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Winged warning: Understanding insect declines in a changing world

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Abstract
This research paper explores the significant effects of changing environmental conditions on global insect populations. Insects, crucial for their ecosystem services such as pollination, nutrient cycling and serving as a food source for other species, are experiencing dramatic population shifts due to factors like climate change, habitat destruction, pollution, and agricultural practices. This study thoroughly examines trends, identifies causes and assesses the far-reaching consequences of these changes. The research emphasizes the crucial link between insect health, ecosystem stability and human well-being, highlighting how declining insect populations impact biodiversity and ecosystem services, thereby affecting human livelihoods. The paper advocates for immediate action to preserve insect diversity, essential for ecological balance and the continuation of vital ecosystem functions critical to human survival.

Keywords: Insects, climate change, diversity, ecosystem

Introduction

The diversity of life on Earth today is vast, with arthropods representing one of the most varied groups, dating back from the Cambrian period to modern times (Sahney *et al*., 2010) [34]. These creatures share unique features such as distinct body segmentation, a robust semi-rigid exoskeleton that provides support and protection, and jointed limbs for movement. The Phylum Arthropoda consists of 1,214,295 species, with the class Insecta being the largest class, comprising 1,013,825 species (Stork, 2018) [39]. The class Insecta, which includes all insects, is diverse and characterized by different developmental patterns. This class is divided into approximately 29 orders based on shared physical and developmental traits (Table-1). These orders are further grouped according to their metamorphosis process, the biological mechanism through which insects grow and develop.

***Holometabolous* Development:** They undergo complete metamorphosis, transitioning through four distinct life stages: egg, larva, pupa, and adult (Lepidoptera, Coleoptera, Hymenoptera and Diptera).

***Hemimetabolous* Development:** These insects undergo incomplete metamorphosis. They do not have a pupal stage, and the young (called nymphs) generally resemble the adults but lack fully developed wings and reproductive structures until they mature (Orthoptera and Hemiptera).

***Ametabolous* Development:** They do not undergo significant changes as they grow; there is no distinction between the larval and adult stages, and they lack a nymphal phase. These are usually primitive, like silverfish, and this development type is less common than the others.

The significance of insects extends beyond their sheer numbers; they play crucial roles in ecosystems, affect agriculture, human health and natural resources. Their vast diversity and ecological functions have made them central to research in various scientific fields including biomechanics, climate change adaptation, developmental biology, ecology, evolutionary studies, genetics, paleolimnology, and physiology (Sahney *et al*., 2010) [34].

Insects play a pivotal role in the Earth's ecosystems. Their contribution to pollination, decomposition, and as foundational elements of food webs underscores their importance. However, drastic shifts in insect populations due to climate change, habitat loss, and pollution have sparked significant concern, threatening biodiversity, agricultural output and health. Pollinators, such as bees, butterflies, and other insects, are crucial for the reproduction of over 85% of the world's flowering plants, and more than two-third of the world's crop species. Similarly, insects contribute significantly to nutrient cycling and the decomposition of organic matter, influencing soil health and plant growth (Nichols *et al*., 2008) [30].

By exploring the causes, effects, and solutions related to insect population changes, this research aims to highlight the urgent need for conservation and sustainable management practices to protect these crucial creatures and by extension, the ecosystems and human populations that depend on them.

Table 1: Estimated numbers of described species across the largest orders of insects

Class Insecta Orders	Description	Approximate Number of Species (Stork, 2018) [39]
Coleoptera	Beetles, members of this order boast hardened forewings and intricate body structures, serving diverse ecological roles from pollinators to predators. They are celebrated for their vivid colours and striking shapes, fascinating collectors and researchers alike.	386,500
Lepidoptera	Encompassing butterflies and moths. They are revered for their stunning wings and metamorphic life cycles. Their delicate beauty and vital role in pollination capture the imagination and underscore nature's interconnectedness.	157,338
Diptera	Flies and mosquitoes reside in this group, characterized by their single pair of wings and	155,477

	compound eyes. Despite their pesky reputation, they're crucial for ecosystems, acting as pollinators, decomposers, and a food source for many species.	
Hymenoptera	Bees, wasps, and ants belong here, recognized for their complex social structures and, in many cases, their stinging capabilities. They're indispensable for pollination, biological control, and providing insights into social behavior.	116,861
Ephemeroptera	Mayflies, these insects are famed for their short adult life spans and elegant, transparent wings. They're key indicators of freshwater health and serve as essential food for various aquatic animals.	3,240
Hemiptera	This order includes true bugs like aphids and cicadas, known for their piercing and sucking mouthparts. They play diverse ecological roles, from pest control agents to symbols of seasonal change.	103,590
Odonata	Dragonflies and damselflies: known for their large eyes, long bodies, and powerful flying ability. These predators are admired for their dazzling colors and aerial agility. They're crucial for mosquito control and act as indicators of wetland health.	5,899
Orthoptera	Grasshoppers, crickets, and locusts make up this group, noted for their jumping hind legs and musical stridulations. They're vital in nutrient recycling and serve as important food sources in many ecosystems.	23,855
Blattodea	Encompassing cockroaches and termites, members of this order are often viewed unfavourably but are important decomposers and ecosystem engineers. Their social structures and resilience offer fascinating scientific insights.	7,314
Neuroptera	Lacewings, antlions, and dobsonflies are predators with delicate, veined wings, playing significant roles in controlling pest populations and maintaining plant health.	5,868
Phasmida	Stick and leaf insects belong to this order, masters of camouflage. They intrigue with their plant mimicry abilities, serving as a window into evolutionary adaptation and insect-plant interactions.	3,014
Trichoptera	Caddisflies, akin to aquatic butterflies, construct protective silk cases as larvae. They're vital for freshwater ecosystems, contributing to the bioengineering of streams and rivers.	14,391
Thysanoptera	Thrips, minute yet impactful, reside in this order, affecting plants by feeding on them or acting as pollinators. Despite their size, they have major impacts on agriculture and horticulture.	5,864
Siphonaptera	Fleas, the blood-feeding parasites, are known for their role in transmitting diseases but also for their remarkable jumping abilities. They're a subject of medical and biological research, highlighting the complexity of host-parasite relationships.	2,075
Psocoptera	Barklice and booklice, though less known, play crucial roles as detritivores, cleaning up organic debris and contributing to the decay process, highlighting nature's recycling system.	5,720
Plecoptera	Stoneflies, aquatic insects, are indicators of water quality and essential parts of freshwater ecosystems. Their presence and diversity reflect the health of their aquatic habitats.	3,743
Mantodea	Praying mantises, with their iconic raptorial forelegs and keen hunting skills, are natural pest controllers and subjects of fascination due to their predatory behaviors and unusual mating rituals.	2,400
Phthiraptera	Louse, these parasitic insects are closely adapted to their hosts, offering insights into coevolution and the dynamics of host-parasite relationships.	5,102
Dermaptera	Earwigs, recognized by their pincers, contribute to the decomposition of plant material and serve as prey for many predators, playing subtle yet important roles in garden ecosystems.	1978

Several insect orders, including Order Archaeognatha (513); Zygentoma (560); Embioptera (463); Grylloblattodea (34); Mantophasmatodea (15); Zoraptera (37); Strepsiptera (609); Megaloptera (354); Raphidioptera (254), Mecoptera (757) having less than 1,000 described species, underscoring their unique and often overlooked diversity within the insect world (Stork, 2018) [39].

The Role of Insects in Ecosystems

Insects are indispensable to most ecosystems. They perform critical roles (Table-2) that contribute significantly to the functioning and health of ecosystems around the globe.

Table 2: Role of Insects in Ecosystems

Role of Insects	Description	Impact on Ecosystem
Pollination	Insects like bees, beetles butterflies, and moths transfer pollen between flowering plants, which is crucial for the reproduction of many types of plants, including many fruits, vegetables, and nuts.	Facilitates the reproduction of over 75% of the world's flowering plants and about 35% of the world's food crops, contributing to biodiversity and food security (Halls, 2018) [18].
Decomposition and Nutrient Cycling:	Insects such as termites, dung beetles, and various larval forms consume dead organic matter, breaking it down into simpler substances. Carrion beetles serve as nature's undertakers, being drawn to the carcasses of deceased animals.	Speeds up the decomposition process, returning nutrients to the soil, enhancing soil fertility, and maintaining ecosystem health (Yang & Gratton, 2014) [50].
Soil Aeration	While earthworms are celebrated soil engineers, insects like beetles, ants and termites play similar roles. Dung	Increases soil aeration and water absorption, promoting healthier and more productive plant growth (Alyokhin *et al.*,

	beetles bury faeces, aiding in nutrient recycling and soil structure improvement. Ants underground colonies create tunnels, facilitating soil mixing and enhancing water infiltration, akin to natural tilling.	2020) [1].
Biological Control	The ladybug, often portrayed for its gentle appearance, is actually a voracious predator of aphids, playing a crucial role in protecting plants from potential pest damage. Insects like lacewings, and parasitic wasps prey on pest insects, naturally controlling their populations.	Reduces the need for chemical pesticides, lowers agricultural costs, and minimizes environmental and health hazards associated with pesticide use (Sarkar *et al*., 2018) [36].
Food Source and Food Web Support	Insects are a fundamental part of many food webs. Many species, including birds, amphibians, reptiles, and small mammals, rely on insects as a primary food source.	Supports biodiversity by maintaining balanced predator-prey relationships within food webs (Hallmann *et al*., 2014) [16].
Seed Dispersal	Insects such as ants and beetles help in the dispersal of seeds by carrying them to new locations, often in exchange for a nutritious seed coating.	Aids in plant diversification and colonization, leading to robust and resilient ecosystems (Warren and Giladi, 2014) [46].
Indicator Species	Insects such as mayflies serve as important indicators of water quality in freshwater environments and fireflies or lightning bugs are useful indicators of land health and ecosystem quality.	Insects can act as bioindicators, providing information about the health of an ecosystem (Wang *et al*., 2023) [44].
Genetic and Medical Research	Fruit flies, specifically *Drosophila melanogaster*, are widely used in genetic studies due to their short life cycle, high reproductive rate, and well-understood genome.	Insects are used in scientific research due to their short life cycles and genetic simplicity, contributing to advances in genetics, medicine, and environmental science (Markow, 2015) [26]
Insects as Disease Vectors	Mosquitoes, including *Anopheles*, *Aedes*, and *Culex* species, transmit numerous diseases. Furthermore, ticks serve as vectors for diseases such as Rocky Mountain spotted fever and tick-borne encephalitis, affecting both human and animal health.	Malaria, spread by infected female *Anopheles* mosquitoes, remains a significant global health concern, especially in Africa, Asia, and South America. Mosquitoes also carry diseases like dengue, Zika, and West Nile virus, each with distinct health and economic impacts. Additionally, ticks, though arachnids, are another important group of disease vectors (Wilson *et al*., 2020) [48].

Factors Contributing to Changing Environments

The global decline in insect populations can be attributed to various environmental changes (Table-3).

Table 3: Factors Contributing to Changing Environments

Factor	Description	Expanded Impact on Environment
Climate Change	Resulting primarily from the burning of fossil fuels, deforestation, and industrial processes, climate change is characterized by alterations in global temperatures, precipitation patterns, sea level rise, and an increase in extreme weather events like hurricanes and droughts.	Disrupts ecosystems by altering habitat conditions, leading to species migration and extinction, changes in agricultural productivity, and increased frequency of natural disasters. Rising temperatures, changing precipitation patterns, and extreme weather events can disrupt the phenology of insects, affecting their reproduction and survival rates. For instance, warmer winters and earlier springs can lead to mismatches between the life cycles of pollinators and the flowering times of plants they rely on for food (Hegland *et al*., 2009) [19].
Deforestation	The large-scale removal of forests for agricultural expansion, timber extraction, and urban development.	Leads to habitat destruction affecting countless species, reduces Earth's capacity to absorb carbon dioxide, exacerbating climate change, and disrupts local and global water cycles (Kumar *et al*., 2022) [23].
Pollution	Encompasses the release of harmful substances into air, water, and soil, including chemical runoff from agriculture, industrial waste, plastic pollution, and emission of toxic gases.	Harms aquatic and terrestrial life, contaminates drinking water sources, contributes to respiratory and other health problems in humans, and accumulates in ecosystems, leading to long-term degradation. Chemical pollutants, such as heavy metals and persistent organic pollutants, can accumulate in insects, leading to lethal and sub-lethal effects (Owens *et al*., 2020) [31].
Overfishing	Excessive fishing practices that deplete fish stocks faster than they can replenish, often due to lack of regulation, illegal fishing activities, and the use of destructive fishing techniques.	Leads to the collapse of fish populations, affecting marine food webs, leading to the loss of marine biodiversity and disrupting livelihoods of communities reliant on fishing (Mollmann *et al*., 2008) [27].
Urbanization	The conversion of natural lands into urban areas due to population growth and economic development, leading to habitat fragmentation and increased demand for resources.	Reduces biodiversity, increases surface runoff leading to flooding and water pollution, contributes to the urban heat island effect, and strains local resources and infrastructure. Habitats such as forests, meadows, and wetlands are crucial for many insects species survival, providing essential resources like food, shelter, and breeding sites (Fahrig *et al*., 2011) [11].
Agricultural Practices	Refers to modern farming techniques that include extensive use of synthetic fertilizers, pesticides, and herbicides, as well as practices like monoculture and intensive livestock farming.	Results in soil erosion, nutrient depletion, chemical runoff leading to water pollution, loss of insect populations, and reduced genetic diversity in crops and livestock. Pesticides, particularly neonicotinoids, have been linked to significant declines in bee populations and other non-target insect species (Goulson, 2013) [14].
Industrial Activities	Involves the extraction of natural resources, manufacturing processes, and energy	Causes significant air and water pollution, leads to habitat destruction, contributes to global warming through greenhouse gas emissions, and

	production, which often lead to environmental pollution and waste generation.	results in hazardous waste accumulation (Kabir *et al*., 2012) [22].

Effects of Changing Environment on Insect Populations

The changing environment exerts considerable pressure on insect populations, impacting their distribution, abundance, and survival. This section delves into the consequences of environmental alterations on insects, highlighting specific case studies and the underlying biological mechanisms.

Temperature and Climate Change: Climate change, particularly temperature increases, directly affects insects physiological processes, development rates, and life cycles. Many insects are ectothermic; their body temperature and metabolic rates are determined by ambient conditions. Rising temperatures can accelerate life cycles but also increase mortality rates if conditions become intolerably hot or if mismatches occur in food availability. Furthermore, climate change can shift the geographic distribution of insects, with species moving towards higher altitudes or latitudes in search of suitable habitats, leading to altered community compositions and potential local extinctions. Ladybird larvae, in response to increasing temperatures, deposit more long-chain hydrocarbons. These substances act as deterrent pheromones to prevent further egg-laying (Sentis *et al*., 2015) [37]. *Drosophila melanogaster*, when subjected to short-term ozone fumigation at levels ranging from 40 to 120 ppb, experience a loss in their biological functions. In the female moth, *Striacosta albicosta*, an increase in the temperature difference between the daylight and the night significantly impacts their calling behavior (Mozūraitis and Būda, 2006) [28].

Habitat Loss and Fragmentation: The reduction and fragmentation of habitats due to human activities like deforestation, urbanization, and agricultural expansion significantly impact insect diversity and population dynamics. Habitat loss not only reduces the available living space for insects but also fragments populations, disrupting mating, foraging, and migration patterns. This isolation can lead to reduced genetic diversity, increased inbreeding, and higher vulnerability to environmental stresses, contributing to population declines (Wilcove *et al*., 1998) [47].

Pesticides and Chemical Pollutants: The extensive use of pesticides in agriculture poses severe risks to non-target insect species. Pesticides can cause immediate mortality, sublethal effects such as impaired reproduction and navigation, and chronic health issues in insects. For example, neonicotinoids have been linked to significant declines in bee populations, affecting their foraging behavior, reproduction, and immune function. Moreover, pollutants from industrial and urban sources can contaminate insect habitats, leading to toxic effects and disrupting ecological interactions. Western North American monarch butterfly populations drastically fell from millions to under 30,000 due to neonicotinoid insecticides, habitat loss, and extreme weather, hitting an all-time low in 2020 (1899 in numbers). However, more typical weather in 2021 and 2022 helped numbers recover to around 300,000. While natural predators and human activities have some impact, they are not the primary threats to the monarchs (James, 2024) [21]. Heavy metal pollution alters the morphology and physiology of insect pests, such as aphids and butterfly larvae. Skaldina *et al*., (2018) [38] discovered that the red wood ant *Formica lugubris* accumulates heavy metals like Aluminum (Al), Cadmium (Cd), Cobalt (Co), Copper (Cu), Iron (Fe), Nickel (Ni), Lead (Pb), and Zinc (Zn) in their bodies as well as their nest, showcasing their potential as pollution bioindicators.

Invasive Species and Diseases: The introduction of invasive species and pathogens can drastically alter ecosystems and pose direct threats to native insect populations. Invasive predators, competitors, or parasites can decimate native insects, while new diseases can spread rapidly among vulnerable populations. For instance, the spread of the fungal pathogen *Nosema ceranae* has been associated with significant declines in honeybee colonies worldwide. Understanding these impacts is crucial for developing effective conservation strategies and ensuring the sustainability of ecosystems and the services they provide (Wagner, 2020) [43].

Consequences of Insect Population Changes

The decline in insect populations carries significant ecological, economic, and social consequences.

Impact on Ecosystem Services: Insects are fundamental to various ecosystem services, including pollination, nutrient cycling, and biological pest control. The reduction in insect abundance and diversity can lead to a decline in these services, which are crucial for ecosystem resilience and productivity (Potts *et al*., 2016) [32]. For example, pollinator declines can result in lower fruit and seed production, compromising plant reproduction and biodiversity. Similarly, the loss of decomposer species can affect soil health and nutrient availability, impacting plant growth and carbon cycling.

Effects on Food Webs and Biodiversity: Insects form the base of many terrestrial and freshwater food webs. Their decline can have cascading effects throughout the ecosystem, affecting the survival and reproduction of insectivorous organisms, such as birds, bats, and amphibians (Dirzo *et al*., 2014) [10]. This can lead to altered community structures, reduced biodiversity, and the loss of certain functions within ecosystems, further destabilizing environmental balance and resilience.

Implications for Agriculture and Food Security: The decline in insect populations poses direct threats to crop production, food security, and agricultural economies. Reduced pollination can lead to decreased yields and increased production costs, impacting the availability and price of food globally. Additionally, the loss of natural pest predators necessitates greater reliance on chemical pesticides, which can have adverse environmental and human health effects (Sabbahi, 2022) [33].

Human Health and Cultural Impacts: Beyond their ecological and economic roles, insects also have cultural and health-related significance. Certain species are used in traditional medicines, while others are important for recreational activities such as fishing and birdwatching (Wilson, 2017) [49]. The decline in insect populations can thus affect cultural practices, recreational opportunities, and even mental well-being. Furthermore, the loss of insect-mediated ecosystem services can exacerbate environmental health issues, such as air and water purification.

Responses and Solutions

The decline in insect populations due to changing environmental conditions poses significant challenges but also presents opportunities for global, regional, and local responses.

Conservation and Habitat Restoration: Protecting existing habitats and restoring degraded ecosystems are critical steps in supporting insect populations. Efforts should focus on creating and maintaining diverse habitats, such as wildflower meadows, forests, and wetlands, which provide essential resources for various insect species (Thomas, 2016) [40]. Establishing protected areas and ecological corridors can also help preserve biodiversity and facilitate species migration in response to climate change.

Sustainable Agricultural Practices: Transitioning to more sustainable agricultural methods can significantly reduce the negative impacts on insect populations. Practices such as integrated pest management, organic farming, and agroecology emphasize the reduction of chemical pesticide use, the conservation of natural enemies of pests, and the maintenance of habitat diversity within agricultural landscapes. Promoting crop diversity and implementing buffer strips or hedgerows can further support insect diversity and ecosystem services (Nicholls *et al*., 2016) [29].

Climate Change Mitigation and Adaptation: Addressing the root causes of climate change is essential for protecting insect populations and ecosystems as a whole. Reducing greenhouse gas emissions through energy conservation, renewable energy sources, and sustainable transportation can mitigate climate change's impact on insects. Additionally, conservation strategies should incorporate climate adaptation measures, such as preserving thermal refugia and assisting species migration, to help ecosystems and their insect inhabitants cope with changing conditions (Heller & Zavaleta, 2009) [20].

Public Engagement and Policy Action: Raising public awareness and engaging communities in insect conservation can lead to broader support for protective measures. Educational programs, citizen science projects, and community-based conservation initiatives can empower individuals to contribute to insect preservation. Furthermore, informed policy decisions and legislation, such as banning harmful pesticides and allocating funds for conservation projects, are crucial for enacting large-scale environmental protections (Cardoso *et al*., 2020) [6].

Research and Monitoring: Continued research on insect populations, their roles in ecosystems, and the effects of environmental changes is vital for forming conservation strategies. Long-term monitoring programs can provide valuable data on population trends, helping to identify at-risk species and assess the effectiveness of conservation efforts. Collaborative research and data sharing among scientists, policymakers, and conservationists can enhance our understanding and response to insect declines.

Global Reports on Population Trend in Insects

Studies across Denmark, The Netherlands and Belgium-Luxembourg since 1950 reveal significant declines in carabid species, particularly those native to dry, nutrient-poor grasslands and heath vegetation. Habitat loss is identified as the primary cause, affecting mainly species with narrow ecological ranges (Desender and Turin, 1989) [9].

Van Swaay (1990) found that calculating the percentage of squares reporting butterflies over five years revealed six species groups in the Netherlands: 46% decreased or became extinct, 27% hardly changed, 11% expanded their range, and 16% fluctuated. This underscore dynamic shifts in butterfly populations, emphasizing the need for targeted conservation efforts.

Maes and Dyck, 2001 revealed a sharp decline in species in the 20th century by examining data from Flanders' butterfly mapping scheme, with 19 extinctions and half of remaining species now threatened. Intensive agriculture and urban expansion drove an eightfold increase in extinction rates, with hot spots mainly in the northeast, highlighting the urgent need for conservation measures.

Since 1968, the Rothamsted Insect Survey reveals that 54% of Britain's macro-moth species have declined, with 21% facing severe drops in population. This trend, potentially tied to habitat and climate changes, outpaces declines in other British wildlife, signalling urgent concerns for ecosystems and hinting at broader, unnoticed insect declines in temperate zones (Conrad *et al*., 2004) [8].

Over 35 years, two-thirds of studied macro-moth species in Britain have declined, with 21% (71 species) dropping over 30% annually; these would be considered threatened under IUCN criteria. This decline, surpassing that of British butterflies, birds, and plants, raises significant concerns for insect-dependent wildlife and suggests broader, yet undetected, declines among temperate insects (Conrad *et al*., 2006) [7].

The study by Kuussaari *et al*., 2007 [24] examines the distribution of 74 butterfly species in Finland over 50 years, finding a 60% decline in species inhabiting semi-natural grasslands. Conversely, species in open field margins and forest edges have mostly seen increases. This reflects shifts in land use and habitat availability, with variations in species trends linked to their ecological characteristics and overwintering habits.

Long-term monitoring near Liberia, Costa Rica, reveals a significant decline in bee diversity and abundance since 1972, coinciding with increased human population and altered land use. While the natural habitat faced degradation, urban growth introduced diverse ornamental plants, attracting native bees. Despite overall declines, these urban areas may now act as refuges, maintaining reduced but consistent bee visits to the leguminous tree *Andira inermis* (Frankie *et al*., 2009) [13].

A three-year study in the United States reveals significant declines in four out of eight studied bumble bee species, with abundances down by up to 96% and ranges contracted by 23–87% in the last two decades. Declines correlate with higher levels of *Nosema bombi* pathogen infection and reduced genetic diversity, suggesting these factors as critical predictors of bumble bee population declines in North America (Cameron *et al*., 2011) [5].

During the 2009–2010 overwintering season, the eastern North American monarch butterfly population hit a record low in Mexico, continuing a 15-year decline. Despite a slight increase, the area remained low in 2010–2011. Factors like forest degradation, loss of breeding habitat due to GM crops, and severe weather contribute to this decline, raising concerns about the monarchs long-term survival (Brower *et al*., 2012) [3].

A 140-year study on northeastern U.S. bees shows minor overall declines but significant losses in Bombus species, with notable shifts in community traits. This points to resilience among native bees yet underscores the urgent need for conservation focused on specific traits and climate impacts (Bartomeus *et al*., 2013) [2].

Over 120 years, global changes have significantly disrupted plant-pollinator interactions in an Illinois forest USA, leading to 50% bee species loss and degrading network structures. This results from phenology shifts, species extinctions, and reduced spatial co-occurrence, decreasing pollination quality and quantity. Despite historical flexibility, future network resilience is doubtful (Burkle *et al*., 2013) [4].

In the current global biodiversity crisis, 322 terrestrial vertebrates have gone extinct since 1500, while invertebrate populations, including 33% of insects, have faced steep declines, particularly among Orthoptera, Coleoptera, Hymenoptera (Formicidae), Lepidoptera, and Odonata. This "Anthropocene defaunation" is a key driver behind the planet's sixth mass extinction and is drastically changing global ecosystems (Dirzo *et al*., 2014) [10].

Over nearly 2 centuries in southeastern Germany, butterfly and burnet moth species diversity declined from 117 in 1840 to 71 in 2013, with a decrease in specialists and an increase in generalists. Climate change and nitrogen loads likely contribute, emphasizing the need for urgent conservation action (Habel., *et al*., 2016) [15].

Recent studies link the decline in Northern California's lowland butterfly populations to increased neonicotinoid insecticide use, alongside climatic changes and land-use shifts. This correlation is especially pronounced in smaller-bodied species, underscoring the potential impact of neonicotinoids on non-target insects and highlighting the need for further research (Forister *et al*., 2016) [12].

A 27-year study across 63 German nature reserves shows a dramatic 76% seasonal and 82% mid-summer decline in flying insect biomass, irrespective of habitat type. This significant loss, not fully explained by weather, land use, or habitat changes, underscores a critical, previously unrecognized threat to ecosystem services and species relying on insects for food (Hallmann *et al*., 2017) [17].

van Strien *et al*., 2019 [41] highlighted a drastic decline in butterfly populations in the Netherlands, with an estimated 84% reduction from 1890 to 2017, affecting various habitats. Despite some stabilization in grassland and woodland areas, the decline continues in heathland, indicating significant ecological challenges.

Global insect populations, particularly of order Lepidoptera, Hymenoptera and Coleoptera, are under threat, with an estimated 40% at risk of extinction from habitat loss, pollution, and climate change. Swift shifts to eco-friendly agriculture and pollution remediation are vital to prevent further loss and safeguard ecosystem functions (Sánchez-Bayo and Wyckhuys, 2019) [35].

Conclusion

The alarming decline in global insect populations, triggered by multifaceted environmental changes, poses significant threats to ecosystem services, biodiversity, agricultural productivity and human well-being. This comprehensive analysis underscores the intricate relationships between insects and various ecological processes, highlighting the profound consequences of their loss. Climate change, habitat destruction, pollution, and unsustainable agricultural practices have been identified as critical drivers behind the decreasing insect numbers, each contributing to a scenario where the resilience of natural systems is severely compromised.

Insect declines signal a broader environmental crisis that requires immediate and concerted efforts across multiple sectors. The interdependence between insects, healthy ecosystems, and human societies must be overstressed; thus, preserving insect populations is not merely an ecological obligation but a necessity for ensuring sustainable futures. The strategies outlined in this paper ranging from habitat conservation and sustainable agriculture to public engagement and policy reforms provide a roadmap for mitigating the adverse effects on insect populations. However, the success of these approaches hinges on a collective commitment from global to local levels, integrating scientific research with public policy and community action. Addressing the insect decline crisis is a monumental challenge, yet it also presents opportunities for innovation, collaboration, and sustainable growth. Ultimately, the preservation of insect diversity and abundance is not merely a matter of ecological concern but a vital necessity for maintaining the balance of life on Earth. The time to act is now; by committing to sustainable practices and valuing the smallest inhabitants of our planet, we can ensure a healthier, more resilient, and biodiverse world for generations to come.

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