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Aquatic-insects, their biodiversity, importance and conservation: A systematic review

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Abstract
A vital role played by Aquatic-Insects in maintaining a balance of ecosystem, contributing to nutrient-cycling, water quality monitoring, and ecological stability. India, a mega-diverse nation, harbors approximately 5,000 recorded aquatic insect species, significantly influencing wetland biodiversity. These insects exhibit various morphological and physiological adaptations, including specialized respiration mechanisms such as air tubes, gill respiration, and plastrons, to thrive in aquatic environments. The evolutionary history of Aquatic-Insects traces back to the Paleozoic era, with eleven taxonomic orders comprising both fully aquatic and semi-aquatic species. Functional feeding groups *viz*. filter feeders, predators, scrapers, and shredders, enhance aquatic ecosystems by decomposing organic matter and supporting food chains. Aquatic-Insects also serve as bioindicators, reflecting the health of freshwater ecosystems, and are employed in biomonitoring programs to assess environmental changes. However, anthropogenic factors such as industrial pollution, climate change, pesticide runoff, and habitat destruction threaten their populations. Conservation efforts emphasize habitat restoration, improved land-use practices, and biodiversity awareness to mitigate these threats. Furthermore, Aquatic-Insects have societal benefits, including their role in fishery resources, forensic investigations, weed control, and disease vector management. Despite their ecological significance, there is a declining number of trained aquatic entomologists, highlighting the need for renewed interest in aquatic insect research. This scientific review underscores the vital role of aquatic-insects in ecological and sustainability with respect to environment, emphasizing the necessity of conservation strategies and advanced biomonitoring techniques to protect their diverse populations.

Keywords: Aquatic-insects, biomonitoring, functional feeding groups, conservation strategies, ecological indicators

Introduction

One of the mega-diverse nations: India with remarkable array of aquatic-habitats spanning around 3,166,414 square kilometers, characterized by noteworthy fluctuations in rainfall, height, elevation, and latitude. According to Rao *et al*., 2020 [45], an estimated 45,000 aquatic insect species exist globally, with around 5,000 species recorded in India's inland wetlands, primarily originating from North America, Australia, and Europe. Inland; wetlands are home to several well-known insect families, including dragonflies (*Odonata*), mayflies (*Ephemeroptera*), and caddisflies (*Trichoptera*). Aquatic-Insects, such as damselflies and dragonflies (*Odonata*) (Elango *et al*., 2021) [17], are highly colorful and noticeable in wetlands. The various functional feeding groups *viz*. filter feeders, predators, scrapers, and shredders, are crucial links in the recycling of nutrients as described by Subramanian & Sivaramakrishnan, (2007) [55]. Insects from aquatic habitis facilitate the decomposition of wood and leaf litter entering marshes. The nutrients released in this process are further broken down by microorganisms *viz*. fungi and bacteria, enriching the ecosystem. Plants in the riparian region absorb this nutrient content after it is transported through the marshes. In addition to serving as food for fish and amphibians, Aquatic-Insects also have a crucial ecological role.

Aquatic-Insects Evolution

An origins of insects belongs to aquatic habitats are still up for debate, and it's still unclear if aquatic settings are the primary or secondary adaptation for these insects. The ancestor of the myriapod-insect group, which includes insects, millipedes, and centipedes, is said to have lived in leaf litter areas next to pond-like settings. Aquatic-Insects are believed to have evolved from primitive insects inhabiting damp environments (Sharma *et al*., 2020) [52]. They have fossils from the Devonian period of the Paleozoic era. The most rudimentary and unique Aquatic-Insects with young are the dragonflies (*Odonata*) and mayflies (*Ephemeroptera*), among other extended Aquatic-Insects. The scant fossil record of freshwater animals has complicated our knowledge of the evolution and phylogeny of Aquatic-Insects. Live Aquatic-Insects represent eleven insect orders. Of them, the larvae of species of moths (*Lepidoptera*), wasps (Hymenoptera), lacewings (*Neuroptera*), stoneflies (*Plecoptera*), alderflies (*Megaloptera*), dragonflies and damselflies (*Odonata*), flies (*Diptera*), and lacewings (*Neuroptera*) are aquatic with terrestrial adults. Aquatic bugs (*Hemiptera*) and beetles (*Coleoptera*) are entirely aquatic throughout their larval, nymphal, and adult phases (Subramanian and Sivaramakrishnan, 2007) [54].

Taxonomic orders of Aquatic-Insects

Eleven taxonomic orders comprise most Aquatic-Insects (Thorp *et al*., 2009) [58]. The springtails are called *Collembola*; the mayflies are called *Ephemeroptera*; the dragonflies and damselflies are called *Odonata*; the stoneflies are called *Plecoptera*; the true bugs are called *Hemiptera*; the spongillaflies are called *Megaloptera*; the caddisflies are called *Trichoptera*; the butterflies and moths are called *Lepidoptera*; the beetles are called *Coleoptera*; and the true flies are called *Diptera*. There are also a few Aquatic-Insects in the other orders, Blattodea (cockroaches), Hymenoptera (wasps), and Orthoptera (grasshoppers and crickets). Below is a quick synopsis of an important orders of Aquatic-Insects:

I. Order: *Collembola*

Fossilized springtails date back more than 345 million years. Springtails are tiny hexapods or animals with three pairs of legs. They are abundant in areas close to water and on the ocean's surface when vegetation or organic debris, such as leaves washed ashore, is present (DeWalt *et al*., 2010) [15]. They can leap many times their length thanks to a jumping apparatus called a furculum, which is made up of a trigger and a lever that resembles a spring.

II. Order: *Ephemeroptera*

Fishermen are familiar with mayflies because many fish like to eat their larvae, or nymphs and newly emerging adults with wing of this ancient order (Thresher, 2023) [59]. Mayflies are aquatic larvae that live for most of their lives, sometimes for years, before emerging from the water as winged adults that mate and lay eggs in hours or days at most. The "ephemeral" (lasting a brief time) aspect of the adult insect's existence gave rise to the order's name. The only insects known to undergo a molt after developing wings are mayflies. Following their emergence from the water, they exist briefly as subimago, or winged forms, before molting once more to assume their actual adult shape (Kriska, 2023) [28].

III. Order: *Odonata*

The insects belongs to order *Odonata*, comprising damselflies as well as dragonflies, are predators that consume another organisms in their larval (nymphal) and adult stages too, thereby substantially diminishing mosquito populations by preying on mosquito larvae and adults. The larvae of *Odonata* possess distinctive mouthparts that can be elongated to seize aquatic prey, while the adults utilize their basket-like legs to acquire airborne insects (Dambach, 2020) [12]. Extinct ancestors of these ancient insects existed prior to the era of dinosaurs. Certain fossils similar to *Odonata* from the Carboniferous period exhibited wingspans reaching 0.71miter; thus, these insects were larger than certain contemporary hawks. Nair *et al*. (2015) [37].

IV. Order: *Plecoptera*

The *Plecoptera* are known as stoneflies, most likely because this ancient order's larvae (nymphs) are frequently found under the stones of rivers and streams, particularly those with swifter, colder water. Stonefly larvae (nymphs) resemble adult stoneflies only in that the larvae (nymphs) lack wings, which are typically present and folded over the back of adult insect during not flying (Kriska, 2023) [28].

V. Order: *Hemiptera*

The insects belonging to *Hemiptera* are the only true "bugs," technically speaking. The dimention of these aquatic ecosystem insects varies; they can be as little as "water measurers" in the family Hydrometridae, or as large as "giant water bugs," or Belostomatidae, which can grow to be 7 cm or longer and are occasionally eaten by humans. Predators with sharp, piercing mouthparts and grasping (raptorial) forelegs, most aquatic *Hemiptera* species can give painful bites if handled roughly (Sahayaraj and Hassan, 2023) [48]. The most dangerous of these insects is an oval pest known as the Naucoridae (creeping water bug). This bug bites with significant discomfort. "Water scorpions," "backswimmers," "water boatmen," and "water striders" are a few other Hemipterans that can be found in or on water. While some true bugs are indicative of rushing streams, these insects are particularly abundant in regions with stagnant water and emergent flora.

VI. Order: *Megaloptera*

As adults, these insects—also called alderflies and dobsonflies—may make a visually arresting impression (Rivera-Gasperin *et al*., 2019) [47]. "Hellgrammite" is the dobsonfly's immature form. These vicious larvae, which can grow to a length of almost 7.5 cm, have potent mandibles that they use to eat their food. If mishandled, however, they can also administer quite the pinch. Certain species reside in lakes and ponds, where they pursue and ingest other aquatic organisms, while others are common in rocky, swift-moving riverine environments. Many mature males appear to have a highly disproportionate jaw, which may help them attract females (Oswald and Machado, 2018) [40].

VII. Order: *Neuroptera*

Although most neuropterans, or nerve-winged organisms, are terrestrial, the larvae of spongillaflies (family Sisyridae) possess needle-like mandibles that enable them to penetrate and consume freshwater sponges (Nair, 2015) [37]. Their larvae frequently "hide" on their host sponge by affixing little sponge fragments to their back spines to evade discovery by predators (Oswald and Machado, 2018b) [40].

VIII. Order: *Trichoptera*

The popular English term for *Trichoptera* is "caddisflies," which is believed to be a reference to the traveling cloth merchants known as "caddis men" who traveled from town to town during the Middle Ages (Nair, 2015) [37]. Many insects construct and wrap themselves in transportable cases using items they find in the river, such as stones, twigs, leaves, or sand. Others create silken nets to filter food from flowing water and silken shelters. Others are predators that hunt and eat other little creatures. They dwell in the water as eggs, and pupae, but adults, which resemble moths, often spend the day hiding among vegetation along the coast or flying above the water in search of mates or to lay eggs.

IX. Order: *Lepidoptera*

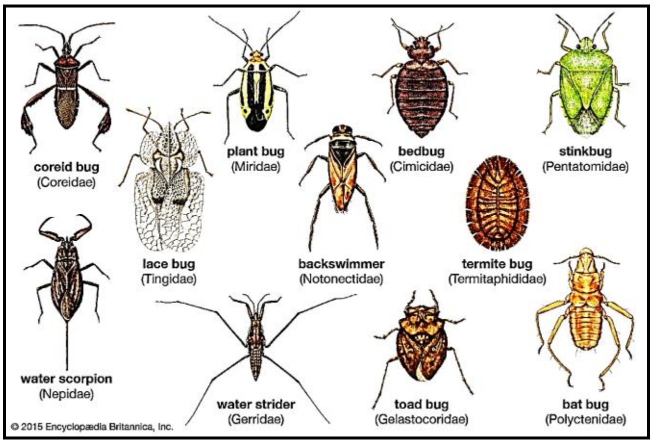
Only a small percentage of *Lepidoptera*, or butterfly and moth family, are aquatic; the majority of moth species and all butterflies are terrestrial (Pabis, 2018) [41]. Some moths live in lakes and rivers as eggs, larvae, and pupae found on aquatic plants' leaves and stems, or beneath silken tents on rocks. When they reach adulthood, aquatic *Lepidoptera* leave the water and fly nearby, just like their related order *Trichoptera*, also known as caddisflies (Paul and Datta, 2022).

X. Order: *Coleoptera*

Since mature beetles' front wings have been altered into rigid covers that protect their rear wings from harm when folded at rest, the name *Coleoptera* roughly translates as "sheath-wing" (Boyel *et al*., 2021). Mostly, flying beetles only use their hind wings for flight. Beetles comprise more species than just about any type of plants or animals worldwide. Over 350,000 different species of beetles have been identified to date. The variety and curiosity of aquatic beetles are remarkable. In weedy ponds, predaceous diving beetles are common. Some of them are almost 2.5 cm long. Whirligig beetles are quite prevalent and frequently observed swimming in big groups on the surface of still water. One pair of eyes sees above the water, while the other sees below, making most whirligig species "four-eyed" (Lin, 2014) [33]. Elmid or riffle beetles, psephenid or water-penny beetles, and the tiny heart-shaped haliplids, or crawling water beetles, are other types of beetles that may be found in rivers. Most of these families' larvae are aquatic, but several beetle families have both terrestrial and aquatic adults (Nair, 2015) [37].

XI. Order: *Diptera*

The order name *Diptera*, which translates to "two wings," alludes to the characteristic distinguishing adult true flies—they have only one pair of wings (Sarwar, 2020). The aquatic *Diptera*, especially the species that prefers to feed on human blood, are among the least preferred insects (Courtney *et al*., 2017) [11]. These include the ceratopogonids (biting midges or punkies), the simulids (biting black flies), the tabanids (horseflies and deerflies), and the culicids (mosquitoes) (Nair, 2015) [37]. Research on mitigating the spread of diseases like malaria and dengue fever has been heavily focused on these insects. Fly colonization of aquatic environments has resulted in various fascinating adaptations, like breathing tubes, silken tunnels, and ventral suction cups. In freshwater environments, non-biting midges can be particularly prevalent and serve as the primary food source for predators. Of all the aquatic insect families, non-biting midges (Chironomidae) are the most prevalent and varied, both as larvae and adults.



(**Source:** https://www.britannica.com/animal/heteropteran)

Fig 1: Some examples of Aquatic-Insects and their families

Morphological and physiological adaptations

To survive in an aquatic environment, Aquatic-Insects have evolved various morphological and physiological adaptations.

Air-tubes: For the extraction of air from plants, hemoglobin pigments, plastrons, cutaneous and gill respiration, and atmospheric oxygen. Aquatic-Insects (*Hemiptera*) and fish (*Diptera*) have air tubes, which limit their activity to the water's surface (Subramanian & Sivaramakrishnan, 2007) [55].

Cutaneous and gill respiration is ordinary in most Aquatic-Insects' juvenile stages. They can survive among submerged substrates because of this. Adult bugs and beetles frequently employ an air bubble for breathing. Certain species have an air film-holding structure called a plastron, which is made up of papillae or microhairs (Subramanian; Sivaramakrishnan, 2007) [55].

These insects can stay underwater longer thanks to plastron respiration. Larvae of the genus Chironomidae (*Diptera*) inhabiting eutrophic aquatic environments use hemoglobin pigments to withstand low oxygen levels. Water current is one of the main physical forces that Aquatic-Insects in moving waters must contend with.

Morphology of Aquatic-Insects

Aquatic insect morphology in moving rivers strongly correlates with hydraulic stress and the need to maintain intimate touch with the substrate. Water insects have a wide variety of body changes. Many families of insects share many common modifications, including flattening of the body, streamlining, reduction of protruding features, suckers, friction pads, hooks, silk, and sticky secretions. Behavior adaptations closely trail morphological adaptations. By burrowing into the substrate or taking up residence in an area with less hydraulic stress, such as a rock fissure or beneath a rock, Aquatic-Insects can evade water currents (Fenoglio *et al*., 2020) [18].

Adaptations for the life cycle

Diverse life history techniques have evolved by Aquatic-Insects to adapt to their surroundings. Many species spawn in temporary pools have egg stages that may stay completely dry (like Aedes). A gelatinous egg mass matrix in numerous caddy fly species shields the eggs and larvae from freezing and desiccation for months. Some species avoid congestion of freshly hatched larvae by having staggered hatching. A tiny percentage of Aquatic-Insects have developed a life cycle that is entirely submerged (Heckman, 2018) [23]. The majority of Aquatic-Insects reside on land for at least a portion of their life cycle. One of the main issues when fully submerged is breathing. Numerous organisms have evolved physical and physiological modifications to endure in specific oxygen concentrations. The difference between running and standing water is readily apparent, with the former having significantly more oxygen. This is a crucial element that impacts the dispersion of taxa such as caddiesflies (*Trichoptera*), stoneflies (*Plecoptera*), and mayflies (*Ephemeroptera*). These groupings thrive in flowing water and depend on dissolved oxygen to reach their greatest variety. Aquatic pupa is found in flies (*Diptera*), caddiesflies (*Trichoptera*), and aquatic moths (*Lepidoptera*) among other holometabolous Aquatic-Insects. Pupa of semi-aquatic or terrestrial species is produced by aquatic beetles, alderflies (*Megaloptera*), and lacewings (*Neuroptera*). Aquatic-Insects experience a variety of physical environmental circumstances throughout their lives, with temperature being the most prominent. The temperature fluctuates both seasonally and every day. This temperature variance impacts the way that Aquatic-Insects emerge. Because of the tropical regions' generally consistent temperatures, a large number of pool breeding species exhibit year-round continuous emergence (Nash *et al*., 2023) [38]. On the other hand, the pre- and post-monsoon months emerge when most stream-breeding species in the Western Ghats emerge. Certain tropical species have an emerging pattern that corresponds with the moon's phases.

Feeding tactics

When they are in their early stages of development, almost all Aquatic-Insects are omnivorous. Similar mouth features have developed in species that employ comparable morpho-behavioral strategies for food acquisition (Wallace and Merritt, 2019). This has made classifying Aquatic-Insects into guild-like functional feeding groups easier. The "functional group" method considers both parallel and convergent evolution that produced species with comparable functions (Baulechner, 2022) [3]. As a larva develops, its mouth, legs, and other morphological features, as well as artificial tools like silk nets, and the feeding habits that accompany them, may alter. The functional groups of shredders, collectors, scrappers, predators, and piercers are well-known.

Scrapers: The unique mouthpieces of scrapers are designed to remove algae grown on the surfaces of rocks and other solid objects. The uppermost layer of algae is stuck quite securely but is incredibly nutritious for those insects that can remove it, and these mouthparts act like a keen blade to remove it (Piper, 2021) [43].

Collectors: Collectors obtain tiny fragments of rotting plant matter or detritus. Certain species filter these tiny particles out of the water using silk nets or long hairs on their legs or head. Other types of collectors capture small particles that are resting on the bottom of their mouthparts and then push this material into their mouths (Morse *et al*., 2019) [35].

Shredders: The mouthparts of shredders are made to grind up soft vegetation, such as twigs, leaves, and flowers, by nibbling on them. The majority of Aquatic-Insects tear apart fallen plant material that is decomposing. Most of this material is derived from shrubs and trees found growing on land near bodies of water (Mutshekwa, 2020) [36]. A small number of species of Aquatic-Insects consume submerged plant components.

Predators: Predators consume the living prey of other animals. Predators frequently possess unique features, such as powerful jaws with teeth, a keen beak, or spiny legs, that enable them to capture and immobilize their prey. Most of the time, predators feed on other invertebrates, but some are big and powerful enough to capture small vertebrates like fish and tadpoles (Sherry, 2016) [53].

Coastal insects and their environments

The environments to which Aquatic-Insects are accustomed are either standing (ponds and lakes) or running (streams and rivers) (Dangles, 2023) [13]. These environments can also be thought of as ecosystems that are frequently colonized by erosion along lakeshores. Similarly, floodplain pools and backwaters are popular places for many depositional environments. It is possible to visualize the water insects' habitats using a variety of spatial and temporal scales. Its size varies greatly on a spatial scale, ranging from millimeter- sized particles to the entire drainage basin, which covers square kilometers. It is possible to see how the ecosystems have changed, from a few days to thousands of years. The spatial scale affects how permanent the habitats' physical structures are. This can be a few days for a single grain and microhabitat; for the drainage network, it can be thousands of years. Wetland insect communities also react to this spatial-temporal variation. Aquatic-Insects use various techniques to stay inside a particular habitat, including clinging, swimming, skating, and burrowing.

The distribution of Aquatic-Insects is affected by the intricate interconnections of substrate, velocity, turbulence, and food availability within a habitat. The mobility frequency within a certain environment is dictated by the species' habit, including its locomotion, attachment, or concealment methods. The substrate is an essential and complex physical component of the ecosystem. The water flow and the nature of the accessible parent material dictate the physical properties of the substrate. Organic waste can profoundly influence an organism's response to its substrate and increase the complexity of the substrata. The faunal makeup varies with the substrate throughout different biomes and continents. In low (streams and rivers) or depositional (ponds and lakes) environments, sand is relatively deficient. Lake basins, river floodplain pools, and stream/river backwaters offer depositional environments, whereas stream/river currents and lakeshore waves generate habitats conducive to erosion. species that have adapted to withstand erosive diversity and abundance (Subramanian and Sivaramakrishnan, 2007) [55]. In silty sand, diversity is rather high, whereas in muddy substrata, biomass may be high and diversity low. Sand and silt cause a decrease in and alteration of fauna. It is recognized that the amount of space available for colonization controls species abundance, at least on stony substrata (Giacobbe, 2024) [21]. Generally speaking, substrate stability and the presence of organic detritus lead to increases in diversity and abundance.

Societal benefits of Aquatic-Insects

There are several reasons why humans and animals benefit from a great diversity of aquatic insect species, but four are particularly significant. These insects play a part in fishing, biomonitoring, food webs, and weed control (Nair *et al*., 2015) [37].

Food webs and Nutrient Cycle: Large-scale nutrient digestion is facilitated by a high density (or abundance) of Aquatic-Insects. The diversity of resources and ecosystem services (such as habitats and nutrients) and the efficient utilization of all available resources in both space and time are ensured by Aquatic-Insects' high taxonomic richness (or diversity). Aquatic-Insects are abundant, have a high birth rate with a short generation time, and colossal biomass, and quickly colonize freshwater habitats, making them potential model animals for studying the structure and function of the freshwater ecosystem (Lancaster and Downes, 2018) [31]. They are crucial to the cycling of nutrients, primary production, decomposition, and material translocation in ecosystems.

Critical linkages in the recycling of nutrients are the several functional feeding groups of Aquatic-Insects, including shredders, scrapers, filter feeders, and predators. Fish, amphibians, and water birds all eat insects. When wood and leaf litter from the adjacent landscape enter the marsh, Aquatic-Insects primarily decompose them. The nutrients decomposed by Aquatic-Insects are subsequently transformed into a form that bacteria and fungi can assimilate. This nutrient-rich solution is transported across the wetlands and assimilated by vegetation in the riparian zone, which endures erosive diversity and abundance

(Subramanian and Sivaramakrishnan, 2007) [55]. Decomposing plant parts and leaves that land on the water's surface are broken down by some Aquatic-Insects. In certain aquatic habitats, this substance serves as the basis of the food chain. Some of them allow light to reach the bottom of streams where algae bloom by filtering suspended particles in the water. Due to the bottom's oxygen enrichment, another aquatic bug mixes the soft silt while looking for food, making the bottom suitable for life. Furthermore, predatory Aquatic-Insects assist in maintaining an equilibrium between various organisms and food sources by lowering the population of other invertebrates (Voshell, 2002) [61]. Aquatic-Insects fulfill a crucial ecological function beyond serving as food for fish and amphibians.

Fish and ducks rely heavily on chironomid larvae as a food source. Lakes are categorized into oligotrophic, mesotrophic, and eutrophic based on the diversity of chironomid species and their sensitivity to eutrophic conditions (Hayford *et al*., 2015). Dipteran flies are the primary arthropod vectors responsible for transmitting diseases in humans and various other animals. In numerous tropical countries, malaria stands out as a primary contributor to illness. Anopheles mosquitoes, comprising approximately 70 species, are estimated to be responsible for the transmission of 500,000 malaria cases each year. Aedes aegypti is the sole mosquito species that has the potential to transmit yellow fever. The vectors responsible for dengue, commonly known as break bone fever, are Aedes aegypti and Aedes albopictus (Duguma *et al*., 2020) [16].

The stability of an aquatic ecosystem heavily relies on its biodiversity. A variety of disruptions are increasingly exerting pressure on aquatic ecosystems. The current situation poses a threat to both human populations and aquatic life resources (Gavrilescu, 2021) [20]. Freshwater habitats are experiencing a notable decline in biodiversity, largely driven by human activities. The main factors consist of the introduction of non-native species, the destruction and fragmentation of habitats, and the impacts of global climate change. (and diversity of an ecosystem.

According to Watson *et al*. (1982) [62], odonates are considered to be a highly effective indicator of the current and historical (long-term) environmental conditions in aquatic ecosystems. In the tropics, Dipterans are the most common group of macrobenthic invertebrates. In addition to being eaten, aquatic *Hemiptera* also frequently serve as significant predators, giving them an intermediate position in the food chain. According to Lawrence (1982) [32], there are between 30,000–50,000 species of *Coleoptera*, or beetles, in existence. However, hundreds of thousands or even millions of species may be undiscovered. Currently, there are over 18,000 species of aquatic *Coleoptera*ns on the planet. Nearly 30 families comprise the incredibly diverse group of aquatic *Coleoptera*ns. According to Wazirani (1977), water beetles exhibit a great color, form, and life cycle variation. The biomass and diversity of stoneflies greatly benefits ponds. They serve as food for fish, especially those with significant commercial value, and other macro-vertebrates.

Plecoptera is a delicate order of Aquatic-Insects found only in environments with high dissolved oxygen levels, pure water, and minimal human involvement (Tamiru *et al*., 2017) [57]. *Trichoptera*, also called functional feeding groups (FFG) of animals, are significant organic matter processors exhibiting various eating behaviors.

Aquatic-Insects in biomonitoring

The systematic application of living organisms or their reactions to evaluate the state of an aquatic ecosystem is referred to as biological monitoring or biomonitoring (Ogidi *et al*., 2024) [39]. In assessing water quality, a diverse range of species is utilized, such as fish, algae, protozoans, and other groups; nonetheless, macroinvertebrates, primarily insects, are more frequently employed. Due to their widespread distribution and susceptibility to disturbances across various aquatic habitats, the numerous species that respond to different environmental stressors, their relatively sedentary nature compared to other aquatic organisms which facilitates precise assessment of the spatial extent of perturbation, and their long life cycles that enable the investigation of temporal changes in abundance and age structure, they serve as suitable and sensitive indicators of water quality and ecosystem health. We can learn about the condition of a stream, pond, river, or lake by looking at Aquatic-Insects. Because Aquatic-Insects are impacted by the physical, chemical, and biological parameters of the water body, they are useful markers of the quality of the water. They exhibit the combined effects of both short- and long-term pollution episodes and cannot escape contamination. They are very vulnerable to the dissolved oxygen content and other aspects of the water quality.

Numerous disturbances are putting more and more strain on aquatic ecosystems. Known as "keystone" species, the presence of mayflies in running streams is thought to be a significant predictor of oligotrophic to mesotrophic (low to moderately productive) conditions. The presence of saprophytic Dipteran species suggests that the water bodies are heavily contaminated and have poor-quality water, which is defined by low oxygen content and high nutrient concentration (eutrophic) (Karaouzas *et al*., 2018) [27]. Numerous chironomids that can withstand pollution are frequently a sign of low-quality water, defined by high fertilizer concentrations and low dissolved oxygen. Relatively low densities and significant species variety frequently indicate excellent water quality conditions. The high Chironomus sp. abundance in aquatic environments suggests that the water bodies are eutrophic. These insects are frequently used to measure the levels of pollutants in an environment since they can thrive in highly contaminated places. Whirling beetles, or Gyrinidae family members, inhabit freshwater ponds, lakes, and freely running streams, among other places. Crawling water beetles, or Haliplidae, live among aquatic vegetation on the margins of lakes, ponds, streams, and creeks (Ramin *et al*., 2022) [44].

Fishing of Aquatic-Insects

Because Aquatic-Insects play such a significant role in the diets of many fish species, including species that people frequently eat, the variety of these creatures is of great importance to humanity (Anankware *et al*., 2015) [1]. People who fish with artificial or natural baits have been particularly interested in them for a long time. For generations, fishermen have tried to mimic the shape and color of different Aquatic-Insects on hooks, often known as angles, hoping to deceive fish into swallowing them and becoming stuck. The most often copied species of insects include mayflies, caddisflies, stoneflies, and non-biting midges. The fish are shown larvae, pupae, and adults in ways that mimic their behavior as they develop on the bottom substrate, float with the current, emerge from the water, or return to the water as dying adults or egg-laying females. A stream's ability to support a wide variety of these insects, each with a distinct emergence period, ensures that fish have access to food for a significant portion of the year and at various times of the day.

Control of noxious weeds

In some places, several noxious, invasive weed species have caused issues by outcompeting native species, clogging otherwise navigable waters and water-intake infrastructure, and excluding species of food fish (Pearce, 2016) [42]. Insect herbivores have also been introduced with considerable success. However, herbicides are still frequently used to suppress these weeds. For instance, three significant herbivores—alligator weed thrip, alligator weed flea beetle, and alligator weed stem borer—have been effective in controlling alligator weed (*Alternanthera philoxeroides*), an invasive invader from South America in the United States. Another example is how two imported species of weevils (*Coleoptera*: Curculionidae) and one imported species of moth were able to successfully control the invasive Brazilian species known as common water hyacinth (Eichhornia crassipes). It is possible to research to find aquatic insect species that could aid in suppressing or eradicating weeds.

Forensic Entomology

When it comes to drowning situations, such as significant and almost certainly unintentional deaths from submersion, Aquatic-Insects play a critical role in forensic investigations (Wallace, 2019). A few Aquatic-Insects that are highly helpful in a death inquiry are Anax Parthenope, Lestes Sponsa, Scarlet Skimmer, etc. When looking at submerged bodies of Aquatic-Insects, it typically takes a team effort and the knowledge of several authorities, especially when working with natural water bodies. *Diptera*, commonly known as true flies, play a crucial role in forensic investigations. The Calliphoridae, Sacrophagidae, and Muscidae represent the most prevalent species within this classification. Sacrophagidae (meat flies) and Calliphoridae (blow flies) might show just minutes after death. House flies, or Muscidae, do not begin colonizing a body until the final stages of decomposition (Joseph *et al*. 2011) [25].

Importance as vector

These insects are crucial in the spread of several diseases that affect both humans and animals. Certain aquatic bug species are significant medical vectors, carrying diseases like dengue, yellow fever, malaria, filariasis, and certain other significant parvoviruses (Subramanian, 2023) [54]. Moreover, a small percentage of them bite humans and animals painfully, causing dermatological problems. According to Chae *et al*. (2000) [8], some serve as hosts for trematods such as damselflies and dragonflies. Due to their ability to spread a parasitic flatworm of Prosthogonimus species, dragonflies are viewed as a hazard to the poultry sector in several countries.

Environmental threats to Aquatic-Insects

Insects that live in water are also susceptible to many other human-caused conditions. Many of these insects are highly sensitive to water quality because they can survive for several years underwater (Deacon *et al*., 2019) [14]. Scientists may use a biodiversity index to track the quality of a stream by looking at the present species composition. For example, the presence of stoneflies suggests a healthy stream because they are known to have a low tolerance for poor water quality. However, since worm-like creatures and fly larvae are highly tolerant of low water quality, pollution may arise if the stream is solely home to these creatures. A few things that can lower water quality are people throwing different types of liquids down city storm drains, runoff from improperly drained regions, and ecosystem changes near streams.

Pesticides (water pollution): Agricultural regions can be particularly problematic since excess silt from rain may wash into streams from runoff of fertilizers and pesticides. Insects find it more difficult to breathe, hunt, and find cover when these sediments cover the streambed and darken the water. Moreover, the stream's ecosystem may change if the surrounding habitat is altered. The typical dynamics of the food chain can be disrupted when a forest is cleared and leaf litter is eliminated from the ecosystem, leading to a decrease in the decomposition of organic matter within the stream (Kadiru *et al*., 2022) [26].

Industrial pollution: Activities such as the discharge of industrial effluents, agricultural methods, challenges in urban waste management, and the rise of urbanization have significantly threatened the freshwater ecosystem in recent years (Meijide *et al*., 2018) [34]. The regular functions of aquatic ecosystems, such as feeding and reproduction, have been influenced by climate change's effects on abiotic factors like temperature and precipitation. Pollution levels have substantially impacted the environments of underwater flora and fauna. Girgin *et al*. (2010) [22] investigated the relationship between several heavy metals, including cadmium, lead, copper, zinc, nickel, iron, manganese, and boron, and various aquatic insect species such as *Ephemeroptera*, *Plecoptera*, *Trichoptera*, and *Odonata*. They found that if heavy metal contamination was high, these insect orders might not exist in aquatic conditions.

Climate change: A Potential Threat

The climate system's internal variability and external factors—man-made and natural— such as rising greenhouse gas concentrations in the atmosphere and natural phenomena like solar radiation, cloud formation, and rainfall—cause variations in the climate. Other components of the environment, such as wind patterns, temperature extremes, average continental temperatures, ocean warming, and sea level rise, are also impacted by human activity (IPCC, 2007) [24]. Variations in climate have an impact on aquatic systems, which in turn affects how organisms are distributed ecologically. Whether a variation is predictable or unpredictable will determine how it affects species diversity under different climate conditions. The latter might affect species richness and the systems in more intricate ways.

the frequency, magnitude, and period of the runoff regime; temperature; and alterations in water chemistry, encompassing nutrient concentrations and suspended organic matter loadings, are the three principal environmental factors that affect the scope and scale of ecological impacts stemming from changes in the climate in freshwater ecosystems. Throughout their life cycle, Aquatic-

Insects experience influences from variations in the hydrological regime and temperature (Sandin *et al*., 2014) [50]. *Plecoptera*n nymphs typically inhabit clear, cold streams characterized by elevated levels of dissolved oxygen and a variety of substrates, such as pebbles, cobbles, and leaf litter. The characteristics of the substratum, the prevailing conditions, the presence of other species, and variations in water temperature and chemistry, along with various environmental factors, all play a role in shaping the specific microhabitat.

Due to the unjustified increase in the global mean temperature, refugial habitats characterized by thermal stability and low-nutrient, oxygen-rich waters are in danger (Fonnesu *et al*., 2005) [19]. Certain delicate species may not always be able to withstand the conditions brought on by naturally occurring mild to moderate climate changes, even if most freshwater organisms have evolved with particular features to do so. Aquatic-Insects are thought to have dispersal rates that may be adequate to keep up with climate change. Dispersal capacity and pace are crucial qualities in adjusting to environmental changes. However, many other freshwater invertebrates tend to disperse across drainages at very sluggish rates, which is probably too slow to keep up with the predicted pace of climate change in current models.

Approaches to Aquatic-Insects' conservation

Conserving freshwater systems throughout the entire catchment is a key management goal. Headwater stream and high-elevation pond conservation for unique insects are particularly essential locally (Richardson, 2019) [46]. Historic seasonality and physiochemical water conditions must be preserved, as well as the landmark river movements. Location-specific factors are also important, including protecting open water areas and promoting the quality and diversity of macrophyte and riparian/bank vegetation for adult Aquatic-Insects, as well as considering river network connectivity, sensitive land use, topographic heterogeneity, and biotic interactions. Avoid channelization because it produces local hydrological shortage and drastically decreases insect diversity. On the plus side, it is important to maintain substrata rich in organic matter and to establish artificial, shallow, and well-vegetated shorelines, as these factors also boost insect diversity. It is important to recover the historical vertebrate engineers, particularly beavers. While alien trees can occasionally take the place of native trees that are lost, foreign trees should usually be eradicated to improve insect habitat significantly. Many terrestrial and Aquatic-Insects now depend on the preservation of floodplains, the preservation or restoration of intact hydrology, the careful management of salty systems, and the preservation of gravel bars (Samways *et al*., 2020) [49].

As with other systems, connectivity is crucial for freshwater systems as well. This is especially true for the several ponds that comprise a pondscape network. High-quality pondscapes should have a high degree of variety, connectedness, and size variation inside the pond and a high degree of functional connection between the ponds and the deposition pools of streams and rivers. Maintaining the natural dynamics of freshwater systems is crucial for enhancing the diversification of insects and flora. As part of pondscape heterogeneity, it is essential to preserve a range of ponds, both permanent and ephemeral, as well as deposition pools of streams, since certain aquatic insect species are adapted to short hydroperiods.

Ephemeral ponds can be colonized by some Aquatic-Insects from permanent ponds and pools, which serve as their source habitat. Around ponds, buffer strips are placed to lessen the impact of cultivation. On the other hand, well-thought-out artificial ponds, superior irrigation ditches, and stormwater ponds can offer beneficial additional habitat for insects found in marshes. Both agricultural and urban ponds benefit from increased natural vegetation variability, but city ponds also benefit from raising awareness of insect conservation. Consequently, there exists significant potential for enhancement regarding artificial ponds, and doing so will enhance the pondscape or the functional interconnection of ponds throughout the landscape. Certain man-made landscapes, such as garden ponds, golf course roughs, and military training zones can greatly enhance aquatic insect conservation. A few unique situations exist that are important for conserving Aquatic-Insects. Strategies such as the biological control of invasive aquatic vegetation, the restoration of mining pools, the careful management of Sphagnum bogs, the removal of non-native predators like fish, the construction of physical barriers to redirect specific threatened flying species, and the implementation of designated paths and duckboards to reduce tourist impact in sensitive habitats exemplify effective conservation efforts (Samways *et al*., 2020) [49].

Demand for a fresh cohort of specialists in Aquatic-Insects

Young people today tend to spend more time indoors, indirectly learning about the natural environment through technological media, and less time outdoors in rural forests, ponds, and streams (Cottrell and Cottrell, 2020) [10]. They, therefore, appear less likely to pursue jobs in biodiversity research or natural settings. Less emphasis is placed on identifying and studying living things in nature, with a greater focus on molecular principles and methodologies in biological instruction and research at secondary schools, colleges, universities, and research facilities. These trends have led to a decline in the number of professional entomologists who are knowledgeable about aquatic insect species and who are eager to learn about their biological traits, applications, and strategies for managing pest species. As we have seen, the ability to discover new species is dwindling just when biodiversity discovery is most needed historically—before many species go extinct. There is an urgent need for a substantial shift in focus toward better job prospects in biodiversity discoveries and toward education and research on biodiversity for today's youth. This shift is likely to happen as we learn more about the benefits of living in a biologically varied world and how to deal with the difficulties a few species provide us.

Conclusion

Recently, the preservation of natural resources and biodiversity has gained significant importance in pursuing an environmentally sustainable future. However, numerous taxa have historically been ruled out as potential indicators due to a lack of data. Their use is becoming more appropriate due to more studies on the habitats and distribution patterns of specific Aquatic-Insects. Because they respond differently to stimuli in their aquatic home, Aquatic-Insects are helpful in monitoring the health of aquatic habitats and assessing the quality of those settings. Aquatic entomologists are working hard to create new and improved methods of biomonitoring utilizing Aquatic-Insects.

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