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Safeguarding Beneficial Insects: Strategies and Innovations for Conservation Amidst Growing Threats

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ABSTRACT

Beneficial insects, including pollinators, pest predators and decomposers, are vital for ecosystem health and agricultural productivity. This review examines the decline of key species such as honeybees, monarch butterflies, ladybugs, and rusty patched bumblebees. Their populations are threatened by habitat loss, pesticide use, climate change, and invasive species. Honeybees are suffering from diseases and pesticide exposure, while monarch butterflies face challenges from habitat destruction and shifting climates. Ladybugs and lacewings are in decline due to similar pressures, and rusty patched bumblebees are nearing extinction. Addressing these declines is crucial for maintaining biodiversity, crop yields, and ecological balance. The current conservation strategies, including habitat preservation through protected areas, habitat management and restoration and improved pesticide management are reviewed. It emphasizes the need to integrate climate change mitigation, public awareness, and education into conservation efforts. Emerging technologies such as Geographic Information Systems (GIS) offer new opportunities for habitat modelling and pest management, while strengthening policies can better address environmental stressors. Effective conservation requires a comprehensive approach that combines scientific advances with robust policies and community engagement. Immediate and coordinated action is essential to address these challenges and ensure the resilience and continued contribution of beneficial insects. By implementing transformative policies and fostering public involvement, we can support the long–term sustainability of these vital species amidst a rapidly changing world.

KEYWORDS: Beneficial insects, habitat, conservation, geographic information systems, modelling

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1. INTRODUCTION

Beneficial insects play a crucial role in maintaining ecosystem health and supporting agricultural productivity. These insects, including pollinators, natural pest controllers, and decomposers, are integral to both the environment and human agriculture. Pollinators, such as bees and butterflies, are essential for the reproduction of many plants. They enhance crop yields by between 18% and 71%, depending on the crop, and contribute significantly to biodiversity (Bartomeus et al., 2014). Without these pollinators, many plants would struggle to reproduce, leading to a decline in plant diversity and a reduction in food sources for other wildlife. Natural pest controllers, including ladybirds and lacewings, provide an important alternative to chemical pesticides. These insects help manage pest populations in a way that supports sustainable agriculture and reduces the reliance on chemical inputs (Van-Lenteren and Manzaroli, 1999). Decomposers, such as certain beetles, ants, and termites, are crucial for breaking down organic matter, including dead plants and animals. This process facilitates nutrient cycling and helps maintain soil health (Frouz and Jilkova, 2008; Griffiths et al., 2018). Despite their importance, many beneficial insect species are facing severe threats due to anthropogenic pressures. Habitat loss, pesticide use, climate change, and invasive species have led to significant declines in their populations (Couvillon et al., 2015). For example, honeybee populations have been severely impacted by diseases and pesticide exposure, which compromise their health and foraging abilities (Collison et al., 2016). Monarch butterflies are suffering from habitat destruction (James, 2024) and shifts in climate, affecting their migration patterns and breeding success. Ladybugs (Evans et al., 2011) and lacewings are also declining due to habitat loss and competition from invasive species, while rusty patched bumblebees, once common, are now nearing extinction. The decline of beneficial insects poses substantial risks (Wagner, 2020). Reduced insect populations can lead to lower crop yields, diminished biodiversity (Sánchez-Bayo and Wyckhuys, 2019) and disrupted ecological balance (Skendzic et al., 2021). This can have cascading effects on food security, ecosystem services, and overall environmental health. Addressing these declines is critical for sustaining both natural ecosystems and agricultural productivity. This review aims to explore the current status of endangered beneficial insects, the threats they face, and the effectiveness of various conservation strategies. It highlights the need for comprehensive approaches to protect these vital species. Conservation strategies include habitat preservation through protected areas, which provide refuge for insect populations and help maintain ecological processes. Habitat management and restoration efforts, such as planting native vegetation and creating pollinator gardens, can enhance the suitability of environments for beneficial insects. Additionally, improved pesticide management practices, including the use of selective insecticides (Gentz et al., 2020) and adherence to best management practices, are crucial for minimizing the impact on non-target beneficial species. Public awareness and education are also essential components of effective conservation (Lamarre et al., 2018; Samways et al., 2020; Hailay-Gebremariam, 2024). Local conservation programs and citizen science projects can engage communities in monitoring and protecting beneficial insects, fostering a sense of stewardship and promoting practices that support insect conservation. Advancing scientific research and integrating emerging technologies, such as Geographic Information Systems (GIS) for habitat modelling (Raina et al., 2011), can further enhance conservation efforts. Future directions for research and conservation include investigating the impacts of modern agricultural practices on beneficial insects, particularly focusing on pesticide exposure and habitat loss. Strengthening policies related to pesticide use, habitat protection, and climate change mitigation will support the preservation of these species. Comprehensive and coordinated action at both local and global levels is essential to address the challenges facing beneficial insects and ensure their continued contribution to the ecosystems and agriculture. By integrating scientific advances with effective policies and community engagement, we can create a resilient environment where beneficial insects can thrive despite the pressures of a rapidly changing world.

2. KEY BENEFICIAL INSECTS AND THEIR ECOLOGICAL ROLES

2.1. Pollinators

2.1.1. Bees

Bees, especially honeybees and bumblebees, are indispensable for pollinating a wide range of crops and wild plants. Bumble bees forage faster than honeybees owing to pollination in fruits and solanaceous vegetables in both field and greenhouse conditions (Zameer et al., 2022) The Rusty Patched Bumblebee (*Bombus affinis*) and the Honeybee (*Apis mellifera*) are notable examples of species facing decline. The Rusty Patched Bumblebee, once widespread in North America, has seen a dramatic reduction in range and abundance. Bee (2020) reported that *B. affinis* at least 99% over the past 30 years in Canada. Honeybee populations have been severely impacted by habitat loss, pesticide exposure, and diseases.

2.1.2. Butterflies

Butterflies contribute to pollination and serve as indicators of environmental health. The Monarch Butterfly (*Danaus plexippus*) is a key example, known for its long migratory journey between North America and Mexico. The Monarch population has declined due to habitat loss in both breeding and overwintering sites, as well as climate change affecting their migratory patterns. Flockhart et al. (2015) predicted that monarch population decline (14%) and a quasi-extinction probability (<1000 individuals) >5% within a century.

2.2.3. Moths

Moths, particularly Hawkmoths, play a role in nocturnal pollination. Though less studied, their decline can also impact night-blooming plants and ecosystems. Hawk moth tongue length seems to coevolve with plant corolla length (Nilsson, 1988, Whittall and Hodges, 2007) and pollinate plants having long corolla. Several hawk moth species along with moths belong to Saturniidae, have undergone long-term declines in the U.S. and Canada. Sphingids, also known as hawk moths or sphinx moths, are a group of insects known for their rapid flight and hovering capabilities. Two species of sphingids are already extirpated from Connecticut, while others, including historically common species like the hog sphinx (*Darapsa Myron*) and the waved sphinx (*Ceratomia undulosa*), are in decline. Pandorus Sphinx (*Eumorpha pandorus*) moths are evidently declining (Wagner, 2012) by facing threats from habitat loss and environmental changes.

2.2. Natural pest controllers

2.2.1. Ladybirds

Ladybugs or ladybird beetles, are vital in controlling aphid populations and other crop pests. The members of ladybird family, Coccinellidae are excellent indicators in environment (Iperti, 1999). Invasive alien species, *Harmonia axyridis* caused decline in native species in Belgium and Britain. The two-spot ladybird, *Adalia bipunctata*, declined by 30% (Belgium) and 44% (Britain) over 5 years after the arrival of *H. axyridis* (Roy et al., 2012). Species such as the seven–spotted ladybug (*Coccinella septempunctata*) have experienced population declines due to habitat loss and the introduction of non-native ladybug species.

2.2.2. Lacewings

Lacewings are effective predators of aphids, mites, and other small pests. Their larvae, known as "aphid lions," contribute significantly to pest control in agriculture. Lacewings, specifically the Chrysopidae (*Chrysopa Formosa)* and Hemerobiidae (*Micromus angulatus*) play a crucial role as natural predators of soft-bodied arthropods. These insects are particularly valuable in the realm of biological pest control, offering promising solutions for *Myzus persicae* (Ntalia et al., 2022). The decline of lacewing populations is linked to the reduction of their natural habitats, climate change, monocultures, invasive alien species and increased pesticide use. The lacewing population was reduced when feeding on bollworm larvae treated with azadirachtin (Qi et al., 2001). The lacewing mortality was increased to 62% with Bt fed prey compared to 37% in non Bt fed prey (Hilbeck et al., 1998). There is potential loss of diversity over time in split-footed lacewing larvae, similar to findings in silky lacewings. The study on split-footed lacewings larvae revealed that fossil specimens from Myanmar and Baltic amber show differences in mandible structure compared to extant larvae (Haug et al., 2022).

2.3. Decomposers

2.3.1. Beetles

Beetles such as dung beetles and carrion beetles are crucial for decomposition and nutrient recycling. The Scarlet Eye Beetle (*Cicindela scutellaris*) is one example of a beetle species facing endangerment due to habitat destruction, climate change and changes in land use or soil management.

2.3.2. Ants

Ants contribute to soil health and seed dispersal. Leaf-cutter ants may concentrate nutrient availability spatially and temporally (Hobbie et al., 2015). Species like the harvester ant (*Pogonomyrmex barbatus*) are threatened by habitat alteration and climate change, which impact their foraging and nesting behaviors. *Pogonomyrmex barbatus* is abundant, but in certain areas of Texas there has been a decline in their density. Competition with the red imported fire ant (*Solenopsis invicta*) is one hypothesized explanation for the decline of *P. barbatus* (Hook and Porter, 1990; Cook, 2003; Quezada-Martinez et al., 2011)

3. CURRENT STATUS OF ENDANGERED BENEFICIAL INSECTS

The status of endangered beneficial insects is assessed using various methods, including the International Union for Conservation of Nature (IUCN) Red List, national conservation assessments, and ecological studies. These tools help identify species at risk and prioritize conservation efforts.

3. Honeybees

The global decline in honeybee populations is attributed to multiple factors, including Colony Collapse Disorder (CCD), pathogens, and pesticides. Apart from CCD, *Varrora destructor* caused greater threat to honeybee health (Traynor et al., 2020). In Europe, several subspecies are under threat due to loss of genetic diversity as a result of admixture (interbreeding populations) (Henriques et al., 2021; Tanaskovic et al., 2021). Studies have shown that honeybee populations have decreased by approximately 30% in some regions over the past decade. Pesticide cocktails, the combination of various pesticide stressors, often found together in agricultural environments can interact synergistically to impair honeybee health by suppressing their detoxification mechanisms (Yang et al., 2023).

3.2. Monarch butterflies

The Endangered migratory monarch butterfly is a subspecies of the monarch butterfly (*Danaus plexippus*). The native population, known for its migrations from Mexico and California in the winter to summer breeding grounds throughout the United States and Canada, has shrunk by between 22% and 72% over the past decade. Legal and illegal logging and deforestation to make space for agriculture and urban development has already destroyed substantial areas of the butterflies' winter shelter in Mexico and California, while pesticides and herbicides used in intensive agriculture across the range kill butterflies and milkweed, the host plant that the larvae of the monarch butterfly feed on (Thogmartin et al., 2017). Monarchs rely on a rich path of milkweed and nectar plants during their migration to be able to breed and consume nutrients and with the increased usage of herbicides, monarchs are beginning to lose that vital resource. Pleasants and Oberhauser (2013) reported that there was a 31% decline for non-agricultural milkweeds and an 81% decline for agricultural milkweeds which ultimately caused 81% decrease in egg production in Iowa agricultural fields. Climate change has significantly impacted the migratory monarch butterfly and is a fast-growing threat; drought limits the growth of milkweed and increases the frequency of catastrophic wildfires, temperature extremes trigger earlier migrations before milkweed is available, while severe weather has killed millions of butterflies (Anonymous, 2022).

3.3. Ladybugs

The Seven-Spotted Ladybug (*Coccinella septempunctata*) is a well-known beneficial insect that is valued for its role in controlling aphid populations, which can be harmful to agricultural crops and ornamental plants. The ladybug preys on aphids, keeping their populations in check and preventing damage to plants. *C. septempunctata* attacks and feed on spinach aphid, *Aphis fabae* Scopoli, coriander aphid, *Hyadaphis coriandri* (Das), cabbage aphid, *Brevicoryne brassicae* L., pea aphid, *Acyrthosiphon pisum* Harris (Arshad et al., 2017) in recent years, there has been concern about the decline of Seven-Spotted Ladybug, due to factors such as habitat loss, pesticide use, and climate change. Apart from this, the impact of the invasive species *Harmonia axyridis* (Asian ladybeetle) on the native ladybird species *Adalia bipunctata* in certain regions such as Belgium and the UK has lead to decline in *A. bipunctata.* Five years after the invasion of *H. axyridis*, there was a significant decline in *A. bipunctata* populations in Belgium and the UK. In Belgium, there was a 30% decline, and in the UK, there was a 44% decline (Roy et al., 2012). *A. bipunctata* populations in the UK were previously increasing before the arrival of *H. axyridis*. Studies have shown instances of asymmetric intraguild predation where *H. axyridis* preys on *A. bipunctata* more effectively than vice versa which is considered as a significant factor contributing to the decline of *A. bipunctata* populations (Hautier et al., 2011; Thomas et al., 2013). Brown et al., 2011 also reported that three native ladybird species of England experienced a decline in population due to invasion of non-native ladybird beetle *H. axyridis.*

3.4. Rusty patched bumblebees

Rusty patched bumblebees, a crucial pollinator species, were initially identified in 1863 (Juers, 2017). Their name originates from the rusty patch of fuzz present on the abdomens of the workers and drones in the colony (Anonymous, 2018b). These bees live in colonies consisting of one queen, numerous female workers, and male drones, and their colonies are notably smaller than those of European honeybees kept by humans. Initially found in twenty-eight states across the Northeast and Midwest, their current range has dwindled to only nine states, marking an 87% decline from their historical range (Lambe, 2018; Anonymous, 2018a). In their range, rusty patched bumblebees are found in various habitats, including residential parks, prairies, woodlands, marshes, gardens, and agricultural landscapes, where they play a pivotal role in pollinating crops and contributing to food security (Anonymous, 2018b). The female workers, also known as foragers, are responsible for collecting nectar and pollen for the colony, which is often located in abandoned underground rodent cavities (Anonymous, 2018b). These bees face various challenges similar to other bee species, including habitat destruction due to urban development and monoculture agriculture, as well as the impact of climate change and disease spillover from other species (Juers, 2017). Pesticide overuse, with over 400,000 tons used annually on agricultural fields, has also significantly contributed to the decline of these bees (Lambe, 2018). Additionally, the rusty patched bumblebee's adaptation to cooler temperatures poses a challenge in the face of rising temperatures (Juers, 2017). Once common until the 1990s, the rusty patched bumblebee is now on the verge of extinction (Schweitzer et al., 2012). Complicating matters, this species has a shorter tongue than other bumblebee species, limiting its ability to access nectar from approximately 30 plant species (Juers, 2017). Furthermore, due to their preference for nesting underground, the use of artificial nest boxes, which is effective for other bee species, has limited impact on this particular bee (Schweitzer et al., 2012).

4. CONSERVATION STRATEGIES

The status of beneficial insects varies significantly across regions. In tropical areas, habitat destruction and climate change have severe impacts on insect diversity. In temperate regions, agricultural intensification and pesticide use are major threats. Understanding these regional differences is crucial for developing effective conservation strategies. The following are some of the conservation strategies.

4.1. Habitat preservation through protected areas

There are relatively few studies exploring insect representation in Protected Areas (PAs), especially when compared to the literature on other taxa (Maxwell et al., 2020; Chowdhury et al., 2022). Studies indicate that PA networks in the UK provide relatively high coverage of insect distributions, with butterflies and other invertebrates undergoing climate-driven range expansions disproportionately colonizing these PAs (Thomas et al., 2012). It's crucial to integrate targeted conservation strategies, such as habitat restoration and monitoring programs, within PAs to effectively support and manage the diverse needs of beneficial insects, ensuring their continued presence and ecological functionality amidst climate-driven changes. Identify pollinators, decomposers and other beneficial insects and their habitat requirements such as food sources, breeding sites and shelter. Designing the protected area helps in supporting different insect species. This might include meadows, woodlands, wetlands and more. This may be followed by implementing conservation practices (habitat restoration: restore degraded habitats like planting native vegetation, creating ponds, or removing invasive species) within the protected area to make them suitable for insects. Set up some of the monitoring programs (surveys, trapping, and population assessments) to track insect populations and the effectiveness of conservation measures. Haddad et al. (2008) found that mark-recapture analysis provides a greater amount of demographic information and precise estimates of population size, detection, survival, and recruitment probabilities for rare butterflies, such as the endangered St. Francis' satyr butterfly. Apart from all these, reserves and national parks provide refuge for endangered insects and help maintain ecological processes.

4.2. Habitat management and restoration

The best beneficial insect habitat is typically open and sunny like meadows, prairies or shrubby areas. Mature forests may provide beneficial insect habitat on their edges, but most forest insects have ecological requirements that differ from those of common beneficial insects found on farms. To improve areas of the farm as beneficial insect habitat, conservation planning should prioritize sunny areas with native grasses and wildflowers. On larger areas, mowing and burning are two common approaches to maintaining diverse grass and wildflower plant communities. If these management practices are used, they should be minimized as much as possible during the growing season so that insects can use pollen and nectar resources. If mowing, burning, or prescribed grazing are used to maintain beneficial insect habitat, harm can be reduced by dividing the on–farm habitat into separate management zones, each less than 30% of the total habitat. Ideally, only one management zone (or 30% or less) of the beneficial insect habitat on each farm should be disturbed in a single year, meaning that each zone has a 3–to 5–year management rotation. This will allow beneficial insects to recolonize disturbed areas from surrounding, undisturbed habitat (Lee et al., 2001). Restoration efforts, such as reforestation and wetland restoration, aim to restore lost habitats and create new ones. Urban green spaces and pollinator gardens also contribute to providing habitats for beneficial insects

4.3. Pesticide management

When both pesticides and natural enemies (predators and parasitoids) are employed in a crop, conflicts can be reduced by use of following selectivity principles of insecticides. The decrease in natural enemies due to the use of non-selective insecticides can disrupt the balance in ecosystems and lead to serious consequences for pest population dynamics. One of these consequences is known as resurgence and eruption of secondary pests (Gallo et al., 2002). Resurgence occurs when the populations of pests rebound after initially being suppressed by insecticides. This rebound can be even more significant than the original pest population, leading to outbreaks and increased damage to crops. Selectivity in the context of insecticide use can be classified into two main categories: ecological and physiological selectivity (Maredia et al., 2003). Ecological selectivity involves the strategic use of insecticides to minimize the exposure of natural enemies to the chemicals. This is typically achieved by applying insecticides during hours of the day when temperatures are mild. During these times, there is generally less movement of natural enemies and other beneficial organisms, reducing the likelihood of their exposure to the insecticides. By timing applications in this way, the goal is to minimize the impact on the populations of natural enemies, thus preserving their ability to help control pest populations. Physiological selectivity, on the other hand, involves the use of insecticides that have low toxicity to natural enemies or those that are more toxic to pests than to natural enemies. In essence, this approach seeks to employ insecticides that specifically target the pest species while minimizing the harm to non-target organisms such as beneficial insects. This is achieved by selecting insecticides that have different modes of action or chemical compositions that are less detrimental to natural enemies, thus reducing the impact on the overall ecosystem. The International Organization of Biological Control (IOBC/OILB) has developed pattern techniques to test the physiological selectivity of insecticides to natural enemies. In this classification system established by the IOBC, insecticides are categorized into four classes (Hassan et al., 1997) based on their effects on natural enemies. Class 1-Innocuous: Insecticides in this class have a low impact on natural enemies, with an efficiency of less than 30% in harming them. These insecticides are considered safe for use as they have minimal negative effects on beneficial organisms. Class 2-Slightly Noxious: Insecticides classified in this category have a moderate impact on natural enemies, with an efficiency ranging between 30% to 79% in harming them. While these insecticides may have some effect on beneficial organisms, they are considered to be relatively safe when compared to more harmful options. Class 3-Moderately Noxious: Insecticides in this class have a higher impact on natural enemies, with an efficiency between 80% to 99% in harming them. These insecticides are considered moderately harmful to beneficial organisms and should be used with caution to minimize negative ecological impacts. Class 4-Noxious: Insecticides classified in this category have a significant impact on natural enemies, with an efficiency of more than 99% in harming them. These insecticides are considered highly toxic to beneficial organisms and are not recommended for use in integrated pest management strategies aimed at preserving natural enemies.

4.4. Climate change mitigation

Supporting insect adaptation to climate change involves protecting critical habitats, maintaining ecological connectivity and promoting climate-resilient landscapes. In the context of managing insect populations and their habitats, it's important to consider environmental elements at both the macro scale (landscape level) and micro scale (micro-habitat level) (Tougeron et al., 2022). At the macro scale, landscape factors like land use, vegetation cover, and habitat connectivity affect insect populations. Human activities such as agriculture, urbanization, and deforestation can disrupt these factors. Management strategies at this level might include agri-environmental schemes, wildlife corridors, or protected areas to support insect populations. At the micro-habitat level, factors such as microclimates, vegetation structure, soil conditions, and resource availability impact habitat suitability for insects. Enhancing micro-habitat quality can involve planting specific species, managing water resources, or adopting sustainable land practices. Mountains and topographically complex areas offer diverse microhabitats that can help animals adapt to climate change. These varied environments provide different temperatures, moisture levels, and shelter, which can support species facing shifting climate conditions. Such topographic diversity allows animals to find suitable conditions and resources, thereby enhancing their resilience and survival as climate patterns change (Forister et al., 2021; Halsch et al., 2021). Habitat management in response to climate change must account for the fact that insects face multiple overlapping anthropogenic stresses, which do not operate independently (Harvey et al., 2020). For example, systemic insecticides can move into floral nectar or honeydew (Calvo-Agudo et al., 2019), harming a wide range of flower visitors and intensifying population–level effects from both random and climate–related events. These diverse stressors interact and should not be addressed in isolation. Therefore, conservation management must integrate factors like habitat loss, fragmentation, invasive species, intensive agriculture, pollution (e.g., pesticides and fertilizers), and other stresses (Harvey et al., 2020; Pryke and Samways, 2012).

4.5. Public awareness and education

Local conservation programs and citizen science projects engage communities in monitoring and protecting beneficial insects. These initiatives raise awareness and foster a sense of stewardship. Public education campaigns highlight the importance of beneficial insects and promote practices that support their conservation, such as planting pollinator-friendly plants and reducing pesticide use. To ecologically improve agricultural lands, we should optimize the landscape by creating networks of habitat corridors and stepping stones. This approach enhances insect diversity and provides climate refugia to mitigate the effects of climate change. Pesticide overuse and industrial fertilizers harm ecosystems (Bernhardt et al., 2017), so they should be minimized and replaced with environmentally friendly alternatives. Adopting strategic and targeted approaches can balance agricultural productivity with biodiversity conservation. Ecological intensification should extend to landscape and city planning, utilizing road verges, public green spaces, and local gardens as crucial habitats and refugia, especially under climate extremes (Gurr et al., 2016). Protecting insects requires action at all levels, from global policies to individual choices. While biodiversity conservation is a systemic challenge, every person can make a difference through their actions. Raising awareness about the crucial role of insects in ecosystems is essential. Engaging the public with charismatic species and educating children about insects' importance in elementary school can help. Scientific advances must be paired with supportive policies, widespread awareness, and stakeholder education (Oberhauser and Guiney, 2009; Wyckhuys et al., 2022). Immediate action by governing bodies is crucial to prevent further species and habitat loss.

5. FUTURE DIRECTIONS

Emerging techniques, such as habitat modelling, offer new opportunities for insect conservation. Innovations in pest management and habitat restoration can enhance conservation outcomes. Geographic Information Systems

(GIS) and Global Positioning Systems (GPS) are crucial in agroecological management and research. For example, in Kibale National Park, Uganda, these tools enabled precise spatial measurements of rainforest trees critical for commercial insects, aiding in understanding their spatial distribution and genetic diversity (Dominy et al., 2001). GIS has also been used to assess wild silkmoth populations and their habitat needs, emphasizing the importance of sustainable forest management and the use of native tree species for reforestation (Mbahin et al., 2007). Additionally, GIS technology has mapped the distribution and nesting biology of honeybee colonies in Botswana and is employed in the Sierra Morena Honey Geographic Information System (SMHGIS) to document and manage honey production within specific regions (Serrano et al., 2008). Strengthening policies related to pesticide use, habitat protection, and climate change mitigation will support the conservation of beneficial insects. Recommendations include expanding protected areas, enhancing IPM practices, and promoting sustainable land use. To effectively preserve insect diversity and overall biodiversity, it is essential to implement transformative policies at a global scale. Governments must prioritize reducing and eventually eliminating fossil fuel use, curbing short-lived pollutants like methane and black carbon, and committing to ecosystem restoration and protection. Policies should also promote plant–based diets, support ecological economics, and stabilize human populations. International agreements such as the Paris Agreement must set clear, ambitious goals with strict time-frames and robust accountability mechanisms. Additionally, a critical policy shift is needed to balance land use by strictly preserving existing natural areas while re-evaluating land allocation for agriculture and urban development. This comprehensive policy approach is crucial for halting climate change drivers and ensuring the long-term sustainability of biodiversity (Harvey et al., 2023).

Future studies to investigate the impacts of modern pest management practices on monarch butterflies, particularly focusing on exposure to genetically modified crop pollens, pesticides, and the potential synergistic toxicity of pesticide mixtures. The studies should include both laboratory and field research to determine the acute and sub–lethal toxicity of these chemicals on monarch butterflies. Research should investigate how modern agricultural practices impact monarch butterflies, particularly focusing on reduced milkweed and floral resources. Ciarlo et al. (2012) showed that agricultural chemicals impair honey bee memory and behavior, such as feeding tasks. This suggests similar pesticide exposure might affect monarch butterflies' learning and memory, which are crucial for their migration and foraging. Research should focus on how different pesticides impact monarchs' ability to learn and remember essential behaviors. Understanding these effects can help assess risks to their migration patterns and overall health, guiding strategies to mitigate potential pesticide-related threats. It should explore the correlation between diminished milkweed habitat, pesticide exposure, and protozoan parasites affecting monarchs.

6. CONCLUSION

Beneficial insects, including pollinators, natural pest controllers, and decomposers, are crucial for ecosystem health and agriculture. However, they face threats from habitat loss, pesticides, climate change, and invasive species. Conservation requires a multifaceted approach, including habitat preservation, pesticide management, and climate change mitigation. Public education and local conservation efforts are vital in fostering awareness and involvement. Immediate action from governments, researchers, and the public is necessary to protect these species and ensure their continued role in ecosystems and agriculture.

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