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The fate of bugs: Decline under the looming threats of climate, habitat loss, and pesticides

Insects are posited to be declining globally. This stark reality poses a grave threat to the delicate balance of ecosystems that depend on these creatures for pollination, decomposition, and as a vital food source. Recent studies emphasize three interconnected forces driving this decline: The substantial impact of climate change on insect populations, widespread habitat destruction due to human activities, and the far-reaching consequences of modern agricultural practices, particularly the extensive use of pesticides. Addressing these interconnected threats is more urgent than ever, as the future of ecosystems and the benefits they provide to human societies are increasingly at risk.

Climate change, with its escalating global temperatures and erratic weather patterns, is proving to be a silent killer for insect populations worldwide. Müller et al. (2024) revealed that extreme weather anomalies, such as unseasonably warmer and drier winters, have mercilessly slashed insect biomass over the past three decades, with any temporary uptick from favorable spring conditions proving fleeting at best. This finding is further reinforced by Kazenel et al. (2024), who explored the impact of climate change on bee diversity, finding that bees with greater tolerance to heat and desiccation are more likely to survive under future climate scenarios. Collectively, these studies underscore the complexity and urgency of addressing the impacts of climate change on insect populations, challenging the notion that these effects are more severe in tropical regions.

Human activities, especially those that destroy habitats and alter environments, are acting as a relentless force driving insect populations towards the brink of collapse. Ghisbain et al. (2024) examined how anthropogenic environmental changes, including those driven by climate change, have diminished suitable habitats for European bumblebees. The fragmentation of landscapes and the depletion of essential resources present long-term threats to insect populations. This is supported by Newbold et al. (2015), who demonstrated that land-use changes driven by human activities, such as urbanization and agricultural expansion, are causing significant declines in local terrestrial biodiversity, particularly among insects. These findings highlight the critical need for habitat conservation and restoration to mitigate the negative effects of human activities on insect populations.

Modern agricultural practices, with their heavy reliance on pesticides, are wielding a double-edged sword —while they control pests, they are also devastating countless non-target insect species, pushing them towards a dangerous decline. While modern agriculture’s reliance on chemical inputs is effective for pest control, it has unintended consequences for non-target insect species. Nicholson et al. (2024) provided an in-depth analysis of the negative effects of pesticide use on European bumblebee populations, showing how these chemicals impair their reproductive capabilities and overall survival. van Klink et al. (2024) also highlighted the broader trend of insect population declines, focusing on the significant reductions in once-common species due to intensive agriculture and pesticide use. Flying insect populations have plummeted drastically in recent decades, even in protected areas, largely due to the aggressive use of pesticides and the intensification of agriculture. These practices, while aimed at pest control, have devastating consequences on non-target species, including vital pollinators, leading to widespread ecological damage. The ongoing loss of insect biomass highlights the reckless disregard for biodiversity in current farming methods, underscoring an urgent need to rethink agricultural practices that are contributing to an ecological crisis threatening the balance of entire ecosystems.

The impacts of climate change, habitat destruction, and pesticide use on insects are not isolated; rather, they interact with each other and with additional factors, forming a complex network that collectively exacerbates the decline of insect populations (Figure1). Climate change, through rising temperatures and increased frequency of extreme weather events, significantly heightens the survival pressures on insects, which are further intensified by habitat loss and pesticide application. For instance, in high-intensity agricultural systems, the synergistic effects of land-use change and climate warming have led to substantial reductions in insect abundance and species richness (Outhwaite et al., 2022). The interplay between habitat destruction and climate change is particularly pronounced in tropical regions, where insect species often have narrower thermal niches and are more sensitive to temperature fluctuations. Habitat fragmentation and loss reduce the availability of microclimatic refuges, making insects more vulnerable to the effects of climate warming. For example, when climate warming interacts with land-use changes, the decline in insect populations is more severe than when either factor operates alone, especially in areas with intensive agricultural activity (Outhwaite et al., 2022). Furthermore, the adverse effects of pesticide use may be amplified in the

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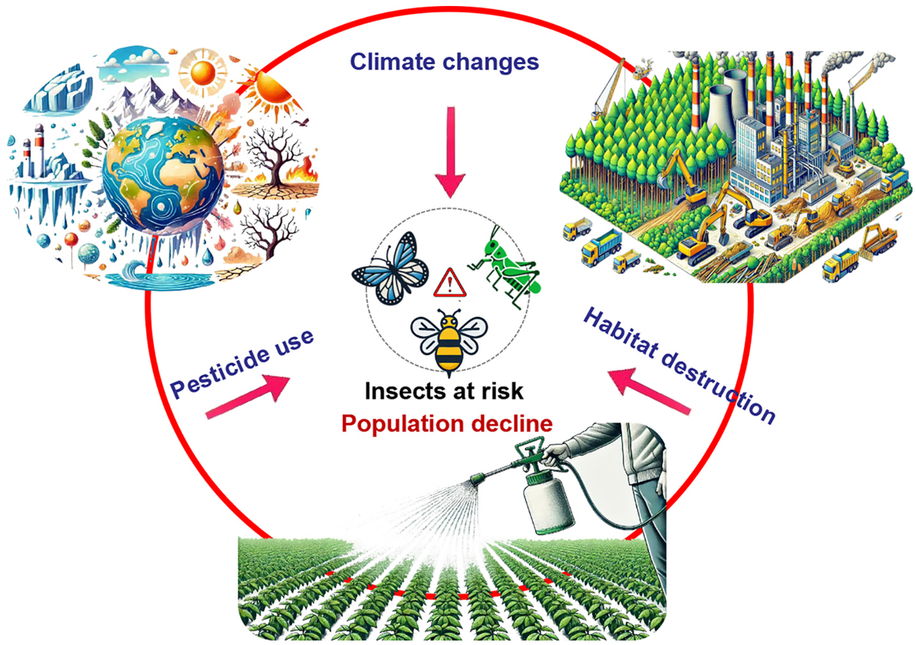

Figure 1 Key factors contributing to insect population decline: Climate change, habitat destruction, and pesticide use

context of climate change and habitat loss. For instance, pesticide residues can interact with other environmental stressors, thereby increasing the health risks and accelerating the decline of insect populations. In some cases, the combined physiological stress from pesticide exposure and other environmental pressures further exacerbates health issues in insect populations. Additionally, there is a complex interaction between pesticide use and habitat destruction. Pesticides not only directly kill target insect species but also reduce the diversity and quality of their habitats, making them more sensitive to environmental changes. The reduction and fragmentation of habitats further restrict the movement and adaptive capacity of insects when exposed to pesticide residues or other environmental pressures, which is particularly critical under the current context of climate change.

The relentless decline of insect populations is driven by a complex interplay of factors —climate change, habitat destruction, and unsustainable agricultural practices —all of which exacerbate each other in a vicious cycle. This decline is more than just an ecological crisis; it poses a direct threat to human well-being, as insects play critical roles in maintaining the balance of our ecosystems. However, reversing this downward trend requires a radical shift in our environmental practices, a task currently hindered by several significant gaps in existing research. Different studies have yielded divergent experimental results and conclusions across a range of topics, possibly due to variations in experimental conditions, geographical scope, and methodologies. For instance, there are conflicting views regarding which population sizes are more vulnerable to environmental changes: One perspective suggests that smaller populations are at greater risk of extinction due to their limited capacity to recover from widespread adverse conditions, such as severe weather events (Müller et al., 2024). Conversely, another viewpoint argues that the most abundant species have generally undergone the most severe declines, contradicting the common assumption that biodiversity loss is primarily driven by the decline of rare species (van Klink et al., 2024). Similar discrepancies are evident in research on butterfly population declines, where some studies emphasize pesticides, particularly neonicotinoids, as the primary drivers due to their lethal and sub-lethal effects on non-target insects (Van Deynze et al., 2024), while others highlight the importance of climate change and habitat loss, especially in regions impacted by urbanization and shifting climates, suggesting that complex interactions among these factors may obscure the impact of any single cause (Shirey et al., 2024). Moreover, investigations into the combined effects of pesticides and other factors often face challenges due to laboratory studies employing pesticide concentrations that do not correspond to realistic environmental conditions. This discrepancy between laboratory and field data limits the relevance of findings to natural environments. Addressing these inconsistencies requires a deeper understanding of the actual pesticide exposure levels experienced by wild insects (Mesnage et al., 2021). However, the lack of specific data on these exposure levels across diverse contexts further complicates efforts to accurately assess the real-world risks posed by the interaction between pesticides and other environmental factors (Mesnage et al., 2021). In addition, many studies tend to focus on individual drivers such as climate change without fully considering the complex interactions between multiple factors like pesticide use, habitat loss, and invasive species (Kazenel et al., 2024). This narrow scope leaves critical gaps in understanding how these drivers collectively influence insect population dynamics. Furthermore, while macro-level studies provide valuable insights into general trends in insect biomass, they often fail to capture the micro-level physiological and ecological responses of individual insects to environmental changes, which are crucial for understanding species-specific adaptations or vulnerabilities (Müller et al., 2024). Moreover, current research is often geographically limited, focusing predominantly on specific regions (such as Central Europe) or a small number of insect groups (like bumblebees), which restricts the broader applicability of their findings (Nicholson et al., 2024). This geographical and species bias makes it difficult to develop a comprehensive understanding of the global insect decline. Compounding these limitations, even studies with long-term datasets frequently lack the necessary temporal depth to fully capture how insect populations respond to environmental changes over extended periods (Müller et al., 2024).

To address these issues, a more integrative approach is needed, involving interdisciplinary integration and multi-factor modeling to uncover complex interactions. This should include the integration of macro- and micro-scale data, coupled with long-term dynamic monitoring to capture both broad-scale patterns and species-specific responses to environmental changes. Additionally, combining laboratory and field experiments will enhance the external validity of findings. Utilizing big data and artificial intelligence can help identify complex patterns and underlying causal relationships, while balancing global collaboration with localized studies will enable the development of context-specific conservation strategies. Only through such comprehensive research, combined with sustained global commitment to monitoring and innovative conservation strategies, can we hope to reverse the decline of insect populations. The stakes are high: Protecting the vital ecosystem services that insects provide is not merely an option—it is imperative for the future of all life on Earth.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

H.Z. conceived the idea. F.Y.Y. wrote the draft. X.Z. and H.Z. revised and edited the draft. All authors read and approved the final version of the manuscript.

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REFERENCES

Ghisbain G, Thiery W, Massonnet F, et al. 2024. Projected decline in European bumblebee populations in the twenty-first century. *Nature*, **628**(8007): 337–341.

Kazenel MR, Wright KW, Griswold T, et al. 2024. Heat and desiccation tolerances predict bee abundance under climate change. *Nature*, **628**(8007): 342–348.

Mesnage R, Straw EA, Antoniou MN, et al. 2021. Improving pesticide-use data for the EU. *Nature Ecology & Evolution*, **5**(12): 1560.

Müller J, Hothorn T, Yuan Y, et al. 2024. Weather explains the decline and rise of insect biomass over 34 years. *Nature*, **628**(8007): 349–354.

Newbold T, Hudson LN, Hill SLL, et al. 2015. Global effects of land use on local terrestrial biodiversity. *Nature*, **520**(7545): 45–50.

Nicholson CC, Knapp J, Kiljanek T, et al. 2024. Pesticide use negatively affects bumble bees across European landscapes. *Nature*, **628**(8007): 355–358.

Outhwaite CL, McCann P, Newbold T. 2022. Agriculture and climate change are reshaping insect biodiversity worldwide. *Nature*, **605**(7908): 97–102.

Shirey V, Neupane N, Guralnick R, et al. 2024. Rising minimum temperatures contribute to 50 years of occupancy decline among cold-adapted Arctic and boreal butterflies in North America. *Global Change Biology*, **30**(2): e17205.

Van Deynze B, Swinton SM, Hennessy DA, et al. 2024. Insecticides, more than herbicides, land use, and climate, are associated with declines in butterfly species richness and abundance in the American Midwest. *PLoS One*, **19**(6): e0304319.

van Klink R, Bowler DE, Gongalsky KB, et al. 2024. Disproportionate declines of formerly abundant species underlie insect loss. *Nature*, **628**(8007): 359–364.