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The Role of Hexapods in Ecosystem Stability and Transmitted Diseases: A Review Article

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Abstract

Hexapods are a diverse group of insects and their related arthropods that play a vital role in shaping and maintaining terrestrial ecosystems. Their ecological functions include pollination, decomposition, soil aeration, and natural pest control, all of which contribute significantly to ecosystem stability. Some species among hexapods are the most efficient vectors of different pathogenic diseases, such as malaria, dengue fever, Lyme disease, and Chagas. Thus, these organisms place themselves in a rather complicated interface of biodiversity conservation and disease epidemiology. Changes in the environment due to climate change, habitat destruction or urbanization would influence the ecological roles played by hexapods in the transmission of vector-borne diseases. This double use highlights their essential ecological roles while also exploring them as agents of disease transmission. Recent studies on both negative and positive impacts will therefore be reviewed here to allow an understanding of how hexapods impact ecosystem functioning and human health. This duality is also very important for integrated strategies that provide support towards achieving ecological sustainability while reducing health risks amid global ecological changes. It seeks to give an even and broad view of the ecological helps by hexapods and the public health dangers linked with insect-borne sicknesses. Such a grasp is key for biodiversity care, sustainable growth, and health readiness in a fast-changing world.

Keywords: hexapods, ecosystem stability, transmitted diseases.

Introduction

Biodiversity sustains all life, balanced nature, and the livelihood of humankind with basic provisioning services like pollination, nutrient cycling, pest control, and disease management. In the past decades, growing pressures on nature led to biodiversity losses around the globe due to habitat destruction, climate change, and increasing pollution (Díaz et al., 2019). This damage to ecology does not only reduce the resilience capacity of natural systems but also takes away their capacities in many ways to mitigate health risks when these systems are under mounting attack. Human health has come into much closer focus as a function of degrading ecosystem service performance in infective disease emergence and spread. (Myers & Patz, 2009).

The most ecologically effective and diverse organisms are hexapods, which is a subphylum of arthropods that includes springtails, insects, flies, and related groups. Insects alone represent more than one million described species and live in almost all terrestrial and freshwater ecosystems (Zhang, 2011). Hexapods perform diverse and vital ecological functions: they are pollinators, decomposers, herbivores, predators, and prey, thereby contributing to ecosystem resilience and productivity (Wilson, 1987). Despite their small size, hexapods have an exceptionally large impact on ecosystem processes and are essential for maintaining ecological balance.

Hexapods contribute significantly to ecosystem stability, which refers to the ability of an ecosystem to maintain its structure and function over time (Loreau et al., 2001). Pollinators such as bees and butterflies are essential for plant reproduction and agricultural productivity (Potts et al., 2010). Detritivores such as beetles and springtails play a key role in decomposition and nutrient cycling (Hopkin, 1997). Predatory insects control pest populations, thereby supporting plant diversity and food web dynamics. With global studies reporting worrying declines in insect populations and diversity, there is growing concern that their ecological services may collapse (Hallmann et al., 2017). Therefore, declines in hexapods could have knock-on effects on overall ecosystem function and food security.

However, not all hexapod functions are beneficial to human health. Some insect groups are vectors of infectious diseases and pose significant risks to public health. For example, mosquitoes transmit malaria, dengue, Zika, and chikungunya viruses (WHO, 2023), while tsetse flies, sand flies, and assassin bugs cause other serious diseases such as sleeping sickness, leishmaniasis, and Chagas disease (CDC, 2023). Fleas and lice have historically been associated with devastating epidemics, including plague and typhus (Paz, 2015). Climate change and globalization is changing the habitats and migration routes of vectors. In new geographic areas an increased risk of vector-borne diseases means more vulnerability added to already existing health concerns in the world (Rocklöv & Dubrow, 2020).

Because they are of such ecological and epidemiological importance, hexapods are a key group at the intersection of biodiversity and public health. The review will discuss dual and sometimes antagonistic roles of hexapods in ecosystem stability and disease transmission. This article adopts an ecological perspective to weigh their contribution to both human health positively or negatively, toward a full understanding of their significance. It further reviews the necessity for integrated conservation and public health policies that simultaneously appreciate the value of essential ecosystem services provided by hexapods yet minimize vector-borne disease risks.

The Role of Hexapods in Ecosystem Stability

Hexapods comprise insects, springtails (Collembola), and all other six-legged arthropods. They are of great functional and structural importance in terrestrial or freshwater ecosystems. Though individually small, hexapods comprise major ecological roles as pollinators, decomposers, contributors to soil formation, herbivory as prey and predators within food webs (Wilson, 1987). Their diversity—more than half of all known organisms—provides them with different ecological niches from which they can interact with different members among themselves; hence, resilience and productivity in an ecosystem result. (Zhang, 2011).

Pollination and Plant Reproduction

Hexapods are recognized for their ecological aspects mainly in the process of pollination. Bees, butterflies, flies, and beetles are the principal agents of about 75% flowering plants' pollination which includes a big portion of human food crops (Potts et al., 2010). Fruit set ensures genetic variation among plant populations as well as ecosystem productivity due to strong insurance legacies related to improved crop yields and stability leading to higher levels of food security and stabile ecosystems (Klein et al., 2007). The mutual relationship between pollinators and flowering plants from millions of years offers another ripeness for complexity and deep dependencies within terrestrial ecosystems.

Nutrient Cycling and Decomposition

Hexapods are important in nutrient cycling and organic matter decomposition. As detritivores, termites, dung beetles, and springtails facilitate the decomposition of plant litter, feces, and dead bodies return nutrients to the soil-potassium or nitrogen very quickly back to the earth (Hopkin 1997). For instance, Isoptera termites are known for an efficient way of breaking down cellulose and further enhancing soil formation-evidence from tropical and subtropical regions-abundantly found there (Jouquet et al., 2011). Springtails and oribatid mites can be responsible for accelerating rates of decomposition by dynamically influencing soil microbial communities (Bardgett & van der Putten, 2014). Such processes ensure fertility as well as the structure of the soils that support plant growth and productivity within an ecosystem.

Trophic Interactions and Food Web Dynamics

Hexapods range in all trophic levels. In some places they are just primary consumers (for example, herbivorous caterpillars and grasshoppers), while in other areas they are the top predators (for example, dragonflies and predatory beetles). They have a great effect on the food web complexity and energy flow. Herbivores control plant population and create evolutionary pressure through selective feeding. Insect predators and parasitoids keep the insect pests' population under control, maintain interspecific balance in nature among different species, and pest outbreaks that can lead to imbalances in a lot of ecological systems (Landis et al., 2000). Many vertebrate species such as birds, amphibians, reptiles, and small mammals consume insects particularly during their breeding season- hence changes in hexapod abundance or diversity will have cascading effects on ecosystems due to this trophic connectivity.

Soil Formation and Maintenance

Hexapods play a very active role in the soil ecosystem. Most favor ants and termites as they burrow and nest within the ground, since they perform their activities as "ecosystem engineers"- improv- ing soil aeration, infiltration of water, and incorporation of organic matter (Folgarait, 1998). Conditions for other organisms' microhabitats set within general soil health improvement too. Collembola may seem minute but dominates many soils; their activities tend to influence the distribution and availability of microbial biomass (Rusek, 1998). The function includes bioturbation and litter fragmentation; therefore, such an essential function towards maintaining sustainability within the soil ecosystem.

Biodiversity and Ecosystem Resilience

Biodiversity has a direct positive effect on ecosystem stability, and hexapods belong to one of the most species-rich major lineages of organisms on Earth. The diversity that hexapods offer ensures functional redundancy where different species performing the same ecological roles ensure ecosystems against any disturbance (Loreau et al., 2001). For example, within a network for pollination, the function performed by one species could be replaced by another species having similar foraging behavior. Equally important, diversity among decomposer species guarantees nutrient cycling under the conditions of environmental stress. This redundancy builds resilience into systems and provides recovery from climate change, land-use change, and invasive species (Hooper et al., 2005).

Indicators of Environmental Change

Hexapods adjust rapidly to environmental fluctuations, making them efficient bioindicators of the health and stability of ecosystems. Any change in the composition, abundance, or phenology of insect communities may be interpreted as a change in temperature, pollution, habitat fragmentation, or trophic dynamics (McGeoch, 1998). For example, it is observed that pollinators dwindle with intensive agriculture and pesticide application as well as urban expansion-a general indication of falling ecological integrity-(Goulson et al., 2015). Thus, monitoring hexapod populations serves the dual purpose of providing an early warning signal on ecological decline and driving conservation strategies.

Threats to Hexapod-Mediated Stability

Hexapods play key roles in ecosystems and despite this, their populations are increasingly threatened. Recent studies documented sharp declines in insect biomass and diversity across different ecosystems. Protected areas do not necessarily protect from a direct loss of habitat; for example, flying insect biomass fell by 75% over just 27 years within protected areas in Germany (Hallmann et al., 2017). The drivers behind such losses include habitat fragmentation, pesticide pollution, climate change, invasive species, and light pollution. Hexapod population declines threaten the stability of the ecosystem itself through undermining top regulation by predators as well as nutrient cycling and many other functions.

Integrating Hexapods into Conservation Strategies

Conservation and management of ecosystems can only be successful if the role of hexapods as central to driving ecosystem functions is acknowledged. Conservation should keep their habitat, avoid exposure to pesticides and other pollutants, as well as plant diversity to sustain pollinator networks. Some strategies at a landscape level that can enhance insect diversity as well as resilience include ecological corridor establishment, heterogeneity maintenance, and agroecological practices (Tscharntke et al., 2005). Furthermore, integrating hexapod data into ecological monitoring and climate adaptation planning will foster long-term sustainability of ecosystems and their services.

The Role of Hexapods in Disease Transmission

Hexapods are very important infectious disease vectors of humans and animals. Diversity, plasticity, and ecological relation multipath make them good pathogen carriers. Some members of hexapod taxa carry pathogens as primary or secondary vectors. Among these are mosquitoes (Culicidae), flies (Diptera), lice (Pseudotoptera), fleas (Siphonaptera) and bed bugs (Hemiptera). They can transmit bacterial, viral, protozoan or helminth pathogens (Lehane, 2005). Therefore, knowledge about them is equally important for the management of Biodiversity under changing climatic conditions and increasing environmental degradation and for public health purpose.

Biological Mechanisms of Transmission

Hexapods generally transmit pathogens by two main means: mechanical transmission, and biological transmission. In the mechanical type, insects just carry the pathogen on their body surface or mouthparts from one host to another, without ever internalizing them. For example, houseflies (Musca domestica) may mechanically transmit enteric pathogens like Escherichia coli, Shigella, and Salmonella through fecal contamination of their appendages and mouthparts (Graczyk et al., 2001). On the other hand in biological transmissionh pathogens have to be internalized within the vector and normally multiply inside it. For example, mosquitoes sustain part of the life cycle of Plasmodium which causes malaria besides viruses such as dengue, Zika, and chikungunya (Weaver & Reisen, 2010).

The biological competence of hexapods to transmit pathogens relies on several factors. These include their immune response, microbiota, the lifespan of the vector, biting behavior as well as environmental conditions. Pathogens have developed with numerous insect hosts a variety of strategies to avoid immune responses and exploit different physiological characteristics for complex life cycles. The co-evolution focuses on the intricate relationship between vector-pathogen-host interactions. (Aksoy et al., 2001).

Mosquitoes and Arboviral Diseases

Mosquitoes are the best known disease vectors among insects. Female mosquitoes belonging to the genera Anopheles, Aedes and Culex transmit protozoa, filariasis causing worms, and arboviruses among a diversity of pathogens (WHO, 2023). Anopheles mosquitoes are the only transmitters of malaria- carrying Plasmodium which results in this deadly disease killing more than 600,000 people every year mostly from sub-Saharan Africa. (WHO, 2022) . Aedes species, especially Aedes aegypti, have been implicated in the transmission of various arboviral diseases, such as dengue, Zika, yellow fever, and chikungunya. These diseases pose a major health threat in tropical and subtropical regions and are increasingly spreading to temperate regions due to global warming, urbanization, and population mobility (Gubler, 2011). Zika virus attracted international attention in 2015-2016 due to its association with congenital microcephaly and neurological complications in newborns (Mlakar et al., 2016). Culex mosquitoes also transmit West Nile virus, Japanese encephalitis, and lymphatic filariasis. The fast spread of Culex quinquefasciatus has greatly increased due to water pollution and the expansion of urban breeding sites (Fonseca et al., 2010).

Biting Flies and Parasitic Diseases

Other hexapod vectors aside from mosquitoes include the Tsetse flies Glossina sp. Transmit Trypanosoma brucei which causes African trypanosomiasis, commonly known as sleeping sickness. If not treated in time, it may prove fatal (Simarro et al., 2012). They mostly occur in sub-Saharan Africa with a distribution pattern found near livestock and wildlife inhabiting riverine and grassland areas.

Leishmania is transmitted by sand flies (Phlebotominae). The clinical manifestations of this disease are cutaneous, mucocutaneous, and visceral. Millions of people are at risk. More than 90 countries report cases, with increasing occurrence in urban and peri-urban areas due to factors such as deforestation facilitated by climate change (Alvar et al., 2012). The black fly, Simulium spp. transmits the parasitic worm Onchocerca volvulus causing onchocerciasis or river blindness and has its endemicity foci in Africa and the Americas; this disease can cause eye lesions leading to visual impairment apart from severe generalized dermatological symptoms (WHO, 2020). The transmission cycle of Onchocerca volvulus has close ecological linkages with rivers which form the breeding sites for black flies suggesting an ecological dimension to the persistence of the disease.

Fleas, Lice, and Historical Pandemics

Hexapods like fleas and lice have carried plagues in days gone by. The Oriental rat flea, Xenops cheirostris, shares with this couple of main vector of Yersinia pestis. It was this bacterium that struck down tens of millions across Europe during the 14th century with Black Death. (Perry & Fetherston, 1997). Fleas pick up the bacteria from infected rodents and transmit it to humans through bites. Lice, especially body lice (P. pubescens), transmit pathogens such as Rickettsia prowazekii (typhus), Borrelia burgdorferi (relapsing fever), and Bartonella quinquefasciatus (trench fever). These diseases are spread in crowded, unsanitary environments, such as refugee camps and during war (Raoult & Roux, 1999). Although modern hygiene and antibiotics have reduced the spread of plague, outbreaks still occur among vulnerable populations.

Hexapods and Zoonotic Spillover

Hexapods also facilitate zoonosis, the transfer of pathogens from animal hosts to humans. Many emerging diseases have zoonotic origins, and insect vectors act as bridges in this cross-species transmission. For example, Aedes mosquitoes, which feed on humans and non-human primates, contribute to the maintenance and spread of sylvatic yellow fever and dengue fever cycles (Vasilakis et al., 2011). Deforestation, agricultural expansion, and expansion of wild habitats increase the likelihood of such events. The One Health approach integrates human, animal, and environmental health, highlighting the need to study insect vectors in a broader ecological context. Hexapods not only connect different host species, but also reflect environmental changes that affect disease dynamics. (Destoumieux-Garzón et al., 2018).

Climate Change and Vector Distribution

Global climate change significantly alters the geographic place, seasonality, and intensity of vector-borne diseases. Warmer average temperatures and changed rainfall patterns now create favorable conditions in new regions for vectors such as mosquitoes and sand flies to establish (Rocklöv & Dubrow, 2020). For example, Aedes albopictus—a mosquito native to Southeast Asian countries—is now established within parts of Europe and America because it can survive even in somewhat lower temperatures and its eggs resist desiccation (Benedict et al., 2007). Similarly, Aedes malaria vectors have now been found at higher elevations than ever before—posing a risk to what were formerly thought to be secure populations (Siraj et al., 2014). This means that the current surveillance and control strategies will face challenges due to changes like this one; thus, ecological and climate data have to inform adaptive management.

Implications for Public Health and Control

Integrated Vector Management (IVM) therefore encapsulates biological, chemical, ecological and community strategies. Some of the interventions presently available or being developed include the use of insecticide-treated bed nets, indoor residual spraying, environmental management and genetic control e.g. sterile insect technique and gene drives (Van den Berg et al., 2012). But for these to work effectively, there must be an understanding of vector behavior, ecology and resistance patterns. Hexapods are highly adaptive increasingly mounting resistance against commonly used pyrethroids among other classes of insecticides thus underscoring the imperative for novel sustainable solutions (Ranson & Lissenden, 2016).

Conclusion

Hexapods are key to the dual functions of ecosystem integrity and human health. In many instances, this fact is largely unacknowledged. They belong to those classes that mainly contribute positive inputs toward the steady maintenance of ecosystems by means of pollination, nutrient cycling, decomposition, and natural pest control. Some hexapod species are principle vectors for infectious diseases in humans and thus threaten global public health. Their ecological functions support biodiversity, crop production, and general environmental robustness — except for a few among them who undermine system resilience by transmitting illnesses — particularly malaria, dengue fever, Lyme disease, etc., via mosquitoes, ticks or lice and fleas) This paper argues for a nuanced understanding based on integrated policies which intend both ecological conservation along with public health considerations as components within further investigations at crossroad areas where lessons learned could facilitate environmentally sustainable yet health-aware interventions directed toward decreasing hexapod-related risks in an ever faster changing world.

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