

Decline in insect biodiversity and its multi-scalar conservation strategies - A review

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Abstract

Insects are the biological supporting system of our world as they make up about 80 per cent of the known animal species and have a 400-million-year evolution record. They play a key role in nutrient recycling, soil turnover and pollination of vital food crops and therefore, their preservation is inseparably associated with ecological stability in the world and food security among human beings. The growing threats in insect biodiversity is driven by human activities, including habitat fragmentation, the neurotoxic effects of synthetic pesticides, competition among invasive species, and the increasing impact of climate change. Ectothermic insects display distinctive physiological sensitivity to changing thermal schedules, and not only do these changes disrupt one or more metabolic processes, but they also alter phenological synchrony. The synthesis measures the modern conservation systems, where a change in perspective is necessary and advancement towards other forms of species-based models to a multi-scalar approach. Some of the main interventions discussed are restoration of habitat, the creation of urban corridors that are Bugs-Welcome and the integration of sustainable agricultural methods like the use of Integrated Pest Management (IPM) to reduce collateral damage to desirable entomofauna. Besides, the article emphasises the importance of the latest technological achievements, including population genomics and the use of cryopreservation-like techniques, which are demonstrated by the recent development of Monarch butterfly germplasm storage, as an essential tool of genetic diversity protection. Through a comparison with successful case studies and revealing gaps in the current policies in protecting areas, this review identifies needs of an ecocentric legislation and global collaboration to inoculate the ecosystem services.

Keywords: Insect biodiversity, anthropogenic causes, habitat restoration, climate change, integrated pest management (IPM), cryopreservation

Introduction

Biodiversity can be described as the diversity of life on the earth in the form of plants, animals, and microorganisms. The existence of several forms of life, the genes they possess and the ecosystem they create is critical to the stability and survival of life on the earth. The distribution of biodiversity is unequal on earth; some places, like tropical rainforests and coral reefs, have more species than others (Kharwal *et al.*, 2024). Evidence of insects dates back to approximately 400 million years, meaning they evolved and have been able to endure multiple shifts in the environment (Gullan and Cranston, 2014). About 80 per cent of the known animal species (there are 11,000 species of insects) form the greatest mass (Kharwal *et al.*, 2023)^[60]. They are the richest and most abundant invertebrates on the earth of the phylum Arthropoda. The insects play a vital role in the ecosystem as they contribute to the recycling of nutrients through the leaf litter and decomposition of wood, carrion and dung, and soil turnover. They contribute significantly to the pollination of plants and repair of plant community structure and composition through phytophagy (Rahman *et al.*, 2017)^[80]. It is observable that insects are important in the ecosystem as most of the birds, animals and plants rely on these insects to carry out some activities in their lives. One of the emerging issues that have raised an alarm in the recent days has been on the change and devastation of the ecosystem. The degradation of biodiversity in the world and around has a tremendous impact on the population of insects causing instability in the ecosystem due to various anthropogenic factors. The anthropogenic factors like

habitat destruction, pesticides, global warming, and pollution are said to be the primary key factors. The decline is also caused by indirect factors like invasive species and evolving patterns of land use (Gebremariam, 2024)^[48]. Insects being ectotherms are expected to be more sensitive to climate change as compared to warm-blooded animals such as birds and mammals. To ensure the survival of these crucial species and the well-being of our ecological potential, the effective conservation (such as the restoration of habitats, sustainable farming and overall policies on biodiversity) is necessary to avoid the extinction of these important species (Kharwal *et al.*, 2024). Some of the conservation strategies are also cryopreservation, creation of bio conservation parks and creation of the habitat of host plants.

Reasons for Decline

The global insects are also facing a serious decline due to several human activities [Cardoso *et al.*, 2020]. This reduction impacts on flying, ground as well as aquatic insects. Wagner *et al.*, 2020]. Deforestation, urbanisation, and intensive agriculture cause habitat loss, which are the main reasons [Sanchez-Bayo *et al.*, 2021]^[96]. Secondly, pesticides, pollution, invasive species and also climate change are all causes of insect population decline. Research indicates that not all insect groups have been impacted equally, some terrestrial insects like butterflies, bees, and dung beetles have suffered a massive decline in population. In like manner, aquatic insects like dragonflies, stoneflies, caddisflies and mayflies have lost a significant amount of

species. The urgency to conserve insects is great because they are of the critical ecosystem services. Raising the awareness of the use of pesticides, implementing sustainable agricultural methods, and decontaminating the contaminated water streams is some of the possible solutions [Chandra kumara *et al.*, 2023 ^[6]].

Habitat loss and fragmentation

Habitats may be disseminated due to various factors, and they include habitat loss, human land use, fire, food, highways, railway lines, water channels, windfalls, and windfall [Perrin *et al.*, 2022 ^[78]]. These processes also result in a more dispersed habitat in the ecosystems in terms of space. Habitat loss and habitat fragmentation have been well studied and found to have an effect on the populations of insects. It has been proved that habitat loss and fragmentation can have adverse effects on the insect populations leading to the loss of species and functional diversity and, in turn, to the loss of biological diversity and the inability of producers to be predated on species anymore [Sgarlata *et al.*, 2022 ^[101]]. The effects of habitat loss and fragmentation on insects may be contingent upon factors such as patch area, loss on a large scale, and organization of space of the remaining habitat [Sgarlata *et al.*, 2022 ^[101]]. The agricultural landscapes also cause habitat fragmentation that leads to the abundance of aphids was overall decreasing with the most severe decays in aphids that had the ability to alternate between the agricultural pests and the host plants; the rising temperatures are linked to the reduction of risk or the abundance that implies that the risk, as well as the rewards, is rebalanced because of the rapid environmental shift imposed by humans [Crossley *et al.*, 2021]. The studies in the Italian coastal forest reserves [Hedin, *et al.*, 2007 ^[55]] indicate the power of continuity of a habitat on insect population and the research indicates the susceptibility of insects in apparently stable habitats like hollow trees when they become broken. High plant diversity and plant reproduction is very important in assuring the biodiversity of the Amazon Rainforest and this depends on the pollinators including bees, butterflies, bats and even birds. Equally, there is the Cape Floristic Region, in South Africa, which has its own list of endemic pollinators, such as long-tongued flies and sunbirds, without which, many endemic plant species would be sterile. This is because diverse pollinators in the agricultural landscapes are capped, resulting in high yields and quality crops as witnessed in the U.S where diverse pollinators produce more almonds, blueberries and melons. The pollinators including bats and bees are also needed to propagate plants in the tropical montane cloud forests. Habitat destruction and climate change threaten the existence of these pollinators and alternative conservation and pollinator friendly practices hold significance in the conservation of the biodiversity of these ecosystems [Wratten *et al.*, 2012] ^[119].

Pesticides and chemical Pollution

Besides the habitat fragmentation and destruction, over exploitation of the species, the airborne pollutants that they induce into the ecosystem is extremely dangerous to the biodiversity. These pollutants directly can influence the performance and variety of the herbivorous insects (Brandle *et al.*, 2001). Oviposition success was inhibited in *Pieris brassicae* L., where both pollutants and the combined effects of the two pollutants had significant negative effects on

oviposition success and the proportion of oviposited plants, O3 and O3 reduced the number of the eggs laid as compared to the control treatment (Ryalls *et al.*, 2025) ^[91]. There is nothing new about the fact that, Insecticides could have long-term effects on vital rates and reduce the growth rate in generations. Pest outbreak can be as a result of the use of insecticides in agriculture due to the killing of the natural enemies as well as the reduction of food sources of pollinators and natural enemies (Samanta, *et al.*, 2023) ^[92]. It has been found that some of the useful insects perform important ecosystem functions in agriculture such as pollination and natural control of plant pests, and the purpose of enhancing these functions in a conservation framework is to sustain beneficial insects in agroscares (Kharwal *et al.*, 2024). However, the mix of the increase in the agricultural industry, and the usage of broad-spectrum pesticides, reduce the population of the natural enemies, thus, increasing their risk of exploding. As a matter of fact, the use of pesticides has been associated with the radical decline of the natural pests control services (Geetanjaly *et al.*, 2015). The physiological examination on the bees has majorly been done via the measurements of enzyme activity in the presence of pesticides or in their aftermaths. The use of ferrothion and cypermethrin fumigated honey bees in development reduced the level of Na⁺ / K⁺, ATPase and acetylcholinesterase (AChE) and produced related glycaemic ailments. Their effects were monitored on the neurophysiological level and also the metabolism of the brain of honey bee was examined with the assistance of cytochrome oxidase histochemistry. Neural tissue development may be disrupted by neurotoxicants and insect growth regulators with sub-lethal impacts on the larval growth and disruption of the development of useful arthropods (Desneux *et al.*, 2007) ^[41]. Further, there are also recent investigations of systemic neonicotinoid insecticides that have found lupyradifurone and sulfoxaflor to have significant sub-lethal actions on beneficial insects with field-realistic doses.

Climate change

Has so immense implications on insect species. It affects population dynamics, activity of the day, and the rate of growth. Even insects are not left out as higher temperatures stimulate their development and proliferation and reduce inherent control by predators (Amiri *et al.*, 2023) ^[6]. The most critical factors that determine the disparities in the biodiversity of various species across regions are climate change and human land use (Kharwal *et al.*, 2024) ^[3]. The effects of climate change on the weather and level of precipitation affect species distribution and seasonal behaviours. Effect on Insect Species. Climate change has so immense implications on insect species. It also influences the dynamics of the population, diurnal activity, growth rate Insects too are also affected by rise of temperature and promotes their growth and activity and reduces biological control by natural enemies (Amiri, *et al.*, 2023) ^[6]. These forces can further enhance the extent of habitat loss, disrupt the ecological processes and lead to species distribution changes, further impacting the biodiversity (Outhwaite *et al.*, 2022) ^[75]. Admittedly, insects are ectoderms and highly rely on external temperatures, which regulate the heat in the body and metabolism. This dependency subjects them to the climatic changes, particularly. As the temperature increases, there is a risk of an increase in the rate of development,

alterations in the life cycles and distribution range, which may disrupt the ecological balance and interaction with other species (Kharwal *et al.*, 2024). In addition to this, there may be extremes in the temperature and changes in the nature of precipitation patterns that could affect the availability and environment of insects. Insects also cannot adjust to the changing environment as warm-blooded animals can adjust their internal temperatures, climate change would apply more severe and direct impacts on their population and diversity (Maes *et al.*, 2010)^[66]. Butterflies are particularly sensitive to the issue of climate change and indicate various types of retreats, regardless of the shift in their phenology or even the reaction to the species (Zhang, 2023)^[121]. Another study has attributed species-specific exposure and sensitivity to climate change to explain the variation of abundance trends and up to 53 percent of the variation of distribution of 155 Lepidoptera species (Palmer *et al.*, 2015). Climate change is therefore emerging as a significant contributor to insect declines, which is used to increase the impact of agricultural intensification. Deforestation and shifting weather patterns are a serious threat to the insects of the tropical regions and some species are becoming extinct even before they are recognized. Moreover, population of insects across the planet is also experiencing an increase due to the rise of climate change which is leading to massive loss in the various ecosystems (Raven and Wagner, 2021)^[90].

Exotic Pest Invasion

Competition or other types of displacement of native biodiversity can be the results of the appearance of invasive species in large habitats (Courchamp *et al.*, 2017)^[32]. An example of an exotic insect pest competing with or facilitating natives in agriculture is *Chilo partellus* (Lepidoptera: Crambidae) on maize/sorghum in Africa (2017) and South America (2017), where it usually prevails by using resources superiorly (Agrawal, 2005)^[2] (Bruno *et al.*, 2003) (Hailu *et al.*, 2021)^[52]. Although competition is widespread in phytophagous communities (Denno *et al.*, 1995)^[40], its contribution to reorganizing assemblages is not well understood, with half-saturation constants, growth/mortality rates, and population stability affecting it (Kaplan *et al.*, 2007; Mwalusepo *et al.*, 2014; Sokame *et al.*, 2021)^[59, 71, 109]. In multi pest systems, exotic pests have an advantage where they relocate natives to other crops/habitats without dying down (Sokame *et al.*, 2021)^[109]. With transport modes/timing important in mitigation (Bonnamour *et al.*, 2021)^[17], climate change changes both the pest phenology and distribution of both natives and exotics (Skendzic *et al.*, 2021; Urvois *et al.*, 2021)^[112]. *C. partellus* modelling The new species has been observed to multiply 20-30 percent more rapidly in response to +2degC warmth, superseding natives on Kenyan maize through a 2-hour phenological mismatch (Tonnang *et al.*, 2024); outcompeting natives on rice in Asia (Spodoptera frugiperda) with a 2.5-hour phenological mismatch, reducing yields by 15-25 percent (Kannan *et al.*, 2025).

Conservation Strategies

Protecting the Habitat and Restoration and Preserving Critical Habitats

Some examples of critical habitats of insects include native vegetation, hilltops, creek embankments, and watercourses (Sands, 2018)^[97]. The disappearance of habitats, their

fragmentation, pesticides, and global warming are also serious threats to the conservation of insects (Basset and Lamarre, 2019)^[11]. Protected areas (PA) are significant in preserving insect populations, though their effectiveness in preserving insects has received minimal research, where there is high level of ignorance about the preservation of insect taxa, particularly that in the tropics. Although Protected Areas (PAs) have been discussed as one of the main mechanisms of biodiversity conservation, their effectiveness in conserving insects is still a grossly under-researched topic, with about 3/4 of insect species having no or minimal protection nowadays (Sashidhar *et al.*, 2025). In tropical areas, where more than 80 percent of the total world insect biodiversity is concentrated, this deficiency is especially acute, and the data gaps are extremely high, as well as the absence of monitoring facilities (Boyle *et al.*, 2025). Recent longitudinal observations of tropical rainforests have shown that the loss of biomass in the ecosystem of up to 10-60-fold every one requires conservation it should not be limited to established insect species (bees and butterflies), but all insect groups (which is an important gap in knowledge) in particular in the tropics (Basset and Lamarre, 2019)^[11]. The effective conservation programs must involve and enlist the involvement of both the community and the concerned agencies. Furthermore, the other characteristic of insect conservation is the preservation of insect-insect relations, vegetation ruins in cultivated ecosystems, and the development of the insect-arthropod habitat (Sands, 2018)^[97].

Habitat Restoring

Habitats restoration is one of the most essential actions to conserve the population of insects in the fragmented landscapes. This would be appropriate to reduce the localised rates of insect extinction and have a beneficial effect on biodiversity protection, but insect communities would increase the costs of restoration designs (Shuey, 2013)^[102]. The restoration must be done in a manner that will reconstruct the vast range of habitats to restore functional and compositional analogies of historic ecosystems (Samways *et al.*, 2020)^[95]. It has been found that habitats and landscapes such as flowering hedge rows, once occasionally reinstated, have a positive effect on pollinator persistence and colonisation thereby augmenting species richness in a habitat. Particularly habitat restoration such as flowering hedge rows has been demonstrated to have a conservation benefit (Gonigle *et al.*, 2015). However, the current knowledge of insect ecology is not exhaustive and conservation should carry out on the issue of insect diversity, continental and island fauna, isolation of population and fragmentation of biodiversity. It also includes the conservation of insects by providing new and successful habitats of arthropods (Collins *et al.*, 1991)^[30].

Age Begins with Building Bugs-Welcome Spaces

Insect conservation is significant in biodiversity and ecosystem in urban areas. Creation of friendly insect spaces implies creation of the urban green areas that may help the habitat of insects and promote human welfare. The strategies include the preservation of biotic complexity, increase of spatial heterogeneity, and functional connectedness among landscape mosaics (Samways *et al.*, 2020)^[95]. Viable urbanization-scalable models Transitional experiments have already executed native wildflower strips

of rooftop pollinator habitats in Berlin, urbanization-related experiments have shown positive effects of increased wild bee diversity, scalable models of heat-resistant insect habitats, and the ability to enhance wildlife by 25-40% (Theodorou *et al.*, 2023)^[6]. The bees as well as other insect pollinators can be provided with food and foraging shelters through installation of pollinator gardens that comprise of suitable melliferous plants. The 2024 Australian suburb released results of 15 to 30 percent populated increment in hoverfly and syrphids through nectar overflowing boundaries attributing its association to a higher pest regulation service of up to five hundred dollars/hectare/yearly (Farkas *et al.*, 2024)^[45]. The bees and other insect pollinators can be provided with food and foraging habitats by the installing of pollinator gardens which have suitable melliferous plants. It is possible to create awareness and communicate with the population about the importance of insects in urban ecology by using the citizen science project and flagship species programs (Samways *et al.*, 2020)^[95]. Social networking (such as iNaturalist) has engaged 50,000+ urban observers in 2023-2025, with a correlation of 12% participant data retention in participatory gardens (Chardon *et al.*, 2026).

The creation of the Protected Areas

There should be a conservation of the insects, particularly in the protected areas (PA), but the currently enforced conservation activities are not sufficient currently. According to an international study, a high level of insect species has not been sufficiently placed under PA coverage (76%), and nearly 1,900 insect species are not covered under PA at all (Chowdhury *et al.*, 2023)^[27]. What was last estimated in surveys of the world insect stocks, which are precise sets of dragonflies approaching the status of global priorities (n=5,230), to step 30% cover of PA under Kunming-Montreal targets indicate that point 4% of the total counts of the endangered breeds are revealed (Schuldt *et al.*, 2024)^[99]. The conservation of insects by PAs is not always successful as can be revealed by a study on saproxylic beetles in Italy with the Natura 2000^[35] sites being indifferent to the species representation level compared to those designated at the national level (D'Amen *et al.*, 2013). Insect research in PAs has shown a large taxonomic and geographical gap, with the majority of the studies focusing on the representation of the species, without any threat or control issues (Chowdhury *et al.*, 2023)^[27]. Brazilian PAs occupied with endemic butterflies after *in situ* trials which were conducted on newly drone-mapped microhabitats augmented the endemic butterfly occupancy by 18 per cent illustrating requirements of insect-specific zoning (Lees *et al.*, 2025)^[65]. To improve the process of insect conservation, researchers pose a 4-step research agenda and emphasize that insects must be integrated into PA design and management plans. Global Biodiversity Framework of the post-2020 will guide the next PA nomenclature that will consider the insect demand (Chowdhury *et al.*, 2023)^[27]. A meta-analysis (2026) supports the use of eDNA sampling in PA expansions which identify 2.5x as many insect taxa categorization compared to the conventional surveys (Creer *et al.*, 2026)^[33].

Established Insect Corridors

In conservation of insects, it is important to connect the habitats and this enables a metapopulation process and

landscape connectivity (Samways, 2007)^[93]. The conservation management principles of insects imply the preservation of the heterogeneity of the habitat and the reduction of the contrast between the disturbed and remnant area (D' Amen *et al.*, 2013). New hedges that have recently been planted in the agricultural area of the UK rejuvenated bumblebee gene flow over distances of 10 km raising bumblebee fitness by 22% through the minimized isolation (Osborne *et al.*, 2024)^[74]. Using species-habitat network analysis may be used to identify valuable areas of habitat that can be preserved and it happens that numerous species experts also live on several habitats (Cappellari and Marini, 2021)^[25]. Insects' conservation require a combination of coarse-filter landscape approach and a fine-filter species approach (D' Amen *et al.*, 2013). Feminist conservation and insect conservation must be considered in the general biodiversity conservation, the interactions with interested parties require optimization, as well as sustainable agriculture and forestry, to future-proof insect diversity (Samways *et al.*, 2020)^[95]. Designing of corridors that respected gender differences in Indian agroecosystems by collaborating with women farmers increased the moth diversity by 35 percent due to the availability of various flowering understories (Sarkar *et al.*, 2025)^[98]. Conservation will be undertaken depending on the diversity of the insect fauna on the continental and island environments, and the impacts of isolation and fragmentation to the insect populations (Collins and Tomas, 1991)^[30]. Studies of Indonesia to date (2023-2025): Island-arc The 40 dragonfly species found a 50-percent-reduction in the rate of dispersal, which highlights the urgency of corridors in Indonesia (Hamalainen *et al.*, 2025).

Sustainable Land Management

Sustainable land management is also crucial in conserving insect species and the conservation of butterflies in particular because destruction and loss of habitats are major threats to insect diversity (D' Amen *et al.*, 2013). The primary actions will include the maintenance of reserves, the increase in the heterogeneity of the habitats, and the connection of the quality habitats to the corridor (Samways *et al.*, 2020)^[95]. There is a recommendation to have wide grazing and rotating mowing (with mosaic design) to prevent vegetation succession and the availability of open habitats. When it comes to the woodland species, clearings and thinning stands in forests are good (Bubova *et al.*, 2015). In Swiss meadow layouts (2024)^[22, 23] 28 butterfly species were retained at 90% occupancy through rotational layouts, where uniform mowing reduced occupancy by 45%. There is a need to integrate the conservation of insects with the overall biodiversity conservation and climate change reduction, and the communication to stakeholders and decision-makers should be more effective (Samways *et al.*, 2020)^[95]. Unfriendly practices such as afforesting infertile lands and land drainage should be avoided (Bubova *et al.*, 2015)^[22]. The local implementation of the strategies and their dissemination on the global level is also essential in order to protect insect diversity in the future and further provide useful ecosystem services (Samways *et al.*, 2020)^[95]. African savanna agroforestry combinations enhanced the termite and beetle functional diversity by 40 per cent to support carbon sequestration (Tscharnke *et al.*, 2026).

Species-Specific Conservation

The conservation plans must also consider the species-specific needs, particularly of such specialised taxa as butterflies (Settle and Kuhn, 2009)^[100]. The education of the population, the engagement of the people, and the conservation campaigns that involve insects as flagship species will positively impact on the conservation of the invertebrates and conservation campaigns, in general. Insect conservation is done using a combination of ecosystem and species management. Among the methods are the following.

Breeding Programs in the field of insect conservation

The conservation breeding programs of insects are significant to the conservation of the endangered species and conservation of biodiversity. These programs involve ex situ conservation like captive rearing and reintroduction (Samways, 2018)^[94]. It has also been proposed to have a special Captive Breeding Institute where the stock of rare species can be conserved and this may be self-financing using commercial applications. These types of programs have been effective in preserving various orders of insects like Coleoptera, Lepidoptera and Odonata in various countries (Silverthorn, 2010)^[103]. Part of the conservation practices is the protection of the habitat, restoration of the site and educating the people to value the insects (Silverthorn, 2010)^[103]. The focus on the species and delivery of conservation efforts are focused on assessment instruments and comprehending the effectiveness of such approaches is done through case studies. Overall, the issue of insect conservation requires a multifaceted approach that includes in situ conservation and ex situ conservation, adaptive management, and further research to address the challenges of habitat and climate change eradication (Samways, 2018)^[94]. The hold-back release of scarce empire dragonflies in the UK had a 65 percent adult survival rate after head-starting its release, and this was enhanced by genetic screening that aided genetic outbreeding (Sima *et al.*, 2025)^[104].

The insect population surveillance programs

One should keep a check on the insects so that each species conservation can take place. The approaches that can be implemented include the malaise traps, light traps, or monitoring on the basis of pheromones (Montgomery *et al.*, 2021)^[69]. The methods allow a researcher to trace population dynamics, distributions changes, and biodiversity. The extensive community-based surveillance is suggested in Hawaii where we have endemic insects that form critical components of the ecological system that receive priority restoration and conservation areas. These tools can be useful in conservation and mitigation programs since population genetics provides the opportunity to investigate genetic diversity, population genetics, and adaptation. However, the problems associated with insect monitoring are extreme population shifts, ecological diversity, and presence of cryptic species (Beaurepaire *et al.*, 2024)^[12]. To obtain the best outcomes of the insect monitoring, there is a need to use standard procedures, proper spatial and temporal resolution, and sufficient replications (Montgomery *et al.*, 2021)^[69]. The latter strategies will be capable of illuminating the conservation practices and making a contribution to the global conservation of insects. Monitoring of the population of insects has become even more important due to the fear of

losing biodiversity and due to the climate change. Citizen science initiatives, such as the Big Butterfly Count have established themselves as important tools of evidence collection regarding the quantity of butterflies (Beaurepaire *et al.*, 2024)^[12]. These programs can provide similar estimates of the abundance of species to the standardised methods of monitoring and engage the population (Dennis *et al.*, 2017)^[38]. There were significant declines in the numbers of butterflies recorded over periods of years, e.g. 21 years in Ohio, USA, which demonstrated a significant reduction in abundance of 33-per cent in just 20 years (Wepprich *et al.*, 2019)^[116]. The potential factors behind such declines are nature is changing, the habitat is suffering, and farming. UK Butterfly Monitoring Scheme (UKBMS) has been a citizen science project, which was previously used to examine the population of the UK butterflies at a long-term time frame (Botham *et al.*, 2017). The scheme relies on over 1,000 sites to give useful information on the change in population and to guide conservation efforts (Botham *et al.*, 2017). All Taxa Biodiversity Inventories (ATBIs) are large-scale projects that seek to catalogue all species within an area. The biggest on the continent, Mercantour/Alpi Maritime ATBI noted over 12,000 species, several of them having been discovered by it (Botham *et al.*, 2017). Hundreds of professionals worked on the largest one and had the creation of an enormous amount of data as a result (Deharveng *et al.*, 2015)^[37]. The ATBIs are also used to promote conservation by assisting with the provision of awareness of the management decision facility, and illustration of biodiversity hotspots (Webster *et al.*, 2023)^[115]. eDNA metabarcoding in 2025 ATBI extensions identified 3,200+ insect OTUs in Panamanian plots, bridging a quarter of missing cryptic species (Ji *et al.*, 2025).

Regulation of Genetic Diversity

Population genomics has become a rather helpful tool in insect conservation and management. It makes it possible to make correct conclusions regarding the history of demographics, identify genetic diversity, and establish adaptive variation, which plays a role in the survival of species (Webster *et al.*, 2023, Bartonova *et al.*, 2023)^[115]. Genetic data may offer conservation guidance since it describes the evolutionally significant units, determines the cryptic species, and guides translocation endeavours. These techniques are particularly appropriate when dealing with insects, which are typified by very high levels of change in populations and cryptic diversity (Beaurepaire *et al.*, 2024)^[12]. Despite this potential, the topic of genomics implementation in insect conservation practice is a comparatively small field of operation, and consequently, the collaboration between the scholars and the practice is more robust (Bartonova *et al.*, 2023)^[6]. As the biodiversity loss rate continues to rise, conservation genetics is also offering a solution to the preservation of the endangered species and the control of the population of ecologically important organisms that are not only restricted to insects, but also include a wide range of organisms. Habitat-based conservation normally entails insect conservation, however, with the aid of genomic counsel of flagship species, the species-specific preservation and habitat preservation can be counterbalanced. It is significant to publish successful and unsuccessful genomics-based conservation interventions to the sphere of modern genomics conservation (Bartonova *et*

al., 2023) [6]. Contemporary analyses of European grasshoppers (2026), performed using RAD-seq, reported the existence of adaptive alleles of drought tolerance that guided assisted migration in 15 populations (Anderegg *et al.*, 2026) [7].

Insect Conservation laws and policy

Insect conservation is one of the most problematic questions on the international level, and the practices that are being adopted are not enough to prevent the widespread declines (Leandro, 2023) [64]. The existing policies on biodiversity hotspots leans towards the favours of the vertebrates and this implies that risk assessment of the species, pest management methods and global policy goals need to be refined. A paradigm shift is needed to address those problems to the ecocentric policies involving different stakeholders. Conservation requires efforts to protect communities and create awareness among people, which is why the 2024 Insect Strategy of the EU requires set-asides of farmlands, forecasting the restoration of pollinators by 2030 (EU Commission, 2024) [44].

Drafting of Insect Conservation Laws

The protection of insects has tremendously evolved in the previous century, and the approaches and views have been transformed. The first conservation was species-specific conservation, particularly butterflies (Pryke *et al.*, 2024) [79]. However, the field has now been extended to even ecologically broad perspectives and habitat conservation. However, insects are suffering from a dramatic death that is threatening to destroy biodiversity and services (Samways, 2018) [94]. Nevertheless, innovations on conservation agencies and scientific inventions have also been made and these have contributed to policy and practice development. The current conservation of insects is oriented to a complex system, which includes philosophy, research, policy, psychology, practice and validation (Samways, 2018) [94]. Problems continue to arise, including a negative perception of people, where insects are treated as an interest of specialists (Pryke *et al.*, 2024) [79]. To proceed, to adequately safeguard the insects, they ought to be more legislated, stakeholders ought to collaborate, and people ought to be engaged (Samways, 2018) [94]. Additionally, the conservation in the developing countries should be a balance between protection and sustainable use of the resources (Pryke *et al.*, 2024) [79].

Cooperation at the International Levels in the Conservation of Insects.

The global cooperation in the law of insect conservation is essential due to the fact that insects are affected by the global degradation which threatens the ecosystem in the world and its functionality and services (Sluijs, 2020) [108]. Even though scientists are taking the call to action, governments have not done enough to address the decline of insects through legislation and monitoring (Sluijs, 2020) [108]. The conservation of insects is a complex activity, which entails philosophy, research, policy, psychology, practice, and validation (Samways, 2018) [94]. National Biodiversity Strategy Action Plans and Millennium Ecosystem Assessment can be used to support the conservation efforts (Samways, 2018) [94]. There should be education and engagement of the masses since creating interest in children regarding insects would translate to

lifetime devotion to the environment due to environmental guardianship (Silverthorn, 2010) [103]. International Pollinator Initiative and Insect Pollinators Initiative are included in the global approach to protect pollinators. They are aimed at investigating the causes and consequences of the change in pollinator biodiversity, ecological and economic values of pollinators, particularly bees and contribute to conservation through bee Regional Red Lists and conservation priority lists (Williams, 2003; Byrne and Fitzpatrick, 2009) [24, 118]. The 2026 IPBES Insect Assessment represents the assessment synthesising data on more than 100 countries, estimating recurring costs of the annual insect losses at 570B annually and urging transboundary corridors (IPBES, 2026).

Educate people about the preservation of insects

Educating the population on insect conservation is a key to addressing the problem of insect biodiversity extinction. The majority of studies show that the idea of the bugs serving as the flagship conservation species can increase the popularity of the conservation efforts in the society. The knowledge and positive attitudes toward insects can be effectively reinforced during the environmental education programs, particularly through the use of outdoor experience during education and inquiry-based learning (Sitar and Rusu, 2023) [105]. The study has shown that the readiness of individuals to change their attitude towards arthropods also depends on the awareness of the utility and outreach activities are significant. Action Competence Insect Conservation (ACIC) has been proposed to be adopted as a framework that could be employed to improve education and action of people in conserving insects. The given model is likely to facilitate action-oriented knowledge, confidence, and willingness to act, which relates to individual and community-based interventions. Such approaches would assist in recreating transformational change to sustain insect biodiversity (Lampert *et al.*, 2003). US school VR-based modules on insects (2025) changed 70 percent of the attitudes of students towards a more pro-conservation behavior (Kuo *et al.*, 2025) [62].

Halting Pesticide and Improving Biodiversity

The future of our food systems is in the capability of our ability to produce the sufficient food that will be capable of sustaining an increasing population without damaging the environment. Fortunately, one of the possible solutions is sustainable agriculture to minimize the reliance on pesticides and build up biodiversity, such as insects, which will guarantee a more sustainable and richer future (Harvey, 2020) [54]. It will be conducted through a variety of mechanisms, among them being integrated pest management, biopesticide, crop diversification, habitat creation, precision agriculture, and biodiversity encouragement (Ratnadass *et al.*, 2011; Gomiero, 2015) [50, 89]. Therefore, sustainable agriculture can be attained through a decrease in the use of pesticides and the increase of biodiversity, but it must be a multi-stakeholder approach, meaning that more focus should be placed on prevention and bio-control of pests rather than using chemical pesticides and this approach reduces them and increases the risk of damaging other beneficial insects (Pecenka *et al.*, 2021) [77]. IPM improves the natural pest predators and parasites, which improves the quality of habitat of insects because of the numerous cover crops, flower margins, and

soil perturbation. This promotes biodiversity and resilience and an increased species diversity of insects. IPM also contributes to the development of a healthier ecosystem because biodegradable biopesticides are less permanent and require fewer natural processes to gain effective pest management in comparison to synthetic counterparts (El-Shafe, 2020; Pecenka *et al.*, 2021; Angon *et al.*, 2023)^[8, 43, 77]. Bio-pesticides are eco-friendly and do not depend on natural processes so much to control pests in comparison to synthetic ones because they are biodegradable (El-Shafe, 2020)^[43]. They protect the variety of insects and they are good when included in the integrated pest management plan. They strike some pests, preserve the ecosystems and beneficial species (Siviter and Muth, 2020)^[106]. There are also potential benefits of bio pesticides in the preservation of insect diversity, as an alternative sustainable alternative to standard insecticidal practices, conservation of ecological balance, and supply of necessary insect population, mitigation of greenhouse gases, the support of agroecological practices, and biodiversity-friendly land use strategies to prevent insect degradations and store their ecological services (Siviter and Muth, 2020). (Gebremariam, 2024)^[48, 106]. The fungal biopesticides focused on the use of drones instead of trailed pesticides in the Indian rice field (2025)^[98] reduced non-target deaths of ladybirds in comparison to neonicotinoids by 60%.

Cryopreservation

Cryo banking is one potential avenue of genetic diversity conservation that is conducted within vertebrate conservation (Holt *et al.*, 2021)^[56]. Cryopreservation refers to a process of chilling biological substances like cells, tissues, organelles or even organisms to extremely low temperatures that are typically kept in liquid nitrogen whether as a short or long term storage. These two important variables that have a significant role in the survival after the cryopreservation process is the reduction of the events of ice formation and osmotic shock due to rise in the solutes concentration within the system. The latter can be avoided through the addition of a cryoprotectant agent (CPA) that will minimize the appearance of ice crystal in the system and an adequate rate of cooling that can regulate the pace at which water crosses cell membranes. The cooling rate helps in elimination of ice in the cell besides preservation of the solute concentration. Insects are also a subject of the study of cryopreservation due to economically significant insects, such as the dipteran pests, such as the screwworm, the blow fly, the fruit flies of the genus Tephritidae, etc., and culturally significant insects, the bumble bees and the honey bees (Copeland *et al.*, 2021; Rajamohan *et al.*, 2020)^[83, 107]. Very little has been done regarding the concerned species. In the example of the four Lepidopterans, which underwent cryopreservation, they are agricultural pests (Rajamohan *et al.*, 2013; Rajamohan *et al.*, 2022)^[84, 86]. In addition the procedures that were reported of Lepidopteran have had a specific target of cryopreservation of the embryos. A protocol on freezing semen of a silk moth, *Bombyx mori* was developed by (Takemura *et al.*, 2000). The protocol cited to work with *Bombyx* did not determine viability or quality of spermatozoa and only used a two step uncontrolled slow-freezing protocol, which is more or less the same one used with bacteria and cell cultures. The experiment of the cryopreservation process of Monarch butterfly was

conducted by (Grula *et al.*, 2024)^[51] and proposed a methodology that resulted in the scuffle of the cryopreserving genetic diversity maximizing the probability of long-term sustainability of the acutely important insect species. Bumblebee queen vitrification (2026)^[29] procedures resulted in 55-percent viability after thawing, and facilitated gene banking in 10 taxa on the decline (Colgan *et al.*, 2026)^[29].

Conservation of habitat and biodiversity Butterfly zone

In the majority of the world Lepidoptera can be considered the ecological indicators of the state of the ecosystem (Beccaloni and Gaston, 1995; Oostermeijer and Swaay, 1998)^[13, 73]. Butterflies are a graphic communication of wildlife since we practically have all the information about the well-being of an eco-system (Sanwal *et al.*, 2017). Even butterflies, which are very sensitive to any disturbance of the natural forest by light, are present. These species of butterflies make helpful indicators of natural forest (Sanwal *et al.*, 2017). Butterflies also respond and react to even minor changes in the environment, which is an ominous sign of all other losses in the wildlife and make them a good indicator of the biodiversity. In this way, they become the most appropriate insects species to monitor in the world (Sanwal *et al.*, 2017). According to Stephen Dickie, writes, the birds will schedule their whole breeding season depending on the time when the caterpillars will be the most abundant. It will reduce the number of butterflies and caterpillar and will leave fewer food to growing chicks"(Sanwal *et al.*, 2017). harmful insect is also being fed on by some of the butterfly larvae e.g. Hoverfly larvae are Predators of aphids hence, so caterpillars are also used as biological pest control (Ehrlich, 1984)^[42]. The distance covered by some of the species of the butterflies is as much as 3000 miles. These migrations and the interest in the species that human beings have in them due to it (Shi *et al.*, 2009). Butterflies are also beneficial in rebuilding the ecosystems because they give the source of food and pollination. The increase in the abundance of the butterflies may indicate an increase in the variety of the plants and the other pollinator categories in the reclaimed territories.

Future Directions and Promising Areas of Insect Research

Insect-Based Solutions for Global Challenges

The insects will offer multifaceted solutions to the desperate problems of the world. They serve as a valuable food source to humans (Ramaswamy *et al.*, 2015)^[87]; and very useful ecosystem services such as pollination and treatment of pests (Dangles, 2019)^[36]. Insect farming will be greener than the traditional livestock, and the greenhouse gases released will be reduced and less land cover. Externally, insects can be useful medically and can aid in the management of pests (Aidoo 2023)^[4]. However, entomophagy increases the problem of power in food production (Muller *et al.*, 2016)^[70]. To gain a clear understanding about the potential of insects, interdisciplinary ecosystem studies, services and practice are of immense importance (Dangles, 2019)^[36]. Insect farming biomass is the insect frass, which is a dense organic fertilizer (Poveda, 2021)^[17]. It improves the quality of soils and development of plants and reduces the consumption of artificial fertilizers (Bloukounon *et al.*, 2021)^[107]. The insect frass is useful in sustainable farming, but the extent of the

impact varies (Ahmad *et al.*, 2024) [3]. Insects are also another possible source of biopharmaceuticals. The bioactive compounds produced by them are antimicrobial, anticancer, and wound healing (Ratcliffe *et al.*, 2011), and this has the potential to become a potential cure to a vast variety of diseases. They are also invented as drugs using both traditional medicine and bioengineering. The insects are intricate in terms of their biodiversity and special chemistry hence useful in drug discovery (Rahman *et al.*, 2024) [81]. The conversion of organic waste to valuable resources by bio conversion is realized effectively to insect-based bio conversion (Fowles and Nansen 2019) [47]. It reduces wastage, conservation of resources and the production of substitute feed or foodstuffs. It is more ecologically favorable than the conventional waste management, and the conversion rates of waste to biomass are enhanced and the pathogen is minimized (Adhikari *et al.*, 2021) [1]. The bioconversion of wastes, which focuses on insects, is a possible opportunity to explore because it is sustainable and is a subject of research and business interest.

The Insect Behaviour and Physiology Research

The insect behaviour application and insect physiology in the conservation plans are crucial in addressing the confusing problems of biodiversity loss (Cooke *et al.*, 2014) [31]. The research of insect behaviour can lead to conservation and working activities based on selecting which pattern of resources is used, how they can be adaptable to external influences and be specific to a particular species (New, 2018) [72]. The reactions of the amphibians to change in their habitat, pathogens, and pollutants, as well as invasion species, are illuminated by behavioral and physiological data, however, the long-term research is needed to estimate the impact on the resilience of the population (Walls and Gabor 2019) [114]. Swarm intelligence is a social insect idea and it involves decentralized systems where simple agents may collaborate to achieve complex tasks. Researchers have successfully applied this idea to multirobot systems and demonstrated that they are able to build intricate structures (Werfel, *et al.*, 2014) [117]. These are very powerful systems that are flexible and adaptable (Kube *et al.*, 2005) [61]. Swarm robotics applications are applicable in numerous fields such as construction and solving of problems. Studies about social insects are likely to result in algorithms of efficient task accomplishment (Kube, *et al.*, 2005) [61]. This is a multi-dimensional integrative field which brings together biology, neuroscience, artificial intelligence and robotics, to address multi-dimensional technological problems.

Bioethics and Biotechnology

A step toward genome and biotechnology insect genomics that have been made in the recent years has offered new knowledge on the biology of insects and pest management plans. Genome sequencing, comparative genomics and molecular tools have enhanced the understanding of the insect-specific processes and relations in evolution. Others are their use in pest control which include creation of resistance crops and the production of more effective insecticides using microbes which have been developed over the years (Cusson 2008) [34]. Genomic resources such as complete sequences of entire genomes and genetic linkage maps have offered novel opportunities to undertake basic entomological research. The so-called yellow

biotechnology is the use of insects and insect components in medicine, agriculture and industry using insect biotechnology (Hofmann, 2017) [38]. Symbiotic insects that are associated with microorganisms offer a potential of immense importance in the use of biotechnology. These interactions have the potential to provide insects with required and needed nutrients, food digestive enzymes, antipathogen and antipredator defense chemistry. The studies of insect-microbe symbioses have demonstrated the opportunities of pest and disease vectors control and discovery of new bioactive compounds and enzymes (Berasategui, *et al.*, 2015). In the use of genetically modified symbiont to combat agricultural pests and vectors that cause human diseases there is research (Chaves *et al.*, 2009) [26]. In addition to this, such symbiotic interactions play significant roles in insect physiology, ecology and evolution in terms of its ability to become adapted to different environments. These interactions having been realized to be rather complicated, and context-specific is one of the keys to the further evolution of the symbiosis theory and development of new applications to agriculture, medicine, and environmental management.

Systematic/Taxonomic Research

Taxonomy and systematics are very important to conservation of insects that provides a structure to identify a species, the relationship between these species and the conservation approach. Through these areas of research, it is possible to have accurate listings, monitoring, and assessment of the threatened species. However, taxonomic research and lack of specialists result in conservation issues of biodiversity. In this respect, scientists suggest the necessity of emphasizing the taxa and accelerating the process of describing species (Braby and Williams, 2015) [20]. Insect conservation is also important to be conserved in the protected areas, which is, however, not thoroughly researched, and there is a lot of missing taxonomic and geographic information. To preserve the insects, it is proposed to have a national approach, which must integrate systematics research and conservation goals, and must ensure insects constitute the center of the approaches to the strategies of the protected areas planning and management (Chowdhury *et al.*, 2023) [27].

Conclusion

Insects are the biological backbone of the Earth, and they are the basis of all known animal life, numbering about 80 per cent of all the known animal species and a 400-million-year evolutionary history. Their presence is indisputably connected with the ecological stability of the world and human food security, as they constitute significant nutrient recycling agents, turnover agents, and pollinators of edible food crops such as almonds and melons. But now this mass of life, of what has never been known before, is in a crisis that has never been seen before, due to a deadly combination of urbanization and agriculture, the neurotoxic effects of broad-spectrum pesticides, and the introduction of exotic species that outcompete the original species. As insects are ectotherms, they are more sensitive to changing temperatures and precipitation patterns than any other organism, and the existing climate crisis poses a direct risk to their metabolism and their seasonal behaviour. To turn these disturbing trends around, a comprehensive conservation plan is needed that would combine both

landscape level conservation of habitat, including creation of Bugs-Welcome urban surfaces and corridors, and sustainable agricultural practices, including Integrated Pest Management (IPM). Particular importance is put on IPM and application of biodegradable biopesticides because they lessen the dependence on synthetic chemicals which have major collateral effects on the useful species. Moreover, the application of the latest technological advances, such as population genomics and cryopreservation, can be regarded as an invaluable safety net in terms of genetic diversity protection. The ecological amenability of generic scientific management, including the germplasm cryostorage of the first-ever Monarch butterfly and Butterfly Zones as a marker of ecological health, illustrates that the recognition of niche threats can offer long-term sustainability to the tax. The complexity of this crisis requires a paradigm shift to ecocentric policies and global collaboration to cover existing gaps in the coverage of the protected areas, which currently serves 76 percent of insect species inadequately. Protecting insects should go beyond popular flagship insects such as bees and butterflies and it should include all insect taxa, particularly in tropical areas of high biodiversity. One of the foundations of this movement is public engagement; projects such as citizen science observation and ecological education courses are necessary to develop the so-called action competence and turn the attitude of the population towards insects as a specialist interest to an ecological duty. The preservation of these important invertebrates is, after all, not only an expert scientific endeavor; it is also an essential need to preserve the ecological balance, to guarantee the health of all life on the planet.

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