

## Review Article

# Exploring the Fascinating World of Entomology: A Deep Dive into the Study of Insects

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## A B S T R A C T

Entomology, the scientific study of insects, plays a crucial role in understanding biodiversity, ecosystem functioning, and human health. Insects are the most diverse group of organisms on Earth, occupying vital ecological niches as pollinators, decomposers, and pest controllers. This review explores the importance of insects, highlighting their ecological and economic roles, including their impact on agriculture, disease transmission, and environmental conservation. The article further examines the various specializations within entomology, such as economic, medical, forensic, behavioral, and conservation entomology. Recent advancements in the field, particularly through genetic tools and insect behavior research, are discussed, emphasizing how these innovations are enhancing our understanding of insect biology. Additionally, the challenges facing the field, such as declining insect populations due to habitat loss and climate change, are addressed. Ultimately, this review underscores the significance of entomology in addressing global issues and advocates for continued research and conservation efforts to protect insect biodiversity.

**Keywords:** Fascinating, Entomology, Environmental, Biodiversity

## Introduction

Entomology, the branch of zoology dedicated to the study of insects, is one of the most expansive and influential fields of biological science. Insects, despite their small size, are incredibly diverse and abundant, with over a million species described, making them the most numerous group of animals on Earth. They occupy nearly every habitat imaginable, from the depths of the oceans to the highest mountains, and their roles in ecosystems are indispensable. Insects contribute to critical ecological processes such as pollination, decomposition, and nutrient cycling, while also serving as a crucial food source for many other organisms.

The importance of insects extends far beyond their ecological functions. They also have a direct impact on human society, influencing agriculture, medicine, and even forensic science. Pollinators like bees, butterflies, and moths

are essential for the reproduction of many crops, while certain insect species are vectors for deadly diseases like malaria, dengue, and Zika virus. Insects also have cultural significance, inspiring scientific innovations and serving as subjects of research in fields ranging from genetics to behavior.<sup>1</sup>

## The Importance of Insects

Insects, despite their often diminutive size, hold an overwhelmingly significant place in the natural world. They are integral to the proper functioning of ecosystems, influencing biodiversity, agriculture, and even human health. As the most diverse group of animals on Earth, insects represent an estimated 80% of all known animal species. Their role in ecological processes, such as pollination, decomposition, and pest control, is fundamental to maintaining environmental balance. Understanding the

importance of insects is key to appreciating the intricate web of life in which they play a central role.

### Ecological Roles

Insects perform several crucial functions in ecosystems, making them indispensable to both natural and human systems. One of their most vital roles is pollination. Many plants, including over 75% of flowering species, rely on insects, particularly bees, butterflies, and beetles, to transfer pollen between flowers, enabling fertilization. This process is not only essential for the plants' reproduction but also supports the growth of fruits, vegetables, and crops, thereby sustaining food production worldwide. Without insects to pollinate plants, human food sources would be drastically reduced, leading to food insecurity and economic instability.

Insects are also decomposers, breaking down organic matter such as dead plants and animals, recycling nutrients back into the soil. This function is critical for nutrient cycling, which maintains soil fertility and supports plant growth. Without decomposers like insects, organic waste would accumulate, leading to a buildup of dead matter and a lack of available nutrients in the environment.<sup>2</sup>

Furthermore, insects are important food sources for a variety of animals, including birds, amphibians, and mammals. They form the foundation of many food webs, supporting higher levels of biodiversity. In turn, many predators of insects depend on them as a primary food source, creating a delicate balance in ecosystems. Insects also help to regulate other populations by acting as biological control agents. Predatory insects, such as ladybugs and parasitic wasps, help to keep harmful pest populations in check, reducing the need for chemical pesticides in agriculture.

### Economic Significance

The economic value of insects extends far beyond their ecological roles. As natural pollinators, they are critical to the success of agricultural industries, especially for crops like almonds, apples, coffee, and cocoa. The loss of pollinators would result in significant financial losses for farmers and a decrease in crop yields, affecting global food security. Insects also have economic importance in the realm of biological pest control. By predating or parasitizing pest species, insects reduce the reliance on chemical pesticides, which can be harmful to both the environment and human health. For example, the use of ladybugs to control aphids or the introduction of predatory beetles to combat crop-damaging weevils are common strategies that benefit agricultural production while protecting the environment.

Insects are also a potential source of novel pharmaceuticals. Many insect species produce unique chemicals, including toxins and antimicrobial compounds, that can have medical applications. For example, the venom of some wasps has

been studied for its potential to treat cancer, while insect-derived proteins are being explored for use in creating sustainable, nutrient-rich food sources.

### Insects and Human Health

While many insects are associated with disease transmission, others have direct benefits to human health. Mosquitoes, for example, are notorious for transmitting diseases like malaria, dengue fever, and Zika virus. However, the study of insect biology has led to advancements in controlling these diseases, such as the development of mosquito-resistant crops, targeted insecticides, and even genetically modified mosquitoes designed to reduce disease transmission.

Insects also have applications in the field of forensic science. Forensic entomology involves studying the types and stages of insect colonization on cadavers to estimate the time of death in criminal investigations. The presence of certain insect species and their developmental stages can help investigators determine the timeline of a crime, which is critical for solving cases.

### Cultural and Scientific Value

Insects also have immense cultural, aesthetic, and scientific value. From inspiring art and literature to contributing to the advancement of technology through biomimicry, insects have had a profound influence on human culture. In the field of biomimicry, scientists have studied insect flight mechanics to improve drone design and learned from the sensory abilities of insects to develop more efficient robots.

The study of insects has significantly advanced scientific understanding in areas ranging from genetics and evolution to ecology and behavior. Insects like fruit flies (*Drosophila melanogaster*) have long been used as model organisms in genetic research, helping to uncover fundamental principles of heredity, mutation, and evolution. Their rapid reproduction rates and simple genetic makeup make them ideal for experimentation, and insights from insect studies have translated into breakthroughs in human biology and medicine.<sup>3</sup>

### A Diverse Field: Specializations in Entomology

Entomology is a vast and multifaceted field of study that spans a wide range of specializations, each focusing on different aspects of insect life, behavior, and interactions with the environment. These specializations not only reflect the diversity of insect species but also the diverse roles that insects play in ecosystems, human society, and even scientific research. Below, we explore some of the most prominent subfields within entomology, highlighting their unique contributions to our understanding of the insect world.

#### Economic Entomology

Economic entomology focuses on the relationship between insects and human economies, particularly the ways in

which insects impact agriculture, forestry, and industries reliant on insect products. This branch of entomology is essential for managing insect pests, which can cause extensive damage to crops, livestock, and stored products. Economic entomologists work to develop integrated pest management (IPM) strategies that combine biological, chemical, cultural, and mechanical methods to control pest populations without harming the environment or human health.

In addition to managing harmful pests, economic entomologists also study beneficial insects that play positive roles in agriculture. For instance, insects like ladybugs, lacewings, and parasitoid wasps are important in controlling aphids, caterpillars, and other agricultural pests. Some insects, such as silkworms and honeybees, are farmed for their products, contributing to industries like silk production and honey harvesting. Economic entomology plays a critical role in ensuring sustainable agricultural practices, minimizing crop loss, and maintaining food security.

### **Medical and Veterinary Entomology**

Medical and veterinary entomology is concerned with the study of insects that affect human and animal health, either as vectors of diseases or as agents of medical significance. This subfield is critical for understanding how insects transmit pathogens and how we can control or prevent these diseases.

One of the primary concerns in medical entomology is the study of vector-borne diseases, which are transmitted by insects like mosquitoes, ticks, and flies. For example, mosquitoes are known vectors of diseases such as malaria, dengue fever, Zika virus, and chikungunya. Understanding the biology, behavior, and ecology of these insects is vital for developing effective strategies to reduce the spread of diseases. This could involve the development of targeted insecticides, genetic modification of mosquitoes to render them sterile, or the use of natural predators to control insect populations.

Veterinary entomology similarly studies the role of insects in transmitting diseases to livestock and pets. Insects like fleas, ticks, and biting flies can spread various diseases, such as Lyme disease in animals and heartworm in dogs. Research in this area is crucial for improving animal health and preventing the spread of zoonotic diseases, which can be transmitted from animals to humans.

### **Forensic Entomology**

Forensic entomology is the application of insect biology to criminal investigations, especially in determining the time of death in cases involving corpses. This field leverages the predictable patterns of insect colonization on a decomposing body, using the types and stages of insects present to estimate when the body was deposited and how long it has been since death.

Insects such as blowflies are among the first to arrive at a body, laying eggs that hatch into larvae. The development rate of these larvae depends on environmental factors like temperature, humidity, and geographic location. By studying these factors, forensic entomologists can create a timeline of events that helps law enforcement determine the time of death with greater precision. Forensic entomology is an essential tool in solving crimes, particularly in cases where other forensic evidence may be scarce or degraded.

### **Behavioral Entomology**

Behavioral entomology is the study of insect behavior, focusing on how insects interact with one another, with their environment, and with other species. This subfield examines a wide variety of behaviors, including mating rituals, foraging strategies, navigation, communication, and social structures.

For example, social insects such as ants, bees, and termites exhibit highly organized behaviors within their colonies, which include division of labor, complex communication through pheromones, and cooperative care of offspring. By studying these behaviors, entomologists can gain insights into how social systems evolve, how individual insects cooperate, and how behaviors are passed down across generations.

Behavioral entomology also extends to insect communication. Insects like moths, crickets, and grasshoppers use sound, pheromones, or visual signals to communicate with each other, whether for mating, defense, or territory establishment. Understanding these communication strategies can aid in pest control methods or even inspire technological innovations in robotics and artificial intelligence.<sup>4</sup>

### **Conservation Entomology**

As insects face increasing threats from habitat loss, climate change, pesticide use, and pollution, conservation entomology has emerged as a vital subfield focused on protecting insect biodiversity. This area of entomology aims to identify at-risk species, understand the ecological factors contributing to their decline, and develop strategies to conserve and restore insect populations.

Conservation entomologists study the habitat needs of endangered insects, investigate the impacts of environmental stressors, and work to mitigate the factors driving insect declines. Insects like monarch butterflies, honeybees, and certain species of dragonflies are among those experiencing significant population reductions, prompting global efforts to protect them through habitat restoration, legal protections, and education programs.

Additionally, conservation entomologists examine the broader impact of insect decline on ecosystems. Since

insects are key players in pollination, decomposition, and food webs, their loss can have cascading effects on biodiversity and ecosystem services. Conservation efforts in entomology are not only crucial for saving individual species but also for ensuring the health and resilience of ecosystems that depend on insects.

### **Systematic Entomology**

Systematic entomology focuses on the classification, identification, and evolutionary relationships of insects. This subfield involves describing and cataloging new species, studying insect taxonomy, and reconstructing evolutionary trees to understand the biodiversity and phylogenetic relationships among different insect groups.

Systematic entomologists work on compiling insect specimens and developing taxonomic keys to help identify species accurately. Their work is essential for understanding the evolutionary history of insects and for creating accurate databases for biodiversity studies. The knowledge generated by systematic entomology can also inform conservation strategies and provide essential information about the distribution and behavior of different species.

### **Recent Advancements in Entomology**

Entomology, the study of insects, has seen remarkable advancements in recent years, driven by innovations in technology, genetics, and ecological understanding. As insects continue to play critical roles in ecosystems, agriculture, and even human health, the need for more precise and effective research techniques has spurred significant breakthroughs. This section explores some of the key recent advancements in entomology that are shaping the future of the field and offering new ways to address environmental, economic, and public health challenges.<sup>5,6</sup>

#### **Advances in Insect Genomics**

One of the most transformative areas of recent entomological research is the advancement of insect genomics. The sequencing of insect genomes has provided deep insights into their biology, behavior, and evolutionary history. For example, the genome of the mosquito species *Anopheles gambiae*, which transmits malaria, was sequenced in 2002, marking a major milestone. This and subsequent genomic projects have led to new methods for controlling insect-borne diseases. Understanding the genetic makeup of insects enables researchers to identify vulnerabilities in their biology that can be exploited to develop targeted interventions.

The development of CRISPR-Cas9 gene-editing technology has revolutionized the ability to modify insect genomes. This technique allows researchers to precisely edit the genes of insects, with applications ranging from the creation of genetically modified mosquitoes that can reduce the spread of diseases like malaria and Zika, to the production

of insects with traits that can help in pest control, such as sterility or resistance to harmful pesticides. The potential of gene editing in entomology is immense, offering a more sustainable approach to pest control, reducing the reliance on chemical pesticides, and providing more effective ways to combat insect-borne diseases.

### **DNA Barcoding and Species Identification**

Advancements in DNA barcoding have revolutionized the way entomologists identify and classify insect species. DNA barcoding involves analyzing short, standardized genetic markers to distinguish between different species. This technique has made species identification much faster, more accurate, and less dependent on physical characteristics, which can sometimes be difficult to assess in certain insect groups.

For example, DNA barcoding has helped streamline biodiversity surveys and insect monitoring, allowing researchers to identify and catalog insect species more efficiently. The ability to identify species quickly is crucial in ecological studies, pest management, and conservation efforts, as it allows scientists to track changes in populations and understand their role in ecosystems. This has also led to a greater understanding of cryptic species, which are genetically distinct but visually indistinguishable, improving our understanding of biodiversity and ecosystem health.

### **Insect Behavior and Communication**

Recent research has deepened our understanding of insect behavior and communication, particularly how insects use pheromones to communicate with one another. Pheromones are chemical signals that trigger specific behaviors, such as mating, foraging, or defense. Researchers have made significant progress in deciphering the molecular mechanisms behind pheromone reception, allowing for the development of more effective pheromone traps and pest control strategies.

For example, in the control of agricultural pests, scientists have developed pheromone-based lures to attract insects like moths and beetles, disrupting their mating cycles and preventing pest outbreaks without the use of harmful chemicals. Similarly, the discovery of new insect communication methods, such as vibrational signaling in ants or ultrasonic communication in bats and moths, has opened up new avenues for research in insect behavior. This knowledge can be used to improve integrated pest management strategies and may inspire the development of biomimetic technologies, where insect behavior is used as a model for designing robots or improving communication systems.

### **Insect Conservation and Biodiversity Monitoring**

The increasing recognition of the critical role insects play in ecosystem services has led to substantial advances in insect conservation. With insect populations declining



globally due to factors like habitat loss, pesticide use, and climate change, conservation efforts have become more urgent. Recent advancements in habitat restoration and the creation of insect corridors aim to protect and rebuild habitats essential for pollinators, decomposers, and other beneficial insects.

In addition, new technologies like remote sensing and environmental DNA (eDNA) are being used to monitor insect populations more efficiently. Remote sensing techniques, such as satellite imagery and drones, help monitor large-scale environmental changes that impact insect habitats, while eDNA allows researchers to detect traces of insect DNA in environmental samples, such as water or soil, to track species diversity and population trends. These tools have improved the ability to detect insect declines early, facilitating more proactive conservation efforts.

### **Insect-Based Sustainable Solutions**

The rise of sustainable technologies and practices has led to increased interest in insects as a source of food, protein, and bio-materials. Insects like mealworms, crickets, and black soldier flies are being explored as alternative sources of high-quality protein for both human consumption and animal feed. Insect farming is considered a highly efficient and environmentally friendly way to produce food, as insects require fewer resources like water and land compared to traditional livestock.

Moreover, insects are being utilized in biodegradation and waste management. The larvae of the black soldier fly, for instance, are being used to break down organic waste, converting it into high-value protein and fat products. This process not only reduces waste but also provides an environmentally sustainable alternative to conventional waste management methods. Research is ongoing to scale up these practices, which could revolutionize waste management and contribute to circular economy models.<sup>7,8</sup>

### **Artificial Intelligence and Machine Learning in Insect Research**

Recent advancements in artificial intelligence (AI) and machine learning are revolutionizing the study of insect behavior, pest management, and taxonomy. AI-powered tools are being used to analyze vast amounts of data, from insect movement patterns to the identification of species based on images or acoustic signals. For example, AI can help detect insect infestations in crops by analyzing patterns of behavior or physical damage in real-time.

Machine learning algorithms are also used to process data from automated traps or drones, which monitor insect populations or track pest behavior. These technologies enhance our ability to conduct large-scale monitoring without the need for constant human intervention, allowing for more accurate and timely responses to insect-related

issues. As these technologies advance, the potential for AI and machine learning to transform pest control, conservation, and ecological research grows significantly.

### **The Challenges Facing Entomology**

While entomology has made significant strides in understanding and utilizing the diverse roles of insects in ecosystems, human health, and agriculture, the field also faces a number of significant challenges. These challenges range from ecological threats, such as declining insect populations, to scientific limitations in the study of complex insect behaviors and interactions. As the world confronts global environmental changes, the importance of entomology becomes even more pronounced, making it essential to address these challenges in order to ensure the continued health of ecosystems and human societies.

### **Declining Insect Populations**

One of the most pressing challenges in entomology today is the declining populations of insects across the globe. Studies have shown that many insect species are experiencing rapid declines due to a combination of factors, including habitat loss, pesticide use, climate change, and pollution. For example, in some regions of Europe and North America, populations of key pollinators like bees have decreased dramatically, with consequences for agricultural productivity and biodiversity. The insect apocalypse—a term coined to describe the dramatic decline in insect populations—has sparked widespread concern, as insects are critical for pollination, decomposition, and supporting food webs.

The loss of insect populations is not only alarming from an ecological standpoint but also from an economic perspective. Many insect species contribute directly to agricultural productivity by pollinating crops or controlling pests. Without insects, the productivity of ecosystems and food systems would be severely disrupted, resulting in both environmental and economic instability. Entomologists face the daunting task of understanding the drivers behind these declines, predicting the long-term impacts, and developing conservation strategies to mitigate further losses.

### **Climate Change and Its Impact on Insects**

Climate change is a major threat to insect populations and ecosystems, influencing insect behavior, distribution, and lifecycle patterns. Changes in temperature, precipitation, and seasonal variability affect the timing of insect development, migration, and reproductive cycles. Some insects, such as certain species of butterflies and moths, are shifting their ranges toward cooler climates, while others may be unable to adapt to these changes.

Insects are particularly vulnerable to climate change because their physiology is closely tied to environmental conditions. As temperatures rise, insects may face altered

habitats, reduced food availability, or increased exposure to predators and diseases. For example, higher temperatures can accelerate the life cycles of certain pests, leading to more frequent outbreaks and increased damage to crops. Conversely, climate change may disrupt the timing of insect pollination, which can adversely affect flowering plants and food crops. Understanding how climate change will impact insect populations and their interactions with ecosystems is a significant challenge for entomologists in the coming decades.

### **Pesticide Resistance**

The widespread use of pesticides to control agricultural pests has led to the development of pesticide resistance in many insect species. As insects evolve to survive exposure to these chemicals, the effectiveness of traditional pesticides diminishes, resulting in increased pesticide use, higher costs, and greater environmental contamination. Pesticide resistance also contributes to the decline of non-target insect populations, including beneficial species like pollinators and natural predators of pests.

One of the biggest challenges in entomology is finding sustainable pest control solutions that do not rely on harmful chemicals. The development of integrated pest management (IPM) strategies, which combine biological, cultural, and mechanical methods with limited pesticide use, is essential for managing pest populations in a way that minimizes harm to ecosystems. However, the challenge remains in implementing these strategies on a large scale, particularly in areas where the overuse of pesticides has become entrenched. Additionally, the emergence of resistance to novel pesticide formulations calls for continued innovation in pest management technologies, as well as research into alternative, more sustainable practices.

### **Limited Public Awareness and Support for Insect Conservation**

Despite their critical importance, insects are often overlooked by the general public, and their conservation is not prioritized in many regions. This lack of awareness and understanding about the ecological and economic importance of insects presents a significant challenge for entomologists seeking to garner support for insect conservation efforts. Public perceptions of insects are often dominated by negative associations, such as the fear of pests or diseases, rather than their valuable contributions to biodiversity, agriculture, and the environment.

Promoting awareness of the value of insects and the threats they face is essential for building public support for conservation programs and sustainable agricultural practices. Entomologists and conservationists must work together to develop effective outreach strategies that educate the public, policymakers, and stakeholders about

the vital role of insects in maintaining ecosystem services. Additionally, encouraging research funding and policy initiatives focused on insect conservation is critical for ensuring that resources are allocated to preserve insect biodiversity.<sup>9,10</sup>

### **Insect Identification and Taxonomy**

Accurate species identification is essential for understanding insect biodiversity, tracking population trends, and monitoring the impacts of environmental change. However, insect taxonomy remains a major challenge in entomology. With an estimated 10 million insect species on Earth, only a small fraction have been formally described, and many species remain poorly understood. The lack of taxonomic knowledge makes it difficult to assess the full extent of insect biodiversity and understand the ecological roles of lesser-known species.

Recent advancements in DNA barcoding and genomic sequencing have made it easier to identify and classify insect species, but taxonomists still face the immense challenge of cataloging and describing new species. Furthermore, taxonomic work is labor-intensive and often requires expertise in identifying subtle morphological differences between species. As the pressure to address insect declines and ecosystem disruptions grows, taxonomists and entomologists will need to work collaboratively to build comprehensive insect databases and improve our understanding of insect diversity.

### **Lack of Funding and Research Support**

While there is growing recognition of the importance of insects, funding for entomological research remains limited compared to other areas of biological science. Insects are often seen as less charismatic than other animals like mammals or birds, leading to reduced funding and research opportunities in comparison. This lack of funding hinders the ability of entomologists to conduct long-term research, implement conservation programs, and develop new pest management strategies.

Securing adequate funding for insect-related research is crucial for addressing the many challenges facing the field, from climate change and habitat loss to pest resistance and biodiversity loss. Researchers need financial support to develop innovative solutions, such as genetic tools for pest control, improved agricultural practices, and strategies for conserving endangered insect species. In addition, funding is needed to facilitate public outreach programs that can educate and engage communities about the importance of insects.<sup>11-13</sup>

### **Conclusion**

Insects are indispensable to the health of ecosystems, human agriculture, and public health, yet they face

unprecedented challenges due to habitat loss, climate change, pesticide use, and other human-induced pressures. The field of entomology has made remarkable progress in addressing these challenges through advancements in genetics, pest management, conservation strategies, and behavioral research. However, significant hurdles remain, such as declining insect populations, pesticide resistance, and a lack of public awareness regarding the importance of insect conservation.

Moving forward, it is crucial that the scientific community, policymakers, and the public collaborate to find sustainable solutions to protect insect biodiversity. This includes funding further research, promoting integrated pest management techniques, supporting habitat restoration efforts, and enhancing education about the vital roles insects play in pollination, decomposition, and food webs. By addressing these challenges head-on, entomologists can continue to make meaningful contributions to preserving insect populations, ensuring ecosystem stability, and fostering sustainable agricultural practices.

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