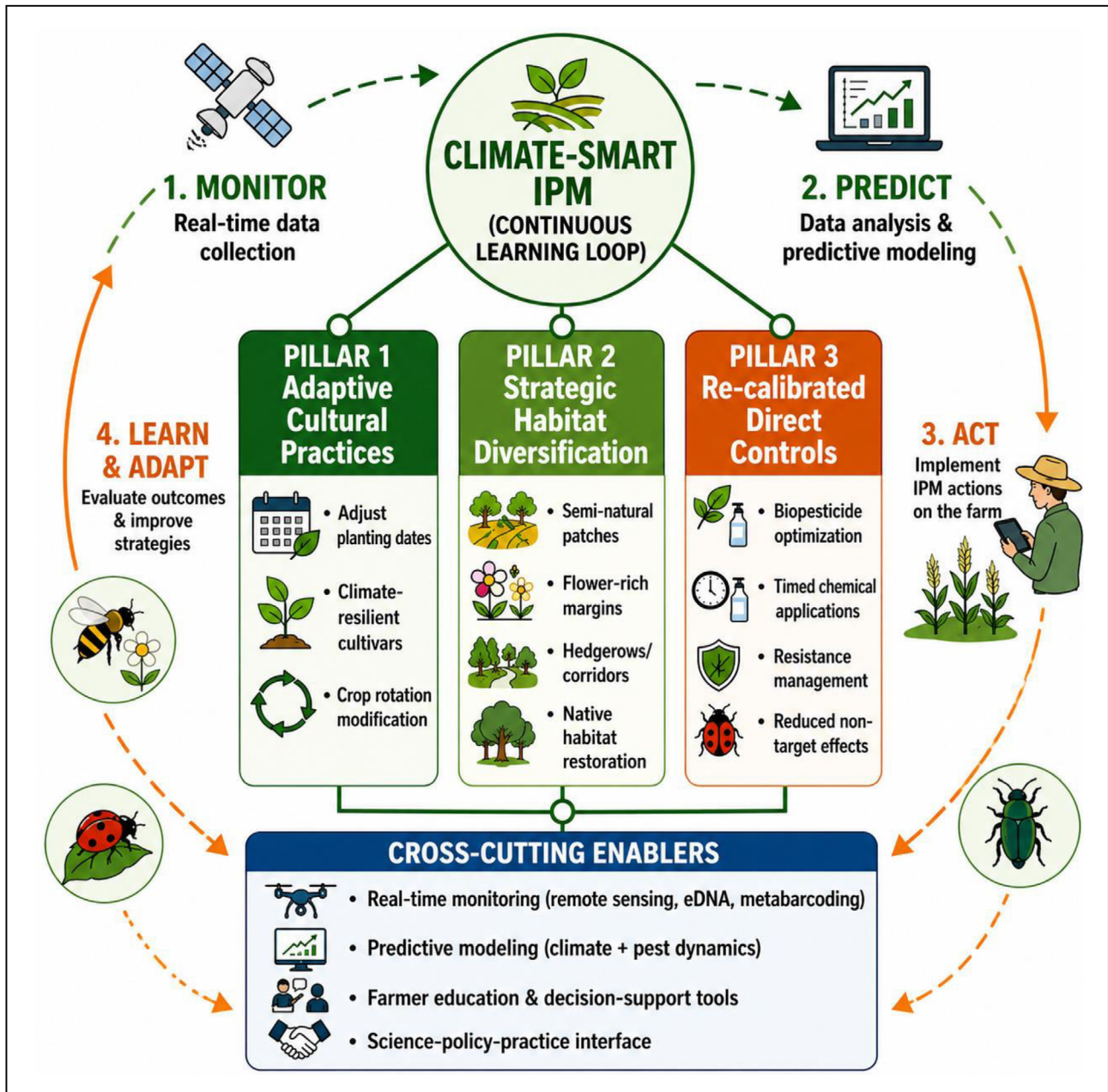


FIGURE 3 The three core pillars of climate-responsive integrated pest management. Climate-responsive IPM comprises three interconnected pillars: (1) adaptive cultural practices (e.g. adjusted planting dates, climate-resilient cultivars), (2) strategic habitat diversification (e.g. semi-natural patches, flower-rich margins, hedgerows) and (3) re-calibrated direct controls (e.g. optimized biopesticides, timed chemical applications). These pillars operate within a continuous learning loop (monitoring → prediction → action) supported by cross-cutting enablers including real-time monitoring, predictive modelling, farmer education and policy interfaces.

with local and indigenous communities, providing a scalable model that integrates conservation with livelihoods.

Challenges and limitations

Despite the promise of these strategies, significant challenges constrain their implementation. Data limitations—particularly in the Global South—hinder the detection of trends and emerging threats (Sánchez

Herrera et al., 2024; Zattara & Aizen, 2021), while a pervasive charisma bias reduces public and political support for insect conservation (Leandro et al., 2017). A fundamental tension persists between agricultural productivity and biodiversity conservation, as increasing pest pressure may drive greater pesticide use, further exacerbating pollinator decline (Deutsch et al., 2018). Additionally, current approaches remain overly species-centric and fail to capture the network-level dynamics that determine ecosystem stability. Evidence shows that climate change disrupts species interactions and destabilizes

communities, highlighting the need for a shift towards network-based frameworks (Wang et al., 2023; Watteyn et al., 2025). These challenges are compounded by major knowledge gaps, particularly in tropical regions. An estimated 85%–95% of tropical insect species remain undescribed, and long-term monitoring data are critically sparse (Boyle et al., 2025). This taxonomic impediment means that declines in tropical insect biodiversity may go undetected until they are severe, and the loss of specialized interactions may be systematically underestimated because undescribed species tend to be smaller, rarer and more specialized than described ones (Boyle et al., 2025). Accurate assessment of pollinator decline is further complicated by methodological limitations. Smaller-scale exclusion experiments may overestimate pollinator dependence due to compensatory processes at the plant level (Webber et al., 2020). Monitoring approaches also vary in effectiveness, with different methods capturing different components of pollinator communities (O'Connor et al., 2019). Global datasets exhibit strong geographic biases, with robust data from temperate regions but limited information from tropical biodiversity hotspots (Zattara & Aizen, 2021). These gaps highlight a critical challenge: pollinator declines may be most severe in regions where they are least well documented, limiting our ability to detect and respond to emerging risks.

Future research priorities

Addressing the limitations outlined above requires a coordinated, multi-scale research agenda. Six interconnected priorities emerge: (1) *Mechanistic resilience*—Develop a deeper understanding of physiological, genetic and colony-level resilience in key pollinator and pest taxa; (2) *Network-level dynamics*—Shift from species-centric studies to empirical research on multi-species interactions, phenological mismatches and trophic stability; (3) *Monitoring technology*—Advance and standardize tools such as remote sensing, metabarcoding and acoustic monitoring, ensuring they are low-cost, scalable and capable of generating measurable indicators aligned with existing policy frameworks (e.g. KMGBF headline indicators); (4) *Climate-adaptive management*—Integrate ecological theory into strategies that prioritize habitat connectivity, functional diversity and climate-smart agriculture; (5) *Tropical and taxonomic capacity*—Expand research and monitoring in tropical regions—where 85%–95% of insect species remain undescribed—through local partnerships, capacity building and sustained taxonomic investment; (6) *Policy implementation and indicator science*—Develop and validate enforceable, domestic-level metrics that translate global targets (KMGBF) and transformative change assessments (IPBES) into measurable national indicators for insect conservation, pollinator protection, pesticide reduction and habitat connectivity. These priorities are not sequential but mutually reinforcing: better monitoring (Priority 3) enables network analysis (Priority 2) and indicator development (Priority 6), which in turn informs adaptive management (Priority 4), particularly in data-sparse tropical regions (Priority 5).

CONCLUSION

Climate change is not acting as a uniform stressor on insect populations but as a selective ecological filter, actively reorganizing communities and producing a dual crisis: pollinator decline alongside pest proliferation. This asymmetry stems from fundamental life-history differences. Generalist, fast-reproducing pest species are pre-adapted to environmental instability, whereas specialized pollinators and other beneficial insects depend on stable conditions and tightly synchronized interactions, making them inherently more vulnerable. Across multiple lines of evidence, a consistent pattern emerges: pest pressure intensifies, pollinator populations decline and the ecological interactions that sustain ecosystems become increasingly decoupled. Climate-driven changes in temperature, phenology, species distributions and trophic relationships collectively destabilize networks, weakening pollination and biological control while amplifying herbivory and outbreak risk. Importantly, these changes do not simply reduce biodiversity—they restructure ecosystems, leading to loss of functional diversity, breakdown of mutualisms and growing spatial and temporal mismatches among interacting species. This reorganization is most concerning where biodiversity is highest but monitoring is most limited, suggesting current estimates may substantially underestimate the true scale of change. Addressing this crisis requires shifting from traditional species-specific management towards network-centric, climate-responsive solutions.

Fortunately, international mechanisms already provide ready-made structures for action. The Kunming-Montreal Global Biodiversity Framework (KMGBF) offers headline indicators and targets for pollinator protection, pesticide reduction and habitat connectivity. The IPBES transformative change assessment reinforces that incremental management is insufficient, calling for fundamental shifts in agricultural and conservation governance. However, these global frameworks remain aspirational without national-level implementation plans. Developing and validating enforceable, domestic-level metrics that translate global targets into measurable national indicators for insect conservation, pollinator protection, pesticide reduction and habitat connectivity is therefore essential. Without such policy alignment—and without the research needed to operationalize measurable domestic metrics—even the best scientific recommendations will remain unrealized. Ultimately, the insect crisis is not only a biodiversity issue but a systemic threat to ecosystem function and food security. Mitigating these impacts depends on our ability to understand, anticipate and manage changes at the level of entire ecological networks, ensuring the resilience of both natural and agricultural systems in a rapidly changing world.

AUTHOR CONTRIBUTIONS

Diriba Fufa Serdo: Conceptualization; formal analysis; methodology; resources; visualization; writing – original draft; writing – review and editing.

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The author declares no conflicts of interest.

DATA AVAILABILITY STATEMENT

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