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Scope and Future of Ecosystem Services in Entomology

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Insects, the most abundant organisms on Earth, play essential roles in various ecological functions and contribute significantly to ecosystem services (ES). These services, which benefit humans and ecosystems alike, can be categorized into four major types: provisioning, regulating, supporting, and cultural services. Insects provide critical provisioning services, such as serving as a source of food and medicine. They are rich in nutrients, including proteins, vitamins, and minerals, and play a key role in reducing malnutrition and supplementing diets. Insects also contribute to regulating services through pollination and biological control, supporting services by aiding in decomposition and nutrient cycling, and cultural services by being integral to education, spiritual values, and

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cultural heritage. The importance of insects in ecosystem services underscores their value in maintaining ecological balance and enhancing human well-being. This review highlights the multifaceted roles insects play in ecosystem services, emphasizing the need for further research and conservation efforts to protect these vital organisms.

Keywords: Ecosystem; entomotherapy; food; insects; pollinators.

1. INTRODUCTION

Insects are the most abundant living organisms on Earth, with around 1 million species described and an estimated 5 million more yet to be identified [1]. They play vital roles in various ecological functions, such as controlling agricultural pests, recycling nutrients, dispersing fungal spores, managing waste and animal dung, and boosting agricultural productivity [2&3]. Ecosystem services (ES) are broadly defined as the benefits that humans derive from ecosystems [4]. Insects provide these services across natural environments, human-modified landscapes, and semi-natural areas [5]. According to the Millennium Ecosystem Assessment (2003), insects contribute to all four major categories of ecosystem services (Table 1): (a) Provisioning services, (b) Regulating services, (c) Supporting services, and (d) Cultural services.

Table 1. Different Services Contributed by Insects

Provisioning services	○ Edible insects ○ Food chain supplementation ○ Medicine
Regulating services	○ Pollination ○ Biological control
Supporting services	○ Decomposition ○ Bioindicators ○ Nutrient accumulation
Cultural services	○ Education ○ Religion and spiritual values ○ Cultural heritage

2. PROVISIONING SERVICES BY INSECTS

2.1 Edible Insects – Insects as Food

The key provisioning service provided by insects is to use them as food and feed by the human beings [6]. A recent list has reported about 2141 different species of insects that are directly used as food or feed [7]. Edible insects are one of the many byproducts of low intensity agriculture. Edible insects are seasonal and protein-rich food. Edible insects can be considered as complete diet. Furthermore, edible insects reduce the malnutrition.

Estimated that from 6-10 million insect species noted, 2300 species of 18 different orders have been announced as edible insects. Some insects are edible and consumed by human as food. Such practice of consumption of insects as food is known as entomophagy. Insects are consumed in different metamorphosis stages depending upon the species, for instance, both nymph/larva and adult stages are consumed for dragonfly, bees, wasp, *etc*., grub or larva stages for longhorn beetles and silkworm moth, adult for water beetles and grasshopper. Likewise, insects are being prepared in different ways for consumption *viz*., fried, boiled, roasted or ground and sometime eaten raw. The most commonly consumed species are within the Coleoptera (659 species), Lepidoptera (362 species), Hymenoptera (321 species), Orthoptera (278 species), Hemiptera (237 species), Odonata (61 species), Isoptera (59 species) and Diptera (37 species). In the Mayurbhanj district of Odisha, a chutney made from red weaver ants, known as 'Kai Chutney,' is both a delicacy and a medicinal remedy. This chutney is consumed not only for its unique taste but also for its therapeutic benefits. It is used to treat ailments such as jaundice, common colds, joint pain, coughs, and poor eyesight. Additionally, the local community prepares oils by soaking these ants, which are applied to treat skin conditions like gout and ringworm infections. On January 2, 2024, this distinctive chutney received a geographical indication (GI) tag.

The insect nutrients are easy for the human body to assimilate [8&9] and rich in potassium, phosphorus, iron, zinc, copper, manganese, sodium, vitamin B1 and B2 and niacin. Nutritional value of the insects [10] was given in the below table (Table 2).

Table 2. Nutritional value of different insects

Species name	Edible product	Protein content (g/100 g fresh weight)
Locusts & grasshoppers	Larva	14 -18
	Adults	13 - 28
Silkworm	Caterpillar	10 - 17
Palmworm beetles	Larva	7 - 36
Yellow mealworm	Larva	7-36
Crickets	Adult	8-25
Termites	Adult	13-28

Table 3. Global consumption of insects as food [11]

Continents	Number of insect consuming countries	Percentage of total insect consumption
Asia	29	20%
Australia	14	09%
Africa	26	30%
North and South America	23	39%
Europe	11	02%

Globally, the market for edible insects used as animal feed was valued at USD 5.03 billion in 2022. It is projected to reach USD 96.82 billion by the end of 2031, with an expected compound annual growth rate (CAGR) of 38.9% from 2022 to 2031.

2.2 Insects Role as Food Supplements

Insects are a rich source of minerals, proteins, and vitamins, making them a potential alternative for dietary supplementation. Insect powder can effectively address nutritional deficiencies in various foods, such as gluten-free products. For instance, incorporating 10% cricket powder into gluten-free bread significantly enhances its nutritional value, with the protein content increasing more than seven-fold compared to standard bread [12]. Formic acid, a naturally occurring compound in ants and other insects, is also available as a dietary supplement in capsules or tablets. It is believed to offer several health benefits, including reducing inflammation, aiding digestion, and strengthening the immune system.

Edible insects like house crickets provide a nutrient profile that includes essential amino acids, unsaturated fats, fiber, vitamins, and minerals such as vitamin B12, iron, zinc, and calcium. This makes them a viable alternative to traditional animal and plant foods like pork, chicken, and beef. Consuming edible insects could potentially enhance human health by improving gastrointestinal function, boosting immune response, lowering bacterial infection risks, and reducing chronic inflammation associated with cancer and cardiovascular diseases. Given their diverse nutritional and environmental benefits, edible insects present promising avenues for further research into their role in human diets.

2.3 Entomotherapy – Insects as Medicine

Insects are abundant sources of proteins, bioactive compounds, and other essential nutrients [13]. They can produce and sequester allelochemicals and phytochemicals, which makes them promising candidates for developing new drugs and pesticides [14&15]. Among insects, Hymenoptera includes the largest number of medicinal species, followed by Coleoptera, Orthoptera, Lepidoptera, and Blattodea.

Globally, at least 1,000 insect species are reported to be used for therapeutic purposes. China alone accounts for approximately 300 medicinal insect species, spread across 70 genera, 63 families, and 14 orders. Many other regions, including India, Japan, Turkey, Korea, Africa, Tibet, Spain, and South America, also report the use of insects for medicinal purposes [16].

Traditional Entomotherapy refers to the use of insects or insect-derived products for medicinal purposes, a practice documented in various cultures for centuries. For example, in Brazil, the tenebrionid beetle (*Palembus dermestoides*) is used to treat asthma, arthritis, tuberculosis, and sexual impotence. In Traditional Chinese

Medicine, insects are often used alongside herbal remedies. Centipedes, for instance, are dried, ground into a paste, and applied to treat snake bites, headaches, and muscle soreness. In Koraput District of Orissa, India, local tribes consume the brood of O*. smaragdina* to cool the body and mind in hot weather and improve eyesight. In Kerala, the Paniyan tribes use mud from unidentified ant nests to treat rabies, while termites and their mounds are ground and consumed to address ulcers, rheumatic diseases, and anemia.

Maggot therapy involves deliberately introducing live, disinfected blow fly larvae (maggots) into soft tissue wounds to selectively remove necrotic tissue. This process helps to prevent infection and accelerates the healing of chronic wounds and ulcers [17]. The maggots perform three main functions: they clean the wound by breaking down and removing dead (necrotic) tissue, disinfect the wound by killing bacteria, and promote wound healing [18]. Maggots secrete various chemicals that have antimicrobial properties, such as allantoin, urea, phenylacetic acid, phenylacetaldehyde, calcium carbonate, and proteolytic enzymes [19]. The flies involved in this therapy are from the order Diptera and include families such as Calliphoridae (blow flies) and Sarcophagidae (flesh flies), with common species including *Phormia regina* and *Lucilia sericata*.

Maggot therapy, or larval therapy, has been used since ancient times for wound healing. Today, the technique has advanced with modern technology and is currently undergoing rigorous testing in a clinical trial at the Malcom Randall VA Medical Center in Gainesville, Florida. This therapy has experienced a global resurgence, becoming an approved treatment under the NHS since 2004 and receiving regulatory approval in the US during the same year. Clinical-grade larvae are now cultivated in various countries, including the US, Australia, China, Turkey, and parts of Africa such as Nigeria.

2.4 Apitherapy

Apitherapy involves using honeybee products such as honey, pollen, propolis, royal jelly, bee wax, and bee venom to treat various diseases and disorders. Bee wax, rich in Vitamin A, supports cell development and has antiseptic properties, making it useful in body lotions and as a coating for pills to aid ingestion [20]. Apipuncture refers to therapy using bee stings, where melittin, the main peptide in bee venom, helps reduce inflammation and is employed in treating conditions like rheumatoid arthritis and multiple sclerosis [21]. Apitoxin, or honey bee venom, can be applied through direct stings to alleviate polyneuritis and asthma [20]. Honey is used to address digestive issues and as a general health tonic. It can be heated and consumed to treat head colds, coughs, throat infections, laryngitis, tuberculosis, and lung diseases, or applied to the skin to manage scar tissue, rashes, and burns [22]. Honey's phenols, including quercetin, hesperidin, and caffeic acid, also have anti-cancer properties [23]. Bee bread, or bee pollen, is consumed for its health benefits and is believed to aid in treating infections, skin diseases, and ulcers. It is a rich source of vitamins (A, B1, B2, B6, C, and E), amino acids, and minerals like calcium, iron, potassium, phosphorus, and sodium [20]. Propolis is a resinous and waxy substance gathered by honeybees, which they use to insulate and seal their hives. It is frequently consumed by menopausal women due to its high hormone content and is reputed for its antibiotic, anaesthetic, and anti-inflammatory properties [20]. Royal jelly is utilized to address a variety of health issues, including anemia, gastrointestinal ulcers, arteriosclerosis, and both high and low blood pressure. It also helps manage reduced sexual libido, promotes cell regeneration and bone marrow production, and supports endocrine system balance [20].

Spanish fly, an emerald-green beetle from the Coleoptera order and Meloidae family, includes species such as *Mylabris pustulata* in India and *Lytta vesicatoria* in Europe. These beetles produce cantharidin, a defensive chemical used to deter predators through reflex bleeding. Beetles contain up to 1% cantharidin by weight. In 2004, the FDA approved cantharidin for treating warts and skin conditions and for its potential to inhibit ovarian cancer cells and treat infections of the urogenital tract and kidneys [21].

2.5 Biomimetics

Entomomedical engineering is the branch of engineering that uses insects either directly or as a source of inspiration to design and develop medical treatments or instruments. This is also called as biomimetics.

2.5.1 Insects as inspiration models in medical engineering

Mechanical failures in guidewires and needle-like instruments often result from buckling. To address this issue, one can either increase the critical load the tool can withstand or reduce the load required to penetrate the substrate. Mosquito proboscises and wasp ovipositors serve as natural examples of effective buckling prevention strategies. Insect orders Diptera and Hymenoptera have inspired bio-engineered needles.

2.5.2 Mosquito-inspired microneedles

The mosquito's biting process and its phases have been electronically monitored. [24] were pioneers in developing a hollow microneedle modelled after the mosquito proboscis, featuring a serrated design inspired by the mosquito's maxillae to facilitate cutting and reduce the contact area between the needle and the surface.

2.5.3 Wasp-inspired steerable and self-propelling needles

According to [25] the Hymenoptera ovipositor integrates multiple strategies to prevent buckling. [26] designed a probe capable of navigating curved trajectories to access deep brain lesions.

The probe is designed with two parallel segments featuring an interlocking mechanism similar to the olistheter found in the Hymenoptera ovipositor, which links the three segments of the ovipositor. In addition to strategies for preventing buckling, the ovipositor's three longitudinal segments enable the tip to be reoriented to a bevel-shaped end.

2.5.4 Bio-inspired clamp

The Formicidae family within the Hymenoptera order serves as the primary inspiration for bio-inspired clamps. [27] created a surgical clamp modeled after the Atta laevigata ant. This clamp is designed to enhance efficiency and reduce patient trauma during placement and removal. It features a handle mechanism to open the clamp and a contact system for interaction with the skin.

2.5.5 Food web dynamics

Insects accumulate energy and nutrients throughout their life cycles, and when they die and decompose, these nutrients return to the soil in a more concentrated form. This process not only aids in nutrient cycling but also supports primary and secondary productivity. Insects have a high food-to-biomass conversion rate, meaning they utilize a larger portion of energy from their food compared to mammals [9]. Being poikilothermic, insects do not need energy to regulate their body temperature. Their rapid life cycles and high reproduction rates further enable them to produce biomass at a much faster rate than mammals, thus significantly contributing to both primary and secondary productivity [28].

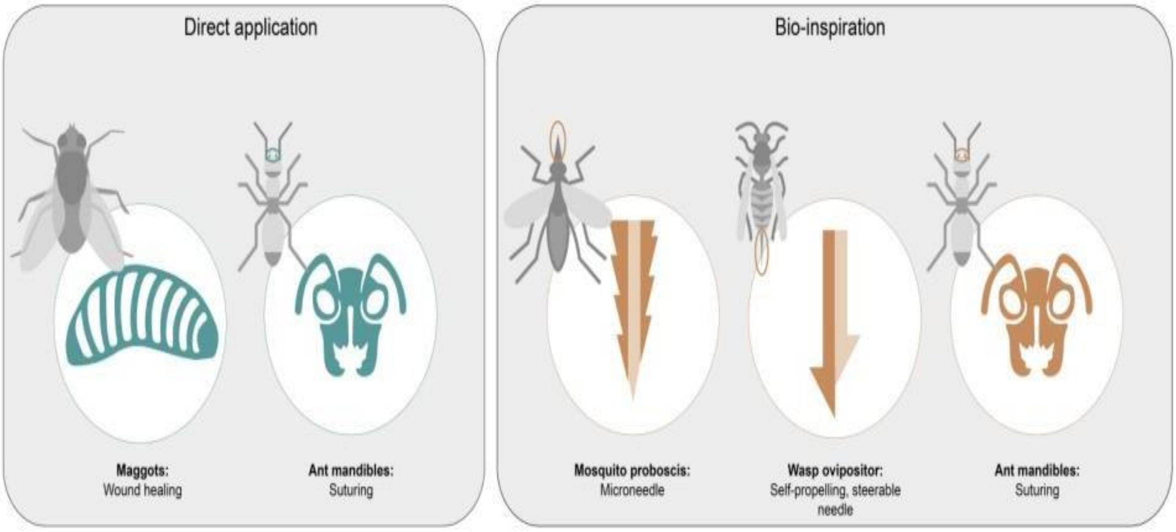

Fig. 1. Direct application and bio-inspiration

3. REGULATING SERVICES

3.1 Pollinators

Most flowering plants rely on insects for pollination. Insect pollination (entomophily) offers several advantages, including reduced pollen wastage, increased efficiency in pollination, successful pollination in less ideal conditions, and the enhancement of plant species diversity in a given area [29]. Recent estimates indicate that approximately 88% of all flowering plants and 35% of the global plant-based food supply depend on pollinators for their success. Bees, in particular, are crucial pollinators, with bee pollination in the United States alone valued at up to USD 3.07 billion [30].

Table 4. Different insects as predators and parasitoids

Predators	Pest targeted
Coccinella septumpunctata	Aphids
Scymnus coccivora	Grapevine mealy bug
Cryptolaemus montrouzieri	Grapevine mealy bug
Rodolia cardinalis	Cottony cushion scale
Menochilus sexmaculata	Mealybugs and scales
Ground beetles	Coconut BHC, Rice BPH
Tiger beetles	Small caterpillars
Crytorhinus lividipennis	Rice BPH
Platymeris laevicollis	Coconut rhinoceros beetle
Eucanthecona furcelleta	Red hairy caterpillar
Parasitoids	**Targeted pest**
Trichogramma japonicum	Egg parasitoid of yellow stem borer (YSB)
Trichogramma chilonis	Egg parasitoid of leaf folder, Case worm, YSB etc.
Isotima javensis	Sugarcane top borer
Anagrus *spp*	Egg parasitoids of leaf and plant hoppers
Cotesia flaviceps	Larval parasitiod of lepidopteran pests like stem borers
Brachymeria nephantidis	Pupal parasitiod of *Opisinia arenosella*
Epiricania melanoleuca	*Pyrilla perpusilla*
Platygaster oryzae	Rice gall midge

3.2 Biological Control

Pest control is crucial in agriculture and is often achieved using chemicals, which can harm the environment and reduce soil productivity. Nowadays, there is a growing focus on biological control methods for managing harmful insects. A significant number of insects are natural predators or parasites, with about 10% being parasitoids. Entire insect orders, such as Odonata (dragonflies) and Neuroptera (lacewings and antlions), are predators. Additionally, many true bugs (Hemiptera), beetles (Coleoptera), flies (Diptera), and members of Hymenoptera (wasps, bees, and ants) are also predatory (Table 4). Typically, beneficial insect species in agro-ecosystems greatly out number harmful ones.

4. SUPPORTING SERVICES

4.1 Decomposition

Insect communities regulate and control the process of waste biodegradation. Beetle larvae, flies, ants, and termites break down dead plant matter into finer particles, which are further decomposed by microbes. Dung beetles, with around 4,000 documented species, are crucial for manure decomposition. If dung is left on the soil surface, approximately 80% of its nitrogen is lost to the atmosphere, contributing to global warming. Dung beetles enhance soil health by increasing levels of nitrogen, phosphorus, potassium, calcium, and magnesium, and they help reduce greenhouse gas emissions by 7% to 12% through their role in the carbon cycle. Wood-decomposing beetles, such as the Huhu beetle (*Prionoplus reticularis*), aid in decomposing dead pine wood, with insects globally contributing to up to 29% of deadwood decomposition. In tropical forests, insects account for 28.2% of decomposition, 6.3% in temperate forests, and 3.3% in boreal forests.

4.2 Forensic Entomology

A new subfield within forensic entomology, known as "entomotoxicology," is emerging. This area focuses on analyzing toxins in arthropods primarily flies and beetles that feed on decomposing bodies. By examining these arthropods at a crime scene or on a corpse, investigators can determine whether toxins were present in the body at the time of death. This technique represents a significant advancement in forensic science, as it allows for the analysis of toxins in cases where traditional methods would be impossible due to severe decomposition and the absence of intact tissue and bodily fluids. Ongoing research in entomotoxicology is exploring how toxins affect arthropod development, which helps refine estimates of postmortem intervals.

Current studies in entomotoxicology are investigating how drugs influence the development of insects that have fed on the decomposing tissue of drug users. It has been observed that certain drugs, such as cocaine, can accelerate maggot development. For example, *Lucilia sericata* larvae found in the nasal cavity of a cocaine user grew over 8 mm longer than larvae of the same species from other parts of the body. Researchers are also developing methods to detect and measure drug levels in older fly pupae. To date, various substances, including bromazepam, levomepromazine, malathion, phenobarbital, trazolam, oxazepam, alimemazine, clomipramine, morphine, mercury, and copper, have been identified in maggots.

4.3 Green Burial

In recent years, the rising costs of burial systems have been linked to pollution from decomposition products, which include chemicals and microorganisms affecting soil and groundwater. Green burial aims to minimize environmental impact and conserve natural resources.

Insects like *Musca domesti*ca (Diptera: Muscidae), which colonize carcasses, bring with them a range of pathogenic microbes, over 100 in total. Putrescine, a volatile compound associated with decomposition, attracts blowflies while deterring male carcass beetles (Coleoptera: Silphidae). Additionally, putrescine plays a role in the swarming behavior of bacteria such as *Proteus mirabilis*, which is commonly found with blowflies.

4.4 Formation of Soil and Nutrient Cycling:

Insects play a crucial role in soil formation and nutrient recycling, which are essential regulating services. Termites and ants, for instance, act as key soil engineers. They not only forage on the surface but also inhabit deeper layers of soil, transporting substantial amounts of nutrient-rich organic matter to the surface. This process enhances soil nutrient levels and helps maintain soil fertility [31&32]. Burrowing insects such as ants, termites, and beetles help aerate the soil and improve water infiltration by creating tunnels. Dung beetles, for example, bury animal waste, which prevents disease spread and adds organic matter to the soil, thereby boosting its fertility. Additionally, palm weevil larvae burrow into fallen trees, consuming inner tissues and accelerating decomposition, which contributes to nutrient cycling and soil formation [33].

4.5 Biodegradation

Polyethylene (PE) has long been considered non-biodegradable, though there have been occasional reports of bacterial cultures degrading PE. Recent research has shown that waxworms, specifically the larvae of *Plodia* i*nterpunctella*, can chew and consume PE films. Two bacterial strains capable of degrading PE, *Enterobacter* a*sburiae* YT1 and *Bacill*us sp. YP1, were isolated from these worms' gut. After a 28-day incubation with these bacteria on PE films, viable biofilms formed and the hydrophobicity of the PE films decreased. Scanning electron microscopy (SEM) and atomic force microscopy (AFM) revealed noticeable damage on the PE films, including pits and cavities 0.3−0.4 μm deep.

Several insect species have been reported to degrade plastics, including mealworms (*Tenebrio molitor*) [34], superworms (*Zophobas atratus*) [35], and greater wax moth larvae (*Galleri*a *mellonel*la) [36&37]. Mealworms, for instance, have been shown to degrade polyester-PU foam by up to 67% [38]. The efficiency of plastic degradation by insects varies due to the different chemical properties of plastics. *Galleria mellonella* larvae degrade PE faster than polystyrene (PS) [39]. This degradation may be influenced by diets high in nutrients that enhance the diversity of the intestinal microbiome in the larvae. For example, beeswax can increase the species richness and evenness of the gut microbiome in PE-fed larvae [39].

4.6 Bioindicators

Insects have long been integral to ecological studies and are commonly used as bioindicators. They provide insights into the condition of their habitats. For example, ant species are utilized to assess habitat restoration, heavy metal contamination, and land management practices [40]. Honeybees serve as bioindicators for environmental pollution [41], while wasps are employed to evaluate habitat conservation status [42].

5. CULTURAL SERVICES

5.1 Cultural Identity, Art and Poetry

In many countries, indigenous insects are an essential part of local culture and identity. For instance, the edible grasshopper *Sphenarium purpurascen*s is consumed across Mexico, with Oaxaca highlighting it as a symbol of its cultural heritage. In Burkina Faso's Bobo region, shea caterpillars are celebrated through annual festivals, underscoring their significance to local communities. In Japan, annual wasp festivals are held in various towns, emphasizing the importance of local wasps to the community [43].

Insects also play roles in art and folklore worldwide. For example, rice grasshoppers (*Oxya* spp.) feature in Asian art and poetry, while termites appear in African folklore. Ancient Egyptians revered scarab beetles, incorporating them into religious practices, architecture, and art. Scarabs symbolized good luck and cherished memories, and hand-carved scarabs were buried with the dead as part of their customs [44].

5.2 Education and Recreation

In many countries, the collection of edible insects is a common activity for women and children, with the latter often learning about the insects' habits and habitats through this process. For example, in Japan, wasp hunting trips are organized for local children and tourists to help them understand these insects in their natural environment [45]. The migration of species like the Monarch butterfly in North America [46] and the firefly aggregations in Malaysia attract tourists to these areas [47]. In central Japan, harvesting insect larvae from water bodies has raised awareness about eutrophication and water pollution [48,49,50,51,52]. Additionally, the study of social insects has inspired innovations in architecture and engineering. For instance, the ventilation systems in Macrotermes mounds have been replicated in buildings in Harare, London, and Melbourne, leading to energy savings of over 90% compared to conventional structures [53,54 & 55].

6. CONCLUSION

In recent decades, there has been a notable decline in insect populations. At the current rate of extinction, it is projected that up to 40% of global insect species could disappear within a few decades. This decline threatens to disrupt the ecosystem services provided by insects, which could have widespread repercussions. Insect populations are declining due to several factors, including the use of fertilizers, agricultural practices, global warming, habitat destruction, deforestation, pollution, and urbanization. The potential loss of such a diverse group of organisms, which are crucial for both ecosystems and human well-being, underscores the urgency of their conservation. To support and restore these populations, various solutions can be implemented. Habitat restoration and afforestation can help recover and expand natural environments for insects. Developing entomophage parks can provide protected spaces for insect populations while reducing water contamination is essential for their health. Increasing awareness about the benefits of ecologically based practices and the judicious use of pesticides can promote better management of insect populations. Additionally, addressing the negative impacts of invasive species, reducing greenhouse gas emissions, and limiting the overexploitation of insect taxa are crucial for their conservation.

To address this issue, future research must focus on rapidly identifying insect species through advanced techniques such as DNA barcoding and metabarcoding. Additionally, comprehensive studies are needed to assess the impact of climate change on insect diversity and to develop real-time models predicting how climate change may alter insect populations and their geographic distributions. Furthermore, there is a need for extensive global studies on insect decline and extinction, along with increased media coverage to raise awareness about these critical issues.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Stork NE. Species of insects and other terrestrial arthropods are there on Earth?

Annual Review of Entomology. 2018; 63:31-45.

2. Nichols E, Spector S, Louzada J, Larsen T, Amezquita S, Favila ME, Network TSR. Ecological functions and ecosystem services provided by *Scarabaeinae* dung beetles. Biological Conservation. 2008; 141:1461–1474.
3. Togni PH, Venzon M, Souza LM, Santos JP, Sujii ER. Biodiversity provides whitefly biological control based on farm management. Journal of Pest Science. 2019;92:393-403.
4. MEA-Millennium Ecosystem Assessment. Ecosystems and human well-being: synthesis. Island Press, Washington; 2005.
5. Prather CM, Laws AN. Insects as a piece of the puzzle to mitigate global problems: an opportunity for ecologists. Basic and Applied Ecology. 2018;26:71-81.
6. Mitsuhashi J. Edible insects of the world. CRC Press. 2016;296.
7. Van Huis A. Insect pests as food and feed. Journal of Insects as Food and Feed. 2020;6(4):327-331.
8. Ayieko MA, Kinyuru JN, Ndong'a MF and Kenji GM. Nutritional value and consumption of black ants (*Carebara vidua* Smith) from the Lake Victoria region in Kenya. Advance Journal of Food Science and Technology. 2012;4(1):39-45.
9. Van Huis A, Van Itterbeck J, Klunder H, Mertens E, Halloran A, Muir G and Vantomme P. Edible insects: future prospects for food and feed security. Food and Agriculture organization of the United Nations; 2013.
Chowdhury GR, Datta U, Zaman S, Mitra A. Ecosystem services of insects. Heart. 2017;17:23.
10. Chowdhury GR, Datta U, Zaman S, Mitra A. Ecosystem services of insects. Heart. 2017;17:23.
11. Mahlangu M, Foligni R, Mozzon M. Can insects save humanity? African Journal of Rural Development. 2019;4:185-202.
12. Kowalczewski PŁ, Gumienna M, Rybicka I, Gorna B, Sarbak P, Dziedzic K, Kmiecik D. Nutritional value and biological activity of gluten-free bread enriched with cricket powder. Molecules. 2021;26:11-84.
13. Sun-Waterhouse D, Waterhouse GI, You L, Zhang J, Liu Y, Ma L, Gao J, Dong Y. Transforming insect biomass into consumer wellness foods: a review. Food Research International. 2016;89:129-151.
14. Marco HG, Šimek P, Clark KD, Gade G. Novel adipokinetic hormones in the kissing bugs *Rhodnius prolixus, Triatoma infestans, Dipetalogaster maxima* and *Panstrongylus megistus*. Peptides. 2013; 41:21-30.
15. Shi YN, Tu ZC, Wang XL, Yan YM, Fang P, Zuo ZL, Hou B, Yang TH, Cheng YX. Bioactive compounds from the insect, *Aspongopus chinensis*. Bioorganic and Medicinal Chemistry Letters. 2014;24: 5164-5169.
16. Meyer-Rochow VB. Therapeutic arthropods and other, largely terrestrial, folk-medicinally important invertebrates: A comparative survey and review. Journal of Ethnobiology and Ethnomedicine. 2017;13(9).
17. Sun X, Jiang K, Chen J, Wu L, Lu H and Wang A. A systematic review of maggot debridement therapy for chronically infected wounds and ulcers. International Journal of Infectious Diseases. 2014; 25:32-37.
18. Sherman, Ronald A, Hall MJR, Thomas S. Medicinal maggots: An ancient remedy for some contemporary afflictions. Annual Review of Entomology. 2000;45:55-81.
19. Heuer H, Heuer L. Blowfly strike and maggot therapy: From parasitology to medical treatment. In Nature Helps, ed. Heinz Mehlhorn. Parasitology Research Monographs. 2011;301-323.
20. Ramos-Elorduy, de Concini J, Moreno JM and Pino. The utilization of insects in the empirical medicine of ancient Mexicans. Journal of Ethnobiology. 1988;8(2):195-202.
21. Ratcliffe NA, Mello CB, Garcia ES, Butt TM and Azambuja P. Insect natural products and processes: new treatments for human disease. Insect biochemistry and molecular biology. 2011;41(10):747-769.
22. Feng Y, Zhao M, He Z, Chen Z, Sun L. Research and utilization of medicinal insects in China. Entomological Research. 2009;39(5):313-316.
23. Abubakar MB, Abdullah WZ, Sullaiman SA,d Suen AB. A review of molecular mechanisms of the anti-leukemic effects of phenolic compounds in honey. International Journal of Molecular Sciences. 2012;13(11):15054-15073.
24. Oka K, Aoyagi S, Arai Y, Isono Y, Hashiguchi G and Fujita H. Fabrication of a micro needle for a trace blood test.

Sensors and Actuators A: Physical. 2002;97:478-48.

25. Sakes A, Dodou D, Breedveld P. “Buckling prevention strategies in nature as inspiration for improving percutaneous instruments: A review”. Bioinspiration Biomimetics. 2016;11(2):021001.
26. Frasson L, Ko S, Turner A, Parittotokkaporn T, Vincent JF and Baena FRY. Sting: A soft-tissue intervention and neurosurgical guide to access deep brain lesions through curved trajectories. Proceedings of the Institution of Mechanical Engineers, part *H*. 2010;224(6):775-788.
27. Brito TO, Santos BBD, Araújo LS, De Almeida LH and Da Costa MF. Analysis of biomimetic surgical clip using finite element modelling for geometry improvement and biomaterials selection, in Proceedings in 3rd Pan American Congress. 2017;3-9.
28. Payne CL and van Itterbeeck. Ecosystem services from edible insects in agricultural systems: a review. Insects. 2017;8:1-24.
29. Gullan PJ and Cranston PS. The insects: an outline of entomology. John Wiley and Sons; 2014.
30. Losey JE and Vaughan M. The economic value of ecological services provided by insects. Bioscience. 2006;56:331-323.
31. Whitford WG. The importance of the biodiversity of soil biota in arid ecosystems. Biodiversity and Conservation. 1996;5:185-195.
32. Evans J, Muller A, Jensen AB, Dahle B, Flore R, Eilenberg J and Frost MB. A descriptive sensory analysis of honeybee drone brood from Denmark and Norway. Journal of Insects as Food and Feed. 2016;2:277-283.
33. Choo J, Zent EL and Simpson BB. The importance of traditional ecological knowledge for palm-weevil cultivation in the Venezuelan Amazon. Journal of Ethnobiology. 2009;29:113-128.
34. Yang SS, Brandon AM, Andrew Flanagan JC, Yang J, Ning D, Cai SY, Fan HQ, Wang ZY, Ren J, Benbow E, Ren NQ, Waymouth RM, Zhou J, Criddle CS and Wu WM. Biodegradation of polystyrene wastes in yellow mealworms (larvae of *Tenebrio molitor* Linnaeus): Factors affecting biodegradation rates and the ability of polystyrene-fed larvae to complete their life cycle. Chemosphere. 2018;191:979-989.
35. Peng BY, Chen Z, Chen J, Yu H, Zhou X, Criddle CS, Wu WM, Zhang Y. Biodegradation of Polyvinyl Chloride (PVC) in *Tenebrio molitor* (Coleoptera: Tenebrionidae) larvae. Environment International. 2020;145:106106.
36. Jiang S, Su T, Zhao J and Wang Z. Biodegradation of polystyrene by *Tenebrio molitor, Galleria mellonella*, and *Zophobas atratus* larvae and comparison of their degradation effects. Polymers. 2021;13:35-39.
37. Wang Y, Luo L, Li X, Wang J, Wang H, Chen C, Guo H, Han T, Zhou A, Zhao X. Different plastics ingestion preferences and efficiencies of superworm (*Zophobas atratus* Fab.) and yellow mealworm (*Tenebrio molitor* Linn.) associated with distinct gut microbiome changes. Science of the Total Environment. 2022;837:155-719.
38. Liu L, Xu K, Zhang B, Ye Y, Zhang Q, Jiang W. Cellular internalization and release of polystyrene microplastics and nanoplastics. Science of the Total Environment. 2022;779:146-523.
39. Lou Y, Ekaterina P, Yang SS, Lu B, Liu B, Ren N, Corvini PFX, Xing D. Biodegradation of polyethylene and polystyrene by greater wax moth larvae (*Galleria mellonella* L.) and the effect of co-diet supplementation on the core gut microbiome. Environment Science and Technology. 2020;54:2821-283.
40. Skaldina O, Pera Niemi S and Sorvari J. Ants and their nests as indicators for industrial heavy metal contamination. Environmental Pollution. 2018;240: 574-581.
41. Celli G and Maccagnani B. Honey bees as bioindicators of environmental pollution. Bulletin of Insectology. 2003;56:137-139.
42. De Souza MM, Louzada J, Serro JE and Cola Zanuncio J. Social wasps (Hymenoptera: Vespidae) as indicators of conservation degree of riparian forests in Southeast Brazil. Sociobiology. 2010;56:387-396.
43. Payne CL, Evans JD. Nested houses: Domestication dynamics of human–wasp relations in contemporary rural Japan. Journal of Ethnobiology and Ethnomedicine. 2017;13:1-20.
44. Cherry RH and Kritsky G. Insects as sacred symbols in ancient Egypt. Bulletin of the Entomological Society of America. 1985;31:15-19.

45. Payne CLR, Scarborough P, Rayner M, Nonaka K. Are edible insects more or less ‘healthy’ than commonly consumed meats - A comparison using two nutrient profiling models developed to combat over and undernutrition. European Journal of Clinical Nutrition. 2015;70:285-291.
46. Tucker CM. Community institutions and forest management in Mexico's Monarch Butterfly Reserve. Society and Natural Resources. 2004;17:569-587.
47. Nallakumar K. The synchronously flashing aggregative fireflies of Peninsular Malaysia. Biodiversity. 2003;4:11-16.
48. Murakami T, Yamaguchi A. Deliberation on "Zazamushi"; Origin and eating-habit transition of traditional insect food in Ina District, Nagano Prefecture, Central Japan. Journal of Nagoya Womens University. 2009;55:79-84.
49. Hensel R, Neinhuis C and Werner C. The springtail cuticle as a blueprint for omniphobic surfaces. Chemical Society Reviews. 2016;45:323-341.
50. Brambilla M, Ferrante E, Birattari M and Dorigo M. Swarm robotics: A review from the swarm engineering perspective. Swarm Intelligence. 2013;7:1-41.
51. French JRJ and Ahmed BM. The challenge of biomimetic design for carbon-neutral buildings using termite engineering. Insect Science. 2010;17: 154-162.
52. Sanchez-Bayo F and Wyckhuys KAG. Worldwide decline of the entomofauna: a review of its drivers. Biological Conservation. 2019;232:8-2.
53. Lister BC and Garcia A. Climate-driven declines in arthropod abundance restructure a rainforest food web. PNAS. 2018;115:10397-10406.
54. Seibold S, Gossner MM, Simons NK, Bluthgen N, Muller J, Ambarlı D, Ammer C, Bauhus J, Fischer M, Habel JC and Linsenmair KE. Arthropod decline in grasslands and forests is associated with landscape-level drivers. Nature. 2019;574:671674.
55. Regnier C, Achaz G, Lambert A, Cowie RH, Bouchet P, Fontaine B. Mass extinction in poorly known taxa. PNAS. 2015;112:7761-7766.

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