Annals of the Entomological Society of America, 2026, **00**(00), 1–12
https://doi.org/10.1093/aesa/saag039
Review

ENTOMOLOGICAL SOCIETY OF AMERICA
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OXFORD

Insects and human cultural identity, social cohesion, and quality of life

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Subject Editor: Karen Sime

Insects impact many aspects of human life, shaping ecosystems, driving economies, and serving as muses for the arts and music. They pollinate crops and gardens, and are food sources for many animals, including humans. They can vector pathogens that cause disease and can be pests in urban and rural settings. Given current rates of decline in insects, vital positive human–insect interactions may be disrupted, and negative interactions exacerbated as insect abundance and biodiversity decrease. Here, we review some of the ways that insects impact human quality of life and how their decline may impact humanity.

Keywords: Anopheles, Lampyridae, Danaidae, human well-being, ecosystem services, cultural entomology, human-insect interactions, livelihoods, entomophagy, entomotourism

Introduction

Insects are declining both in abundance (e.g. Hallmann et al. 2017, Wagner 2020, Saunders et al. 2025) and in diversity (e.g. Sánchez-Bayo and Wyckhuys 2019). Declines have been reported in several insect groups when comparing collections made over decades. Winged insects and basal hexapods evolved ~400 million years ago (Labandeira 2006, Grimaldi 2010, Bernhard et al. 2014), long before our most distant, early hominin ancestors evolved 6 to 7 million years ago (Brunet et al. 2002). As such, we have never known a world without insects, and it is difficult to adequately predict how different an insect-free world would be. Insects are vital to the human condition, providing ecosystem services like pollination and decomposition, but they are also shapers of human culture,

Received: 27 April 2026. **Revised:** 18 August 2026. **Accepted:** 25 August 2026
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from Indigenous cultures to ecotourism and the pet hobby industry. They are used in forensic entomology and serve as food for countless organisms, including an estimated 2 billion of the world's human population (Food and Agriculture Organization of the United Nations 2013).

There are over 1.1 million described insect species (Stork 2018), and the ways that people interact with them vary dramatically across taxa. A single species, *Apis mellifera*, the Western honey bee, is beloved; people plant pollinator gardens to support honey bees, and honey bees are reared in backyards and agricultural hives. By contrast, *Pediculus humanus*, the head louse, or *Cimex lectularius*, the common bedbug, are almost universally reviled (Fig. 1). The ways that we interact with insects also vary regionally, as species of insects regularly encountered by people change from rural to suburban to urban settings. Furthermore, insects can be deadly in some regions of the world, but not in others; *Anopheles* mosquitoes vector the pathogen that causes malaria and are responsible for more than 600,000 human deaths annually (Fig. 1; WHO 2025a). Indeed, to understand the impact of insect biodiversity loss and how it will impact people requires a global perspective that considers all aspects of the insect tree of life.

Here, we review the myriad roles that insects play in the context of human health, economies, and culture, with an emphasis on the impact that declines in insects can have. While insects are involved in many aspects of human life, we have chosen here to focus on their impact on food, water, and energy, economies and livelihoods, human health and security, and cultural identity.



Fig. 1. Insects can be appreciated for their beauty and cultural significance, like butterflies and (A) damselflies (illustrations: B. Klein), or for their ecosystem services, like pollinating bees and (B) decomposing dung beetles (multimedia models: B. Klein). Others are almost universally reviled, like (C) the human head louse, *Pediculus humanus* (photo: Stephen Doggett) and (D) the Asian tiger mosquito, *Aedes albopictus* (photo: Ary Faraji).

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Throughout our review, we implement standardized language adopted by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) to assess the available evidence and general consensus for our major conclusions (Díaz et al. 2015, Díaz et al. 2019). Conclusions are italicized and labeled into 4 categories: those based on meta-analysis, a similar synthesis, or many independent studies that agree (well established); those for which there is broad agreement but limited research (established, but incomplete); those with many studies but inconsistent or contradictory results (unresolved); and those with limited evidence and major gaps in understanding (inconclusive) (Figure SPM. A2 in IPBES 2019, see also (Moss and Schneider 2000).

Access to Food, Water, and Energy

Pollination, Pest Regulation, and Decomposition Services by Insects Are Essential for Agricultural Crops and Wild-Collected Fruits and Seeds (Well Established)

Food security, fundamental to human survival, is intricately linked to insect biodiversity. Many insects pollinate crops, aerate soil, and cycle nutrients, all of which are essential ecosystem services that underpin food production. Insects pollinate approximately three-quarters of the world's crops, accounting for over 40% of their yields (Siopa et al. 2024), and play a major role in the provisioning of vitamins and essential micronutrients for people (Eilers et al. 2011). In addition to agricultural plants, roughly 80% to 90% of wild plants are pollinated by animals, the vast majority of which are insects (Ollerton et al. 2011, Ollerton 2017, Rodger et al. 2021, Tong et al. 2023), and many of these plants are central to food security. Wild-collected fruits and seeds are important in the diets of 100s of millions of people globally (Shackleton and De Vos 2022, Pironon et al. 2024) and are critical genomic resources for crop breeding (Migicovsky 2025). As decomposers, insects influence soil fertility and structure, thereby affecting crop yields (Neher and Barbercheck 2019, Griffiths et al. 2021). Predatory and parasitoidal insects also regulate crop pests, reducing herbivory and maintaining yields (Stiling and Cornelissen 2005, Boldorini et al. 2024).

Insects Serve as Food for People, Livestock, and Animals that People Rely on as Food Sources (Well Established)

Eating insects as food (entomophagy) and using them as animal feed have been practiced for millennia, with the earliest records of entomophagy occurring over 10,000 years ago (Olivadese and Dindo 2023). Today, more than 1,600 insect species are traditionally eaten worldwide (Itterbeek and Pelozuelo 2022), and over 470 species are regularly eaten by people on the African continent alone (Kelemu et al. 2015). Far more insect species serve as feed for other organisms that people rely on. Many insects, especially grasshoppers, locusts, crickets, moth caterpillars, beetle larvae, and termites, are highly nutritious food sources and also benefit livestock production (van Huis et al. 2021, see Fig. 2 for examples of edible insect dishes). The use of insects as food and feed has grown rapidly in recent decades because insect farming requires less water, land, and chemical inputs than beef and other agricultural products (e.g. Oonincx and de Boer 2012, Matandirotya et al. 2022) and is a relatively sustainable food system that creates employment opportunities, especially in rural areas (Matandirotya et al. 2022). Moreover, insects are a major food source for vertebrate species (Cook et al. in review), many of which are hunted, trapped, or fished for sport or subsistence (e.g. trout: Kruzhylina and Didenko 2011).

Access to Freshwater Is Regulated by Insects, Which Provide Critical Ecosystem Services Like Water Purification and Nutrient Cycling (Well Established)

Freshwater is a vital, limiting resource upon which much of life depends. Aquatic insects are key filters, purifiers, and indicators of water quality. They maintain freshwater quality by breaking down organic matter and cycling nutrients, and also improve water clarity by limiting the amount of nitrogen and phosphorus available to algae (Suter and Cormier 2015). Because many aquatic insect taxa are sensitive to water quality, especially in their larval stages, they are critical for monitoring pollution and aquatic ecosystem health (Paisley et al. 2014, Castillo-Figueroa et al. 2018) and serve as bioindicators of water quality. Many plants also play a role in water purification (Kola et al. 2025, Lu et al. 2025), and the insect pollinators play a key role in maintaining plant populations, thus indirectly supporting access to water through their many ecosystem functions.

Global Energy Demands Are Met In Part by Insects, Which Provide Pollination and Pest Regulation Services for Biofuel Crops, and Are Themselves Used in Insect-Based Biofuels (Established but Incomplete)

Many insects are pests of agricultural crops, but despite this status in some systems, insects also play vital roles in crop production. Given their important roles in soil formation and decontamination, plant pollination, and pest control (Grames et al. 2026), insects are fundamental to the production of biofuel crops such as canola (*Brassica*), sunflowers (*Helianthus*), and jatropha (Euphorbiaceae) (Abrol 2024). These same functional roles also make them indispensable for the population persistence of wild woody and herbaceous plants used for fuel (Landis and Werling 2010). The use of insects, such as termites and black soldier flies, as biofuels (e.g. to produce biodiesel or biogas) is an emerging field of research due to their efficient processing of organic waste and high lipid content (Ali et al. 2022, Odoi-Yorke et al. 2025).

Economies and Livelihoods

Economies Driven by Edible Insects Improve Socioeconomic Well-Being in Rural Areas (Established but Incomplete)

The use of insects as food and feed has evolved from opportunistic collection of insects for food in early human history (Olivadese and Dindo 2023) to economies based on the collection, rearing, and manufacturing of insect-derived products that form the backbone of economies in many developing regions (van Huis 2013, Kipkoech et al. 2023, Shen et al. 2023, Caparros Megido et al. 2024) and in urban centers for use in pharmaceuticals and biotechnology. As a livelihood,

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Fig. 2. Entomophagy: (A) Joseph Yoon of Brooklyn Bugs creates culinary delights, here featuring ants, superworms, bee pollen, and honey, prepared in the United States (photo: B. Klein). (B) "Maungu" saturniid moth caterpillars feeding on mango tree leaves, they are a traditional delicacy in Kilifi, Kenya (photo: E.Kioko), (C) Orthoptera for sale on a food stall in Yunnan, China, and (D) *Vespa* sp. larvae (with nests featured on table) on sale for consumption at a market in Yunnan, China (photos C & D: J. Ollerton).

the collection and trade of edible insects contribute to socio-economic well-being, especially for rural families, and contribute to the Sustainable Development Goals of no poverty and achieving economic empowerment for women. Selling edible insects can generate roughly $3 USD per day in Nigeria (Adeoye et al. 2014), and in some cases, results in a household income greater than can be achieved by farming agricultural crops (Chidumayo and Mbata 2002). The price per kilogram of grasshoppers is valued at more than goat meat (Agea et al. 2008). Collectively, the economic value of mopane worms in southern Africa is valued at anywhere from $39 to 84 million USD annually (Hope et al. 2009, Hlongwane et al. 2021). Edible insects can provide a stable livelihood and buffer local economies and food security when other harvests fail (Hope et al. 2009, Imathiu 2020). The income generated from edible insect collection and rearing is typically used for basic household needs such as paying school fees for children or buying food (Hlongwane et al. 2021), indicating the importance of this income source for fundamental quality of life in rural areas.

Women-Driven Economies in Lower- and Middle-Income Countries Are Heavily Dependent on Edible Insects (Established but Incomplete)

In regions where entomophagy is common, especially in many parts of Africa and Asia, the collection and trade of edible insects is a viable livelihood that has a relatively low cost of entry and is often dominated by women (Fig. 2; Hope et al. 2009, Imathiu 2020) or youth (Bvochora and Galavotti 2025). The edible insect economy in these regions is nearly entirely driven by women, who are often responsible for the entire value chain, including collecting, processing, and selling insects (Adeoye et al. 2014, Kenis et al. 2025). For instance, in parts of southern Africa, more than 95% of mopane worm harvesters are women (Illgner and Nel 2000), and this number can be as high as 99% for commonly harvested and traded grasshoppers (Alaroker et al. 2025). Women are especially involved in insect harvesting, a practice passed down from generation to generation (Netshifhefhe et al. 2018) and often associated with substantial cultural traditions (Agea et al. 2008). Women are often less involved in later stages of the edible insect economy, such

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as trade and marketing (Agea et al. 2008), and there are safety concerns during collecting (Netshifhefhe et al. 2018). More recently, efforts to farm insects such as crickets have the potential to transform women-driven economies. On farms in East Africa, more than 70% of all workers rearing black soldier flies as edible insects are women (Tanga and Kababu 2023); however, this sector is rapidly growing and general patterns of demography in this industry are unclear (Kenis et al. 2025). Many of these edible insects that form the basis of women-driven economies are predicted to be in decline; models by Shen et al. (2023) suggest that mopane worm habitat, for example, is predicted to decrease by 70% by the year 2080. Given the importance of insects to women-driven economies of insect rearing and harvesting, declines in insect abundance and diversity could result in the loss of these essential sources of protein, associated economic benefits, and related cultural heritage practices (Braun 2017), which in turn would negatively impact the lives of many women and limit their access to financial empowerment and independence.

Beekeeping Is Central to Social and Cultural Identity in Many Regions, and Is a Key Component in the Economies of Many Regions (Established but Incomplete)

Among pollinators globally, perhaps the most well-known is the Western honey bee (see Fig. 2), and while honey bees are important garden pollinators, they are not native to much of their habitat and are a "managed exotic" species. The Western honey bee is native to Europe, Africa and Western Asia, but it has been introduced everywhere except Antarctica as a vital pollinator for human agriculture (Moritz et al. 2005). Bees have been cultivated by people for honey for millennia with honey collecting depicted in the early Neolithic cave art at Cuevas de la Araña in Valencia, Spain (Kritsky 2020). For commercial beekeeping, colonies are transported across landscapes to provide pollination services for high-value crops, linking insect biology directly to food security and rural economies. During the last 20 years, honey bee hives have suffered from colony collapse disorder (CCD), where many to most members of a hive die off unpredictably. Research suggests that a combination of invasive hive beetles (*Aethina tumida*) and Varroa mites (*Varroa destructor*) that feed on developing bees in the hive, along with certain pesticides, may be the main cause of CCD. Bees have high economic value, as honey bee pollination services were estimated to be worth $235 to $577 billion USD globally in 2015 (Potts et al. 2016), while the honey industry was estimated at $8.58 billion USD globally in 2021 (Sokhai and Mardy 2024); the beeswax industry has not been thoroughly valued. A loss of honey bee ecosystem pollination services could be mitigated by the presence of native pollinators in the wild, but not entirely in managed systems, and would result in the overall loss of added-value product revenue. Other than bees, several insects have long been domesticated for their products (e.g. Melillo 2014). Shellac is derived from lac insects (*Kerria lacca*), and cochineal was used as a dye by the Inca and Indigenous Oaxacans long before European colonizers arrived and began exporting it as a commodity (30,000 kg in 1989; Ruiz 1991). The silk industry is primarily driven by a single species of moth (*Bombyx mori*) that has been managed for almost 5,000 years (Zhou 1980, Liu 2010). The global value of silk farming through production of textiles and other products was $13 billion USD in 2025 and is expected to increase to more than $28 billion USD by 2034 (Silk Market Report 2026).

Recreational Activities, Including Hunting and Fishing, Are Dependent on Insect Ecosystem Services (Well Established)

Wildlife-based recreational activities such as birding, hunting, and fishing are a major economic sector in many parts of the world. In the United States alone, wildlife-based recreation is a $395 billion USD industry (USFWS 2022), in which more than 1 in 3 adults participate (USFWS 2022). While these activities largely center on interactions between people and nonhuman vertebrate animals, they are fundamentally dependent on insects. For instance, approximately 75% of terrestrial and freshwater bird species, many of which are waterfowl or upland gamebirds important to hunters, rely on insects as food, especially during the breeding season when energetic demands are highest (Whelan et al. 2015, Grames et al. 2023). Grizzly bears rely on army cutworm moths as a part of their diet, spending time in the summer at moth aggregation sites in places like Yellowstone National Park (French et al. 1994). Insects also make up the vast majority of the diet for freshwater salmonid fishes, especially during their juvenile stages. The importance of insects to the recreational fishing industry is underscored by the popularity of fly fishing. More than 8 million people engage in this sport in the United States each year, spending over $3.5 billion USD on equipment and travel (USFWS 2015, Recreational Boating and Fishing Foundation 2025). (Losey and Vaughan 2006) estimated that insects contributed approximately $27.9 billion USD to recreational fishing and $220 million USD to commercial fisheries. In fly fishing, anglers intentionally imitate the morphology, coloration, and behavior of aquatic and terrestrial insect larvae, pupae, and adults using artificial "flies" to attract fish (e.g. Walton 1676, McCafferty 1983). Because many fish exhibit selective feeding behavior, the success of fly fishing depends on how closely "flies" mimic the insect taxa, particularly the hatches occurring in a given area (McCafferty 1983). Other forms of freshwater fishing (both recreational and commercial) may also rely indirectly on insects because insects play a foundational role in aquatic food webs (e.g. Cummins 1973).

Entomotourism Is a Growing Sector of the Tourism Industry Globally (Established but Incomplete)

Insect-based tourism, or entomotourism, contributes to livelihood security by directly linking income generation with the conservation and sustainable use of insects (Le et al. 2021). Across diverse geographic and cultural contexts, entomotourism has been used to transform ecological processes into sustainable economic opportunities that reinforce insect conservation. For example, more than 250,000 people travel to a monarch butterfly sanctuary in Mexico annually to witness the mass overwintering sites of this migratory species (Barkin 2003, Huntly et al. 2005, Noort and Hamer 2005). In Australia and New Zealand, glow-worm tourism is a multi-million dollar industry. The Waitomo Caves in New Zealand, famed for their bioluminescent fungus gnat larvae (*Arachnocampa luminosa*), receive more than 400,000 visitors each year, with daily visitation rates exceeding 2,000 people during the peak summer season (Baker 2003). There are also numerous regional firefly-watching initiatives across East and Southeast Asia and

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an ever-expanding number of butterfly houses, insectaria, and insect-based festivals worldwide (Kanaujia and Rai 2023). Collectively, these insect-based tourism initiatives create employment opportunities such as guiding services, transportation, accommodation, dining, handicrafts, environmental education, and ecological monitoring and conservation management, especially in rural and biodiverse regions (e.g. Tisdell and Wilson 2004). The impact of the entomotourism sector on quality of life is evident in livelihood diversification, supplementary household income, and local economic multipliers (Lemelin et al. 2019). Environmental education using insects allows an easy entry point into understanding biodiversity and conservation literacy. When supported by appropriate governance frameworks, environmental education, and equitable benefit-sharing, insect-focused tourism can deliver material, regulating, and non-material benefits while strengthening resilience in rural and biodiversity-dependent communities.

Insect-Based Tourism Reinforces Sustainable Use of Natural Resources and Has Cascading Benefits to Local Communities (Established but Incomplete)

Nature-based tourism, including entomotourism, depends on the protection and management of biodiversity heritage and thus contributes indirectly to livelihood security by strengthening public awareness of insect conservation, habitat degradation, and ecosystem function (e.g. Álvarez 2025). Entomotourism revenues incentivize the protection of forests, wetlands, mangroves, riparian corridors, and other habitats that sustain insect populations, thereby promoting local biodiversity conservation efforts (Álvarez 2025). By supporting insects and the ecosystem services they provide (pollination, nutrient cycling, water regulation, etc.), entomotourism enhances the local environment. This benefit has been realized in many regions where synchronized firefly displays have become focal attractions, such as Malaysia, Thailand, India, and Japan, as these natural phenomena occur only in extremely specific habitats and are dependent on habitat quality. For instance, communities near the Kampung Kuantan Firefly Reserve in Malaysia benefit from entomotourism, and local boat operators, guides, small vendors, and other service providers recognize that their income is dependent on the persistence of healthy rivers and riparian systems (Li et al. 2022). Similar initiatives in other parts of Southeast Asia have demonstrated that firefly-based tourism enhances community awareness of ecosystem services, fosters stewardship attitudes, and strengthens local support for conservation initiatives (see inset box for a discussion of firefly-based entomotourism in the Smoky Mountains of the United States). Entomotourism also helps to reshape societal narratives that frame insects as pests by instead recentering their ecological and economic importance, fostering aesthetic appreciation, cultural identity, and emotional connections with nature (Kanaujia and Rai 2023). Empirical evidence indicates strong public acceptance of insect-based tourism, with high levels of willingness among both visitors and local residents to support conservation and environmental education activities (Saikim et al. 2015, 2020, Lemelin et al. 2017, Le et al. 2021). Overall, entomotourism is a relatively low-impact livelihood strategy that aligns biodiversity conservation with sustainable development objectives.

Human Health and Security

Anthropogenic Change May Increase Vector Populations While Reducing Their Natural Enemies (Established but Incomplete)

While many insects transmit pathogens, no other group comes close to the role that mosquitoes play in human health (Marquardt 2004), despite the fact that most mosquito genera do not vector pathogens that cause human diseases. The morbidity and mortality associated with the malaria parasite

Firefly Tourism as a Socio-Ecological Phenomenon: Opportunities and Uncertainties for Conservation (Established but Incomplete)

Fireflies in particular are charismatic beetles whose bioluminescent courtship displays have recently drawn global attention through nature tourism (Lewis et al. 2021). There are over 2,200 firefly species worldwide (Xerces Society 2025), and their flash patterns (e.g. Hess 1920, Lloyd 1966, Carlson and Copeland 1985) and mechanisms of bioluminescence used for mating (e.g. Copeland and Moiseff 1994, Faust 2010), evading predators (e.g. Lewis and Cratsley 2008), and attracting prey (e.g. Eisner et al. 1997) have been well studied. In recent years, firefly watching has become a significant form of ecotourism, with more than 1 million people traveling annually to firefly-viewing sites in at least 12 countries (Lewis et al. 2021). Fireflies have shaped the cultural identity of many regions where they occur. For example, 19 firefly species have been documented in Great Smoky Mountains National Park (B. J. Nichols, pers. comm.), with additional species likely to be discovered. One area of the park, Elkmont, has become globally renowned for the spectacular display of the synchronous firefly Photinus carolinus (Green 1956). Firefly tourism attracts visitors and creates unique economic opportunities for surrounding communities. Park officials administer an annual lottery to limit visitation to Elkmont during peak viewing to protect the population and its habitat. In 2024, more than 20,000 people entered the lottery for 960 vehicle passes (GRSM 2025). Synchronous fireflies also provide a fundraising opportunity for the park's nonprofit science partner, Discover Life in America (DLiA). Drawing on knowledge gained through coordinating the All Taxa Biodiversity Inventory in the Smokies, DLiA hosts an educational fundraising event adjacent to the national park to support biodiversity research and education. In recent years, additional populations of synchronous fireflies and other prominent species, such as the blue ghost firefly (Phausis reticulata [Say 1825]), have been discovered in parts of Tennessee, North Carolina, South Carolina, and Virginia, contributing to the growth of regional firefly ecotourism (Fallon et al. 2021, Lewis et al. 2021). As interest continues to grow, researchers emphasize the need for responsible management practices—including habitat protection, community involvement, and visitor education—to minimize impacts on firefly populations (Lewis et al. 2021).

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Plasmodium transmitted by *Anopheles* mosquitoes (see Fig. 2), for instance, caused an estimated 282 million cases and over 600,000 deaths in 2024 (WHO 2025a). Additional arboviral diseases, such as chikungunya, dengue, eastern equine encephalitis, West Nile, yellow fever, and Zika viruses, also have a substantial impact on human health (WHO 2025b), and the pathogens that cause them are vectored by genera like *Aedes* and *Culex*. These arbovirus diseases not only cause sickness but also impact quality of life by decreasing outdoor recreation and relaxation (Worobey et al. 2013, Halasa et al. 2014). Thus, changes in mosquito populations are likely to have a substantial impact on public health and quality of life. Insect decline may alter the ecological checks and balances that limit mosquito populations, and the loss of insect biodiversity could result in increased disease prevalence. In diverse ecosystems, mosquitoes may be suppressed by natural predators such as dragonflies in their juvenile aquatic stages (Fincke et al. 1997) or aquatic insects that prey on mosquito larvae. There are many other vectors of disease-causing pathogens, thus the impact of changes in insect biodiversity and abundance may be broad (Fig. 1). For example, lice (*P. humanus*) transmit epidemic typhus, trench, and relapsing fevers; fleas (Siphonaptera: Pulicidae) carry plague, murine typhus, and tularemia; biting midges (Diptera: Ceratopogonidae) are vectors of the pathogen for epizootic hemorrhagic disease and bluetongue, and can transmit Oropouche viruses; black flies (Diptera: Simuliidae) can transmit the pathogen for African onchocerciasis or river blindness and can transmit vesicular stomatitis; sand flies (Diptera: Phlebotominae) vector the pathogen for leishmaniasis; tsetse flies (*Glossina* spp.) are vectors for pathogens that cause African trypanosomiasis or sleeping sickness; and kissing bugs (Triatominae) carry Chagas disease or American trypanosomiasis. As insect community composition shifts as a result of anthropogenic change, natural predators are often lost from communities, resulting in enemy release and a marked increase in mosquito abundance (e.g. Rochlin et al. 2016, Hunt et al. 2017). Initiatives that promote the stability of ecosystems and resilience of insect communities to global change, such as the One Health approach, may result in greater quality of life and reduced disease prevalence by supporting the insects that regulate vectors of pathogens that cause disease (e.g. Faburay 2015).

Insects Can Aid Legal Investigations Through Their Use in Forensic Entomology (Well Established)

Some insects, such as blow flies (Diptera: Calliphoridae), can locate and colonize decomposing human remains within minutes after death. Forensic entomologists can use insects to assist in determining a time of death; in this field, understanding the biology, development, and ecological succession of insect populations and communities that colonize human remains is key (Kreitlow 2009). For instance, a time of colonization can help determine not only how long an individual has been deceased (Campobasso et al. 2001, Amendt et al. 2011), but insects can aid in detection of xenobiotics—foreign substances in a body such as drugs or heavy metals-in human remains (Jain et al. 2024), and provide identifications through DNA analysis in investigations where no body is found (e.g. Wells 2002). Given the usefulness of insects to legal investigations, the field of forensic entomology has grown rapidly in the last 30 years (Wiraagni et al. 2024), with increased standardization to ensure that testimony based on evidence from insects is presented by qualified experts and supported by the scientific process (Koehler et al. 2023). The effectiveness of forensic entomology relies on biodiversity, as different insect species have different colonization times, developmental rates, habitat preferences, and behavioral responses that can aid investigations (but note that many commonly used species of forensic importance are currently abundant). Therefore, documenting and preserving insect biodiversity strengthens the reliability of insect evidence in legal investigations.

Cultural Identity

Emotional Connections to Insects Form A Core Part of Cultural and Personal Identity (Established but Incomplete)

Experiences involving insects often elicit strong emotional responses, fostering concern for biodiversity loss and encouraging pro-environmental behavior (e.g. Simaika and Samways 2018). These experiences can take place in a tourism (e.g. seeing fireflies or glow-worms) or cultural institution (e.g. live butterfly houses) context. Live butterfly houses or vivariums are popular tourist attractions; over 50 countries have public live butterfly exhibits (Boppré and Vane-Wright 2012). In many regions, insects are integrated into cultural norms. In Japan, for instance, beetles are commonly kept as pets (Shiozawa and Sato 2025), and there are many insect-themed events ranging from beetle wrestling competitions to poetry competitions (Hosaka et al. 2016). Childhood experiences with insects, including as pets, result in more positive attitudes toward biodiversity conservation later in life (Hosaka et al. 2017). In many Western countries, insect hobbyists who breed insects have a deep understanding of the husbandry and life history traits of the insects they rear. This understanding may foster an emotional connection to insect biodiversity and could help form an individual's personal identity. The popularity of insect breeding is evident in the large beetle hobby trade, with pre-made substrates and packaged foods available, and in the presence of insects far outside their native ranges. Some exotic stick insects, like the Indian walking stick (*Carausius morosus*), have established populations in California, which is likely the result of escaped or released pets (UC ANR Publication 74157).

Insects Have Inspired Countless Works of Art (Well Established)

The visual arts portray insects as muses, totems, or symbols and are frequently crawling with insects (Fig. 3; Dicke 2000, Klein 2007, Rooney 2017), even tangibly, in the form of live, dead, or piecemeal insects, and especially in the form of their products used as art media (silk, wax, shellac, cochineal, etc.) (Klein 2022). Cave paintings of honey robbing in Africa and Europe, and aboriginal beeswax figures in Australia, reveal utilitarian practices and spiritual traditions deeply rooted in history, while using insects to comment on today's destruction of the living planet reveal contemporary challenges (Klein and Brosius 2022, 2024). Charles Hogue, with the ambition of formalizing a field to study how insects have shaped human cultures across the world and throughout our history, published a review nearly 40 years ago of what he called "cultural entomology" (Hogue 1987). Though few systematic reviews have followed (Berenbaum 1995, Klein 2024, Kritsky 2024), the field permeates myriad aspects of human endeavor, reflecting the ubiquity of insects and their pervasive effects on our

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Fig. 3. Cultural entomology spans every human endeavor, from composing music and poetry to waging war, as recorded in this small sample of relevant books (top and bottom; photos: B. Klein). (A) The act of honey bee nest robbing is captured in millennia-old cave paintings, here in Cuevas de la Araña, Spain (max age 3000 BCE; composite image and tracing by B. Klein over photo by Gene Kritsky). It is a culturally common practice to deliberately adorn ourselves with insects, including (B) immature *Margarodes* sp. scale insects, strung into necklaces by Zulu people of southern Africa, and (C) *Euchroma gigantea* beetle elytra, traditionally worn as ear ornaments by the Awajún/Aguaruna in Brazil (The Field Museum of Natural History, #48807 and 28750-1, respectively; photos by B. Klein). We also fashion ourselves into insects, including (D) monarch butterflies, icons of ecotourism in Mexico, here personified/insectified by Day of the Dead celebrants (photo: Polo Aguila, a.k.a. Poloide93, Creative Commons).

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pursuits. Culture is often marked by the arts, and insects influence music (Coelho 2000, Rothenberg 2013), dance (Lonsdale 1982), film (Bellin 2009, mostly in the context of fear, although several depict insects as compelling characters), oral traditions (Thomas 2003), and the written word, including the earliest documented sentence written in an alphabetic script (written about head lice; Vainstub et al. 2022). Countless literary touchstones (e.g. Franz Kafka's *The Metamorphosis*) showcase our desire for the familiar or dread of the alien represented by insects.

Local and Indigenous Communities

Insects Play Diverse and Significant Roles in Indigenous Communities and Their Knowledge Systems (Well Established)

For many Indigenous communities, insects and other more-than-human relations are understood and cared for as kin. The role of insects, and other arthropods, in creation stories and storytelling has taught Indigenous Peoples lessons of relationality and interdependence. For example, Na'ashjé'íí Asdzáá (spider woman) taught the Diné how to skillfully weave blankets and rugs, providing essential skills for surviving winters. Many cultural practices, including song and dance, show appreciation for insect life forms and recognize the significant ecosystem services they provide. The Hopi Butterfly Dance, for instance, is a social dance of prayer and thanksgiving for a successful harvesting season by recognizing butterflies as vital pollinators. Insects further serve as symbols of resilience, reflecting deep connections between people and more-than-human relations. The ogweñ•yó'da' (periodical cicada) helped the Onondaga Nation survive starvation by emerging in great numbers as a source of sustenance following attacks on their villages and food systems during the Clinton-Sullivan Campaign of 1779 (University of the State of New York 1929). Today, periodical cicadas continue to be honored as symbols of survival and resilience within the community. Globally, Indigenous communities have long recognized the importance of insect kin and their ecosystem services, contributing to biodiversity conservation and the protection of beneficial species. For example, the Blackfeet Nation built pollinator protections into their climate adaptation plans (Blackfeet Nation 2018) and the Karuk Tribe shapes Cultural Fire practices to promote ecological conditions supporting healthy insect communities (Karuk Tribe 2019). These efforts, representing only a small subset of broader efforts, have generated measurable benefits for local ecosystems while sustaining ceremonial and cultural practices. Indigenous communities maintain strong generational and place-based knowledge systems that help create deeper understanding of insect presence, behavior, and ecological roles. In the Amazon, honey collectors of the Enawene-Nawe Tribe identified 48 distinct stingless bee species based on morphology and ecological niche, of which only 21 were previously identified by Western scientists (dos Santos and Antonini 2008). This study highlights the significant gaps that remain in entomological knowledge when Indigenous Knowledge is not meaningfully included. Indigenous Ecological Knowledge and stewardship practices are grounded in relationality and reciprocity, emphasizing mutual responsibility between people and more-than-human kin. These knowledge systems are critical to ensuring healthy ecosystems, including diverse insect communities that provide essential ecosystem services.

Integrative Summary

Insects precede all humanity and have shaped the human experience in many ways. We rely on insects for food, energy, ecosystem services, science, and products, and we interact with them in ways that inspire wonder, awe, and enjoyment of nature. Changes in insect biodiversity and abundance will negatively impact human (and other animals') access to food, water, and energy, so policy measures are needed to conserve key insect taxa that provide pollination, soil aeration, decomposition, and water filtration services. In a changing world, the impacts that insects have on human health will likely be increasingly negative. Despite often negative interactions with insects in the context of food security and human health, insects are vital to many economies, from women-driven entomophagy-based insect-rearing operations to hobbies such as fishing, firefly watching, and insect pet-rearing. In general, insects are woven into the fabric of human culture, and hence, the human experience is predicted to change profoundly as insect biodiversity is lost.

Acknowledgements

The collection of papers in this volume arose from work by the Status of Insects Research Coordination Network, which was funded by NSF RCN Award #2225092. This RCN includes over 500 members, from over 50 countries, representing diverse sectors of the entomological community, including researchers in academic and non-academic institutions, students, practitioners, artists, and other stakeholders. We thank the entomological and RCN community for thoughtful discussions about the topics covered here.

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Funding

Preliminary funding for development of the network came from the Doris Duke Charitable Foundation, and the UConn Office of the Vice President for Research. The collection of papers in this volume arose from work by the Status of Insects Research Coordination Network, which was funded by NSF RCN Award #2225092.

Conflicts of Interest

None declared.

References

Abrol DP. 2024. *Pollination biology of cultivated oil seeds and pulse crops*. CRC Press.

Adeoye OT, Alebiosu BI, Akinyemi OD, et al. 2014. Socio economic analysis of forest edible insects species consumed and its role in the livelihood of people in Lagos State. *J. Food Stud.* 3:104. https://doi.org/10.5296/jfs.v3i1.6026

Agea JG, Lugangwa E, Obua J, et al. 2008. Role of indigenous knowledge in enhancing household food security: A case study of Mukungwe, Masaka District, Central Uganda. *Indilinga Afr. J. Indig. Knowl. Syst.* 71:64–71.

Alaroker MF, Twongyirwe R, Nyeko P, et al. 2025. Local knowledge, perception and practices regarding edible insects among different ethnic groups in Northern Uganda. *J. Ethnobiol. Ethnomed.* 211:45. https://doi.org/10.1186/s13002-025-00799-9

Ali SS, Al-Tohamy R, Mohamed TM, et al. 2022. Could termites be hiding a goldmine of obscure yet promising yeasts for energy crisis solutions based on aromatic wastes? A critical state-of-the-art review. *Biotechnol. Biofuels Bioprod.* 15:135. https://doi.org/10.1186/s13068-022-02131-z

Álvarez LM. 2025. Entomotourism and environmental conservation. *Environ. Res. Ecotoxicol.* 4:180. https://doi.org/10.56294/ere2025180

Amendt J, Richards CS, Campobasso CP, et al. 2011. Forensic entomology: applications and limitations. *Forensic Sci. Med. Pathol.* 7:379–392. https://doi.org/10.1007/s12024-010-9209-2

Baker C. 2003. Australian glow-worms: managing an important biological resource. *J. Australas. Cave Karst Manage. Assoc.* 53:13–16.

Barkin D. 2003. Alleviating Poverty Through Ecotourism: Promises and Reality in the Monarch Butterfly Reserve of Mexico. *Environ. Dev. Sustain.* 5:371–382. https://doi.org/10.1023/A:1025725012903

Bellin JD. 2009. Us or them!: Silent Spring and the "big bug" films of the 1950s. *Extrapolation* 50:145–168. https://doi.org/10.3828/extr.2009.50.1.10

Berenbaum MR. 1995. *Bugs in the system: insects and their impact on human affairs*. Addison-Wesley.

Bernhard M, Shanlin L, Karen M, et al. Phylogenomics Resolves the Timing and Pattern of Insect Evolution. November 7, 2014. Science.

Blackfeet Nation. 2018. Blackfeet climate change adaptation plan. files.wordpress.com/2018/04/bcap_final_4-11.pdf

Boldorini GX, McCary MA, Romero GQ, et al. 2024. Predators control pests and increase yield across crop types and climates: a meta-analysis. *Proc. Biol. Sci.* 291:20232522. https://doi.org/10.1098/rspb.2023.2522

Boppré M, Vane-Wright RI. 2012. The butterfly house industry: conservation risks and education opportunities. *Conservat. Soc.* 10:285–303. https://doi.org/10.4103/0972-4923.101831

Braun SF. 2017. Mourning ourselves and/as our relatives: environment as kinship. In: Cunsolo A, Landman, K, editors. *Mourning nature: hope at the heart of ecological loss and grief*. Routledge. p. 64–91. https://doi.org/10.1515/9780773549357-007

Brunet M, Guy F, Pilbeam D, et al. 2002. A new hominid from the Upper Miocene of Chad, central Africa. *Nature* 418:145–151. https://doi.org/10.1038/nature00879

Bvochora SMD, Galavotti I. 2025. Dismantling the market of privilege: an integrated framework for inclusive entrepreneurship education in Africa. *Equal. Divers. Incl.* 1–23.

Campobasso CP, Di Vella G, Introna F. 2001. Factors affecting decomposition and Diptera colonization. *Forensic Sci. Int.* 120:18–27. https://doi.org/10.1016/S0379-0738(01)00411-X

Caparros Megido R, Francis F, Haubruge E, et al. 2024. A worldwide overview of the status and prospects of edible insect production. *Entomologia*. 44:13–27. https://doi.org/10.1127/entomologia/2023/2279

Carlson AD, Copeland J. 1985. Flash communication in fireflies. *Q Rev. Biol.* 60:415–436. https://doi.org/10.1086/414564

Castillo-Figueroa D, Garzón-Salamanca LL, Albarracín-Caro JF. 2018. Aquatic macroinvertebrates as water quality bioindicators in Colombia: a systematic review. *Neotrop. Biol. Conserv.* 13:235–246. https://doi.org/10.4013/nbc.2018.133.06

Chidumayo EN, Mbata KJ. 2002. Shifting cultivation, edible caterpillars and livelihoods in the Kopa area of northern Zambia. *For. Trees Livelihoods.* 123:175–193. https://doi.org/10.1080/14728028.2002.9752423

Coelho JR. 2000. Insects in rock and roll music. *Am. Entomol.* 46:186–200. https://doi.org/10.1093/ae/46.3.186

Cook R, Grames E, Ollerton J, et al. In review. The consequences of changing insect abundance and diversity for vertebrates. *Nat. Rev. Biodivers.*

Copeland J, Moiseff A. 1994. The occurrence of synchrony in the North American firefly *Photinus carolinus* (Coleoptera: Lampyridae). *J. Insect Behav.* 8:381–394. https://doi.org/10.1007/BF01989366

Cummins KW. 1973. Trophic relations of aquatic insects. *Annu. Rev. Entomol.* 18:183–206. https://doi.org/10.1146/annurev.en.18.010173.001151

Díaz S, Demissew S, Carabias J, et al. 2015. The IPBES Conceptual Framework—connecting nature and people. *Curr. Opin. Environ. Sustain.* 14:1–16. https://doi.org/10.1016/j.cosust.2014.11.002

Dicke M. 2000. Insects in western art. *Am. Entomol.* 46:228–237. https://doi.org/10.1093/ae/46.4.228

dos Santos GM, Antonini Y. 2008. The traditional knowledge on stingless bees (Apidae: Meliponina) used by the Enawene-Nawe tribe in western Brazil. *J. Ethnobiol. Ethnomed.* 4:19. https://doi.org/10.1186/1746-4269-4-19

Eilers EJ, Kremen C, Smith Greenleaf S, et al. 2011. Contribution of pollinator-mediated crops to nutrients in the human food supply. *PLoS One* 6:e21363. https://doi.org/10.1371/journal.pone.0021363

Eisner T, Goetz MA, Hill DE, et al. 1997. Firefly "femmes fatales" acquire defensive steroids (lucibufagins) from their firefly prey. *Proc. Natl. Acad. Sci. U. S. A.* 94:9723–9728. https://doi.org/10.1073/pnas.94.18.9723

Faburay B. 2015. The case for a 'one health' approach to combating vector-borne diseases. *Infect. Ecol. Epidemiol.* 5:28132. https://doi.org/10.3402/iee.v5.28132

Downloaded from academic.oup.com/aesa/advance-article/doi/10.1093/aesa/saag039/9006273 by guest on 02 November 2026

Fallon C, Lewis SM, Walker A., et al. 2021. *Sustainable US firefly tourism: a guide for site managers*. Xerces Society.
Faust LF. 2010. Natural history and flash repertoire of the synchronous firefly *Photinus carolinus* (Coleoptera: Lampyridae) in the Great Smoky Mountains National Park. *Fla. Entomol.* 93:208–217. https://doi.org/10.1653/024.093.0210
Fincke OM, Yanoviak SP, Hanschu RD. 1997. Predation by odonates depresses mosquito abundance in water-filled tree holes in Panama. *Oecologia* 112:244–253. https://doi.org/10.1007/s004420050307
Food and Agriculture Organization of the United Nations. 2013. *Edible insects: future prospects for food and feed security*. FAO.
French SP, French MG, Knight RR. 1994. Grizzly bear use of army cutworm moths in the Yellowstone ecosystem. *Bears Their Biol. Manage*. 9:389–399. https://doi.org/10.2307/3872725
Grames EM, Montgomery GA, Youngflesh C, et al. 2023. The effect of insect food availability on songbird reproductive success and chick body condition: Evidence from a systematic review and meta-analysis. *Ecol. Lett.* 26:658–673. https://doi.org/10.1111/ele.14178
Green JW. 1956. Revision of the Nearctic species of Photinus (Lampyridae: Coleoptera). Proceedings of the California Academy of *Sciences. Fourth*. 28:561–613.
Griffiths HM, Ashton LA, Parr CL, et al. 2021. The impact of invertebrate decomposers on plants and soil. *New Phytol.* 231:2142–2149. https://doi.org/10.1111/nph.17553
Grimaldi DA. 2010. 400 million years on six legs: on the origin and early evolution of Hexapoda. *Arthropod Struct. Dev.* 39:191–203. https://doi.org/10.1016/j.asd.2009.10.008
GRSM. 2025. https://www.knoxnews.com/story/news/local/2025/04/21/synchronous-fireflies-2025-great-smoky-mountains-lottery-dates/83163438007/. Accessed September 18, 2026.
Halasa YA, Shepard DS, Fonseca DM, et al. 2014. Quantifying the impact of mosquitoes on quality of life and enjoyment of yard and porch activities in New Jersey. *PloS One*. 93:e89221. https://doi.org/10.1371/journal.pone.0089221
Hallmann CA, Sorg M, Jongejans E, et al. 2017. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PloS One*. 12:e0185809. https://doi.org/10.1371/journal.pone.0185809.
Hess WN. 1920. Notes on the biology of some common Lampyridae. *Biol. Bull.* 38:39–76. https://doi.org/10.2307/1536232
Hlongwane ZT, Slotow R, Munyai TC. 2021. The Role of Edible Insects in Rural Livelihoods, and Identified Challenges in Vhembe District, Limpopo, South Africa. *Resources (Basel)*. 10:123. https://doi.org/10.3390/resources10120123
Hogue CL. 1987. Cultural entomology. *Annu. Rev. Entomol.* 32:181–199. https://doi.org/10.1146/annurev.en.32.010187.001145
Hope RA, Frost PG, Gardiner A, et al. 2009. Experimental analysis of adoption of domestic mopane worm farming technology in Zimbabwe. *Dev. South. Afr.* 26:29–46.
Hosaka T, Sugimoto K, Numata S. 2017. Childhood experience of nature influences the willingness to coexist with biodiversity in cities. *Palgrave Commun*. 3:17071.
Hosaka T, Kurimoto M, Numata S. 2016. An overview of insect-related events in modern Japan: Their extent and characteristics. *Bull. Entomol. Soc. Am.* 62:228–234. https://doi.org/10.1093/ae/tmw079
Hunt SK, Galatowitsch ML, McIntosh AR. 2017. Interactive effects of land use, temperature, and predators determine native and invasive mosquito distributions. *Freshw. Biol.* 62:1564–1577. https://doi.org/10.1111/fwb.12967
Huntly PM, Van Noort S, Hamer M. 2005. Giving increased value to invertebrates through ecotourism. *S. Afr. J. Wildl. Res.* 35:53–62.
Huntly PM, Van Noort S, Hamer M. 2005. Giving increased value to invertebrates through ecotourism. *S. Afr. j. wildl. res.* 35:53–62.
Illgner P, Nel E. 2000. The geography of edible insects in sub-Saharan Africa: A study of the mopane caterpillar. *Geogr. J.* 166:336–351. https://doi.org/10.1111/j.1475-4959.2000.tb00035.x
Imathiu S. 2020. Benefits and food safety concerns associated with consumption of edible insects. *NFS Journal*. 18:1–11. https://doi.org/10.1016/j.nfs.2019.11.002
IPBES. 2019. *Summary for policymakers of the global assessment report onbiodiversity and ecosystem services of the intergovernmental science-policyplatform on biodiversity and ecosystem services*. In: Díaz S, Settele J, Brondizio ES, et al., editors. Bonn (Germany): IPBES secretariat; p. XX.
Itterbeek JV, Pelozuelo L. 2022. How many edible insect species are there? A not so simple question. *Diversity*. 14:143. https://doi.org/10.3390/d14020143
Jain S, Parrott JJ, Javan GT. 2024. Exploring the impact of xenobiotic drugs on forensic entomology for accurate post-mortem interval estimation. *Front. Insect Sci.* 4:1411342. https://doi.org/10.3389/finsc.2024.1411342
Kanaujia A, Rai A. 2023. Insect tourism. In: Omkar, editor. *Insects as service providers*. Springer.
Karuk Tribe. 2019. *Karuk climate adaptation plan*. Karuk Tribe Department of Natural Resources.
Kelemu S, Niassy S, Torto B, et al. 2015. African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security. *JIFF*. 12:103–119. https://doi.org/10.3920/JIFF2014.0016
Kenis M, Zannou-Boukari ET, Pomalégni SCB, et al. 2025. Role of women in the value chain of insects used as food and feed in Africa. *J. Insects Food Feed*. 12:797–812. https://doi.org/10.1163/23524588-bja10304
Kipkoech C, Jaster-Keller J, Gottschalk C, et al. 2023. African traditional use of edible insects and challenges towards the future trends of food and feed. *JIFF*. 9:965–988. https://doi.org/10.3920/JIFF2022.0076
Klein B. 2024. *The insect epiphany: how our six-legged allies shape human culture*. Timber Press.
Klein BA. 2007. Insects in art. In: Bekoff M, editor. *Encyclopedia of human-animal relationships*. Vol. 1. Greenwood Press. p. 92–99.
Klein BA. 2022. Wax, wings, and swarms: insects and their products as art media. *Annu. Rev. Entomol.* 67:281–303. https://doi.org/10.1146/annurev-ento-020821-060803
Klein BA, Brosius TR. 2022. Insects in art during an age of environmental turmoil. *Insects* 13:448. https://doi.org/10.3390/insects13050448
Klein BA, Brosius TR. 2024. Insects in art: a planet in peril and the insect muse. In: Peterson R, editor. *A cultural history of insects in the modern age*. Vol. 6. Bloomsbury. p. 165–186.
Koehler JJ, Mnookin JL, Saks MJ. 2023. The scientific reinvention of forensic science. *Proc. Natl. Acad. Sci. U S A*. 120:e2301840120. https://doi.org/10.1073/pnas.2301840120
Kola E, Munyai C, Dalu T. 2025. A review of macrophyte phytoremediation in Africa: current research and challenges. *Chem. Ecol.* 41:710–728. https://doi.org/10.1080/02757540.2025.2470315
Kreitlow KLT. 2009. Insect succession in a natural environment. In: Byrd JH, Castner JL, editors. *Forensic entomology*. CRC Press. p. 251–269.
Kritsky G. 2020. Revisiting prehistoric honey hunting at Bicorp, Spain. *Am. Bee J.* 160:1247–1250.
Kritsky G. (Ed.). 2024. *A cultural history of insects*. Bloomsbury.
Kruzhylina S, Didenko A. 2011. Autumn diet and trophic relations of juvenile brown trout (Salmo trutta), rainbow trout (Oncorhynchus mykiss) and European grayling (Thymallus thymallus) in the Shipot River (Ukraine). *Transylv. Rev. Syst. Ecol. Res.* 11:169.
Labandeira C. 2006. Silurian to Triassic plant and hexapod clades and their associations. *Arthropod Syst. Phylo.* 64:53–94. https://doi.org/10.3897/asp.64.e31644
Landis DA, Werling BP. 2010. Arthropods and biofuel production systems in North America. *Insect Sci.* 17:220–236. https://doi.org/10.1111/j.1744-7917.2009.01310.x
Le G, Matusin A, Yusah K, et al. 2021. Entotourism potential in Sabah, Malaysia: a tourists' perspective. *Cogent. Soc. Sci.* https://doi.org/10.1080/23311886.2021.1914950

Downloaded from academic.oup.com/aesa/advance-article/doi/10.1093/aesa/saag039/9006273 by guest on 02 November 2026

Lemelin RH, Boileau EY, Russell C. 2019. Entomotourism: the allure of the arthropod. *Soc. Anim.* 27:733–750. https://doi.org/10.1163/15685306-00001830

Lemelin RH, Dampier J, Harper R, et al. 2017. Perceptions of insects: a visual analysis. *Soc. Anim.* 25:553–572. https://doi.org/10.1163/15685306-12341469

Lewis SM, Cratsley CK. 2008. Flash signal evolution, mate choice, and predation in fireflies. *Annu. Rev. Entomol.* 53:293–321. https://doi.org/10.1146/annurev.ento.53.103106.093346

Lewis SM, Thancharoen A, Wong CH, et al. 2021. Firefly tourism: advancing a global phenomenon toward a brighter future. *Conserv. Sci. Pract.* 3:e391. https://doi.org/10.1111/csp2.391

Li H, Nitanan KM. 2022. Local visitors' willingness to pay for conservation fee at Kampung Kuantan Firefly Park, Kuala Selangor, Malaysia. *J. Trop. For. Sci.* 34:187–198. https://doi.org/10.26525/jtfs2022.34.2.187

Liu X. 2010. *The silk road in world history*. Oxford University Press.

Lloyd JE. 1966. *Studies on the flash communication system in Photinus fireflies*. Miscellaneous Publications. Museum of Zoology, University of Michigan.

Lonsdale S. 1982. *Animals and the origins of dance*. New York (NY): Thames & Hudson.

Losey JE, Vaughan M. 2006. The Economic Value of Ecological Services Provided by Insects. *BioScience*. 56:311. https://doi.org/10.1641/0006-3568(2006)56[311:TEVOES]2.0.CO;2

Lu W, Zhong F, Wu J, et al. 2025. Decoding constructed wetlands: a meta-analysis of performance and key drivers in tail water treatment. *Process Saf. Environ. Prot.* 197:107040. https://doi.org/10.1016/j.psep.2025.107040

Marquardt W. H. (Ed.). (2004). *Biology of disease vectors*. Elsevier.

Matandirotya NR, Filho WL, Mahed G, et al. 2022. Edible Insects Consumption in Africa towards Environmental Health and Sustainable Food Systems: A Bibliometric Study. *IJERPH*. 19:14823. https://doi.org/10.3390/ijerph192214823

Matandirotya NR, Leal Filho W, Mahed G, et al. 2022. Edible insects consumption in Africa towards environmental health and sustainable food systems. *Int. J. Environ. Res. Public Health* 19:14823. https://doi.org/10.3390/ijerph192214823

McCafferty WP. 1983. *Aquatic entomology: the fishermen's and ecologists' illustrated guide to insects and their relatives*. Jones & Bartlett.

Melillo ED. 2014. Global entomologies: insects, empires, and the 'synthetic age'in world history. *Past Present*. 223:233–270. https://doi.org/10.1093/pastj/gtt026

Migicovsky Z. 2025. Genomic resources for crop wild relatives are critical for perennial fruit breeding and conservation. *Am. J. Bot.* 112:e70068. https://doi.org/10.1002/ajb2.70068

Mordor Intelligence. 2026. *Silk market size and share*. https://www.mordorintelligence.com/industryreports/ silk-market. Accessed October 26, 2026.

Moritz RF, Härtel S, Neumann P. 2005. Global invasions of the western honeybee (*Apis mellifera*) and the consequences for biodiversity. *Ecoscience* 12:289–301. https://doi.org/10.2980/i1195-6860-12-3-289.1

Moss RH, Schneider SH. 2000. Uncertainties in the IPCC TAR: Recommendations to lead authors for more consistent assessment and reporting. In:Pachauri R, Taniguchi T, editors. *Cross-cutting issues in the IPCC third assessment report*. Global Industrial and Social Progress Research Institute for IPCC. pp. 33–52.

Neher DA, Barbercheck ME. 2019. Soil microarthropods and soil health. *Insects* 10:414. https://doi.org/10.3390/insects10120414

Netshifhefhe SR, Kunjeku EC, Duncan FD. 2018. Human uses and indigenous knowledge of edible termites in Vhembe District, Limpopo Province, South Africa. S. Afr. J. Sci. 114:1–10. https://doi.org/10.17159/sajs.2018/20170145

Odoi-Yorke F, Abbey ANA, Asante E, et al. 2025. Harnessing Black Soldier Fly Larvae for Sustainable Biofuel Production: A Review of Global Research Trends and Future Directions. *Int. J. Energy Res.* 1. https://doi.org/10.1155/er/8032373

Olivadese M, Dindo ML. 2023. Edible Insects: A Historical and Cultural Perspective on Entomophagy with a Focus on Western Societies. *Insects*. 14:690. https://doi.org/10.3390/insects14080690

Ollerton J. 2017. Pollinator diversity: distribution, ecological function, and conservation. *Annu. Rev. Ecol. Evol. Syst.* 48:353–376. https://doi.org/10.1146/annurev-ecolsys-110316-022919

Ollerton J, Tarrant S, Winfree R. 2011. How many flowering plants are pollinated by animals? *Oikos* 120:321–326. https://doi.org/10.1111/j.1600-0706.2010.18644.x

Oonincx DGAB, de Boer IJM. 2012. Environmental impact of the production of mealworms as a protein source for humans—a life cycle assessment. *PLoS One* 7:e51145. https://doi.org/10.1371/journal.pone.0051145

Paisley MF, Trigg DJ, Walley WJ. 2014. Revision of the biological monitoring working party score system. *River Res. Appl.* 30:887–904. https://doi.org/10.1002/rra.2686

Pironon S, Ondo I, Diazgranados M, et al. 2024. The global distribution of plants used by humans. *Science. (1979)* 383:293–297. https://doi.org/10.1126/science.adg8028

Potts SG, Imperatriz-Fonseca V, Ngo HT, et al. 2016. Safeguarding pollinators and their values to human well-being. *Nature* 540:220–229. https://doi.org/10.1038/nature20588

Recreational Boating and Fishing Foundation 2025; the website where these report is is as follows. https://www.takemefishing.org/corporate/newsroom/. Accessed September 11, 2026.

Rochlin I, Faraji A, Ninivaggi DV, et al. 2016. Anthropogenic impacts on mosquito populations in North America over the past century. *Nat. Commun.* 7:13604. https://doi.org/10.1038/ncomms13604

Rodger JG, Bennett JM, Razanajatovo M, et al. 2021. Widespread vulnerability of flowering plant seed production to pollinator declines. *Sci. Adv.* 7:eabd3524. https://doi.org/10.1126/sciadv.abd3524

Rooney EA. (Ed.). 2017. *Inspired by insects: bugs in contemporary art*. Schiffer.

Rothenberg D. 2013. *Bug music: how insects gave us rhythm and noise*. Picador.

Ruiz W. 1991. Dyeing for economic growth. IDRC Reports, April 1991.

Saikim FH, Le G, Dawood MM, et al. 2020. Tourists' perceptions of insects as determinants of insect conservation through entomological ecotourism. *J. Trop. Biol. Conserv.* 17:79–95. https://doi.org/10.51200/jtbc.v17i.2650

Sánchez-Bayo F, Wyckhuys KA. 2019. Worldwide decline of the entomofauna: A review of its drivers. *Biol. Conserv.* 232:8–27. https://doi.org/10.1016/j.biocon.2019.01.020

Saunders ME, Lees AC, Grames EM. 2025. Understanding and counteracting the denial of insect biodiversity loss. *Curr. Opin. Insect Sci.* 68:101338. https://doi.org/10.1016/j.cois.2025.101338

Shackleton CM, De Vos A. 2022. How many people globally actually use non-timber forest products? *For. Policy Econ.* 135:102659. https://doi.org/10.1016/j.forpol.2021.102659

Shen DY, Ferguson-Gow H, Groner V, et al. 2023. Potential decline in the distribution and food provisioning services of the mopane worm (*Gonimbrasia belina*) in southern Africa. *Front. Biogeogr.* 15:e59408. https://doi.org/10.21425/F5FBG59408

Shiozawa H, Sato K. 2025. Insects as pets and food: influence of childhood experiences with insects on acceptance of entomophagy. *J. Insects Food Feed.* 1:1–12. https://doi.org/10.1163/23524588-bja10197

Simaika JP, Samways MJ. 2018. Insect conservation psychology. *J. Insect Conserv.* 22:635–642. https://doi.org/10.1007/s10841-018-0047-y

Siopa C, Carvalheiro LG, Castro H, et al. 2024. Animal-pollinated crops and cultivars. *J. Appl. Ecol.* 61:1279–1288. https://doi.org/10.1111/1365-2664.14634

Sokhai KMardy S. 2024. A Review on the aspect of beekeeping and economic efficiency. *IInt. J. Integr. Res.* 2:107–114. https://doi.org/10.59890/ijir.v2i2.1223

Stiling P, Cornelissen T. 2005. What makes a successful biocontrol agent? *Biol. Control.* 34:236–246. https://doi.org/10.1016/j.biocontrol.2005.02.017

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Stork NE. 2018. How Many Species of Insects and Other Terrestrial Arthropods Are There on Earth?. *Annu. Rev. Entomol.* 63:31–45. https://doi.org/10.1146/annurev-ento-020117-043348. PMID: 28938083.

Suter GW, Cormier SM. 2015. Why care about aquatic insects. *Integr. Environ. Assess. Manag.* 11:188–194. https://doi.org/10.1002/ieam.1600

Tanga CM, Kababu MO. 2023. New insights into the emerging edible insect industry in Africa. *Anim. Front.* 13:26–40. https://doi.org/10.1093/af/vfad039

Thomas JMC. (Ed.). 2003. *Insects in oral literature and traditions*. Peeters.

Tisdell CWilson C. 2004. *Economics, wildlife tourism and conservation*. Gold Coast, Queensland, CRC for Sustainable Tourism.

Tong Z-Y, Wu L-Y, Feng H-H, et al. 2023. New calculations indicate that 90% of flowering plant species are animal-pollinated. *Natl. Sci. Rev.* 10:nwad219. https://doi.org/10.1093/nsr/nwad219

USFWS. 2015. https://www.fws.gov/media/2016-national-survey-fishing-hunting-and-wildlife-associated-recreation-0. Accessed September 18, 2026.

USFWS. 2022. https://www.fws.gov/media/2022-national-survey-fishing-hunting-and-wildlife-associated-recreation. Accessed September 18, 2026.

Vainstub D, Mumcuoglu M, Hasel MG, et al. 2022. A Canaanite's wish to eradicate lice on an inscribed ivory comb from Lachish. *Jerus. J. Archaeol.* 2:76–119. https://doi.org/10.52486/01.00002.4

van Huis A. 2013. Potential of insects as food and feed in assuring food security. *Annu. Rev. Entomol.* 58:563–583. https://doi.org/10.1146/annurev-ento-120811-153704

van Huis A, Rumpold B, Maya C, et al. 2021. Nutritional qualities and enhancement of edible insects. *Annu. Rev. Nutr.* 41:551–576. https://doi.org/10.1146/annurev-nutr-041520-010856

Wagner DL. 2020. Insect Declines in the Anthropocene. *Annu. Rev. Entomol.* 65:457–480. https://doi.org/10.1146/annurev-ento-011019-025151. PMID: 31610138.

Walton I. 1676. *The compleat angler*. Richard Mariott Publishing.

Whelan CJ, Şekercioğlu ÇH, Wenny DG. 2015. Why birds matter: from economic ornithology to ecosystem services. *J. Ornithol.* 156:227–238. https://doi.org/10.1007/s10336-015-1229-y

Wiraagni IA, Rezadhini M, Setiawan J, et al. 2024. Research trends on forensic entomology for five decades worldwide. *Leg. Med. (Tokyo).* 71:102539. https://doi.org/10.1016/j.legalmed.2024.102539

Wells JD. 2002. DNA techniques for forensic entomology. In: Forensic entomology: the utility of arthropods in legal investigations. p. 341. CRC Press.

World Health Organization (WHO). 2025a. Malaria. https://www.who.int/news-room/fact-sheets/detail/malaria

World Health Organization (WHO). 2025b. Dengue and severe dengue. https://www.who.int/health-topics/dengue-and-severe-dengue#tab=tab_1

Worobey J, Fonseca DM, Espinosa C, et al. 2013. Child outdoor physical activity is reduced by prevalence of the Asian tiger mosquito, Aedes albopictus. *J. Am. Mosq. Control Assoc.* 29:78–80. https://doi.org/10.2987/12-6296R.1. PMID: 23687862.

Xerces Society. 2025. Firefly conservation: a guide to protecting the jewels of the night. https://xerces.org/sites/default/files/publications/19-060_03_Firefly_brochure_web-UA.pdf

Zhou Y. 1980. *A history Chinese entomology*. Entomotaxonomia Press. p. 1–213.

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Annals of the Entomological Society of America 2026 00(00) 1–13
https://doi.org/10.1093/aesa/saag039
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