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Chapter [19]

Aquatic insect's biodiversity: Importance and their conservation

K. Elango[1,*], G. Vijayalakshmi[1], P. Arunkumar[2], E. Sobhana[3] and P. Sujithra[3]

[1]Department of Agricultural Entomology, Division of Plant protection, Imayam Institute of Agriculture and Technology Thuraiyur 621206, Tamil Nadu, India
[2]Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore 641003, Tamil Nadu, India
[3]Department of Agronomy, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai 625104, India

Abstract

Insects are important representatives of the biodiversity of ecosystems. A majority of the insect species lives in freshwater environments, such as swamps, ponds, lakes, springs, streams and rivers these are called aquatic insects. There are about 8600 species of insects, falling under 12 orders, 150 families, known to inhabit diverse freshwater ecosystems. They play important ecological roles in keeping freshwater ecosystems functioning properly. There are many different kinds of aquatic insects as almost every type of freshwater environment habitat from puddles to river to lakes, including both lentic and lotic habitats, can belong to various species of aquatic insects. Aquatic insects are considered as model organisms in analyzing the structure and function of the freshwater ecosystem because of their high abundance, high birth rate with short generation time, large biomass and rapid colonization of freshwater habitat. The aquatic biodiversity gets affected by several factors such as industrial pollution or anthropogenic activities. Hence, this chapter is discussing about the diversity, habitats, roles, constraints and conservation of aquatic insects.

Keywords Aquatic, Biodiversity, Conservation, Ecological indicator, Insects

K. Elango, Email: elaento@gmail.com (*Corresponding author)

Introduction

India is one of the mega diverse countries, with a notable diversity of aquatic habitats of about 3,166,414 Km^2 with significant variations in rainfall, altitude topography and latitude. Insects are the most diverse group of organisms in freshwater. Estimates on the global number of aquatic insect species derived from the fauna of North America, Australia and Europe is about 45,000, of this about 5,000 species are estimated to inhabit inland wetlands of India (Amaravathi *et al*., 2018; Rao *et al*., 2020). Aquatic insects of inland wetlands comprise some well-known groups like mayflies (Ephemeroptera), dragonflies (Odonata) and caddiesflies (Trichoptera). Aquatic insects such as dragonflies and damselflies (Odonata) are very colourful and prominent insects of the wetlands. Different functional feeding groups of aquatic insects such as shredders, scrapers, filter feeders and predators are important links in nutrient recycling (Subramanian and Sivaramakrishnan, 2007; Collins, 2012). Aquatic insects primarily process wood and leaf litter reaching the wetland from the surrounding landscape. Nutrients processed by aquatic insects are further degraded into absorbable form by fungal and bacterial action. Plants in the riparian zone absorb this nutrient soup transported through the wetlands. In addition to this significant ecosystem function, aquatic insects are also a primary source of food for fishes and amphibians.

Evolution of aquatic insects

The origin of aquatic insects has been controversial and doubts still exist as to whether or not insects are primarily or secondarily adapted to aquatic environments. The widely accepted view is that the ancestor of myriapod-insect group (millipedes, centipedes, and insects) lived in leaf litter areas along margins of pond like environment. Primitive insects of this moist environment were ancestors of aquatic insects (Sharma *et al*., 2020). Their fossil record extends to Devonian in the Paleozoic era. Among extend aquatic insects, dragonflies (Odonata) and mayflies (Ephemeroptera) are the most primitive and only insects with aquatic juveniles. The understanding of aquatic insect evolution and phylogeny has been hampered by poor fossil record of freshwater animals. Living aquatic insects represent 12 insect orders (Figure 1). Of this, larvae of species of mayflies (Ephemeroptera), dragonflies and damselflies (Odonata), stoneflies (Plecoptera), alderflies (Megaloptera), lacewings (Neuroptera), flies (Diptera), caddiesflies (Trichoptera), moths (Lepidoptera) and wasps (Hymenoptera) are aquatic with terrestrial adults Larval or nymphal and adult stages of aquatic beetles (Coleoptera) and bugs (Hemiptera) are fully aquatic (Subramanian and Sivaramakrishnan, 2007).

Aquatic insects' orders

Colembola: A small group of six legged arthropods that have a specialized tail that allows them to spring from place to place. Common around vegetation and quiet edge waters. Usually found on o near

Figure 1. Important aquatic insect orders in aquatic ecosystem.

the water's surface.

Ephemeroptera: Mayflies are some of the best-known aquatic insects. Massive hatches are common near Lake Erie that require shovels to remove the dead carcasses from the streets. Mayflies live in both lentic (lakes) and lotic (rivers) systems, however because of their breathing mechanisms heavily silted and polluted streams and lakes are usually void of mayflies.

Odonata: Dragonflies and Damselflies are some of the most distinct aquatic insects. They are usually associated with vegetation and are commonly found in wetlands and backwaters of streams and lakes. They are predators of other insects and even small fishes. They are easily identified by a special mouth-part that protrudes out from their body to capture prey from a distance. The adults are beneficial because they feed on large amounts of mosquitoes.

Plecoptera: Stoneflies are found primarily in streams. They require a larger supply of oxygen to survive than other aquatic insects. Stoneflies can often be seen doing "pushups" after capture by humans in order to stimulate water movement along their bodies to increase oxygen flow. These insects are nearly absent from degraded and polluted streams.

Hemiptera: Many people may know these as water striders, commonly seen on the water surface skating quickly around. These insects are highly predacious on other insects and can put quit a toll on some species such as the larval stage of mosquitoes and other diptera. Water striders are not the only species in this order, others include the back swimmers and giant water bugs. Giant water bugs are also known as fish killers because they have been known to attack small fish and even ducklings. Others might know them as toe biters or stabbers because of what they might do to an unsuspecting bare foot while creeking.

Megaloptera: Smallmouth fisherman may be familiar with this order which includes hellgrammites, a ferocious looking insect that can reach 3 or more inches with giant pincher mouthparts. These are common in riffles of streams and rivers. Other alderflies are common to backwaters and areas with heavy organic matter in the water.

Neuroptera: Closely related to the megaloptera, this order is mainly terrestrial, however, there is a small group of aquatic species that are found only in conjunction with freshwater sponges of which these small insects feed upon. This is a very minor order.

Trichoptera: Caddisflies are an interesting order of insects because they build casing to hide in. They place these under and on rocks using a sticky webbing to keep tem together, some even use webs to capture food. These casings are specific to each family and many can be identified by just the casing because of the shape or type of material used in construction.

Lepidoptera: Most butterfly and moth larvae are terrestrial; however, there are a few that have an aquatic larval stage. These caterpillars are closely related to vegetation in the water, from which they feed upon. Some aquatic caterpillars are harmful to rice patties and water lilies, however some may have potential to be biological controls for invasive or pest aquatic plants.

Coleoptera: Beetles are one of the most diverse order of aquatic insects. Some only have larval stages in the water, while others also live in the water as adults. Some may know one family as whirligig beetles, the little round bugs one sees spinning around in circles on the surface of the water. There are also water pennies that are found stuck to rocks that resemble a small flat circle crawling around amongst the algae. Beetles can be found in all aquatic habitats.

Hymenoptera: Hymenoptera includes terrestrial species such as ants, bees and wasps. There are a few wasps, however, that are parasitic to aquatic species and therefore dive underwater to lay their eggs. Some families lay their eggs in midges or water pennies, others lay their eggs in fishing spiders. As the larvae develop, they eat the parasitized individual fornourishment.

Diptera: The true flies are found in every aquatic habitat imaginable from water left in an abandoned tire to the most pristine mountain stream, from the depths of a lake to the riffles of a stream, brackish to fresh water they all contain fly larvae. The best-known fly larvae would be that of mosquitoes, however, one of the most important larvae ecologically are that of midges. Many may feed these to their fish known as blood worms. Blood worms are the favorite food of yellow perch, trout, darters and many other fish species (Voshell, 2002).

Morphological and physiological adaptations

Aquatic insects have tackled the problem of living in aquatic environment by evolving various morphological and physiological modifications.

Air-tubes: To obtain atmospheric oxygen, cutaneous and gill respiration, the extraction of air from plants, hemoglobin pigments, air bubbles and plastrons. Air-tubes are present in aquatic bu (Hemiptera) and files (Diptera) restricting their activity to water surface (Subramanian and Sivaramakrishnan, 2007).

Cutaneous and gill respiration: It is widespread in the immature stages of most of the aquatic insects. This helps them to live among submerged substrates. Adult beetles and bugs often respire by the use of an air bubble. Some species use plastron (a system of microhairs or papillae) that hold an air film (Buck, 1962; Subramanian and Sivaramakrishnan, 2007).

Plastron respiration: Helps these insects to stay longer under water. Chironomid (Diptera) larvae living in eutrophic aquatic habitats survive in low oxygen levels through the use of haemoglobin pigments. One of the major physical forces faced by aquatic insects of running waters is water current (Thorpe, 1950).

Aquatic insect morphology: In running waters, aquatic insect morphology is closely related to hydraulic stress and the necessity to remain in close contact with the substrate. A diverse range of body modifications are present in aquatic insects. Modifications such as flattening of body, streamlining, reduction of projecting structures, suckers, friction pads, hooks, silk and sticky secretions are widely present in different groups of insects. Morphological adaptations are closely followed by behaviour adaptations. Aquatic insects avoid water current by burrowing into the substrate or occupying a space in the substrate with minimum hydraulic stress such as rock crevices or under the rock (Havel and Shurin , 2004)

Life cycle adaptations: Aquatic insects have evolved diverse life history strategies to suit their environment. Many temporary pool breeding species have egg stage which can remain in total dry condition (eg: *Aedes)*. In many species of caddies flies a gelatinous egg mass matrix protect the eggs and larvae from desiccation and freezing for months together. Some species have staggered hatching which prevents overcrowding of newly hatched larvae. Very few aquatic insects have adapted to a completely submerged life cycle (Pritchard *et al*., 1996). Most of the aquatic insects spend atleast one part of their life cycle in terrestrial habitat. A major problem in being completely submerged is respiration. Many species have developed morphological and physiological adaptations to survive in particular oxygen concentration. The distinction is being very evident in running and standing water, where the former is very well oxygenated than the latter. This is one important factor that determines the distribution of groups like mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddiesflies (Trichoptera). These groups depend upon dissolved oxygen and achieve their maximum diversity in running water. Among holometabolous aquatic insects, aquatic pupa is found in caddiesflies (Trichoptera), flies (Diptera) and aquatic moths (Lepidoptera). Aquatic beetles, alderflies (Megaloptera) and lacewings (Neuroptera) have semi aquatic or terrestrial pupa (Lancaster and Downes, 2013). During the course of life, aquatic insects encounter diverse physical environmental conditions, the most pronounced being temperature. The temperature varies daily and seasonally. This variation in temperature affects emergence pattern of aquatic insects. In tropics because of relatively constant temperature, many pool breeding species show continuous emergence throughout the year. However, in the Western Ghats, most of the stream breeding species emerge during pre- and post-monsoon months. Some species in tropics follow an emergence pattern coinciding with phases of moon.

- Slow season life cycle - Mayflies, Stoneflies, And Caddis flies
- Fast season life cycle - Caddis flies and dragonflies
- Non seasonal life cycle - Hellgrammites

The presence of diapausing egg and pupa are important life history evolutions that help insects to survive unfavorable conditions (Merritt and Wallace, 2001). Aquatic insects complete single or multiple generations during a year. Some tropical species have life cycle greater than a year. Life cycle completion time for a species varies with altitude and latitude.

Feeding strategies: Essentially all aquatic insects are omnivorous, at least in their early instars. Species which use similar morpho-behavioral mechanisms for food acquisition have evolved similar mouth parts. This has facilitated classification of aquatic insects to functional feeding groups, which is equivalent of guild. The "functional group" approach reflects both convergent and parallel evolution leading to functionally similar organisms. Mouth parts, legs and other morphological structures or constructed devices (silk nets) together with associated feeding behaviour may change with larval development. Widely recognized functional groups are shredders, collectors, scrappers, predators and piercers (Ramírez and Gutiérrez-Fonseca, 2014).

Scrapers: Scrapers have special mouthparts that remove algae growing on the surface of rocks or other solid objects. These mouthparts work like a sharp blade to remove the outermost layer of algae, which is attached very tightly but is very nutritious for those insects equipped to remove it.

Collectors: Collectors acquire small pieces of decaying plant material (detritus). Some kinds use long hairs on their head or legs or silk nets to filter these small particles out of the water. Other kinds of collectors use their mouthparts to gather fine particles lying on the bottom and shove this material into their mouths.

Shredders: Shredders have mouthparts that are designed to nibble of pieces of soft vegetation, such as leaves, flowers, or twigs, and grind up this material. Most aquatic insects shred pieces of vegetation that have dropped of plants and are decaying. Most of this material comes from trees and shrubs that grow on land at the edge of the water. Only a few kinds of aquatic insects feed on parts of live plants that grow under the water.

Predators: Predators feed on other animals that are alive. Predators often have special structures for catching and subduing their prey, such as strong jaws with teeth, a sharp beak, or spiny legs. Predators eat other invertebrates most of the time, but some are large and strong enough to catch small vertebrates, such as fish and tadpoles (Mary *et al*., 2015).

Aquatic insects and their habitats

Aquatic insects are adapted to either running waters (streams and rivers) or standing waters (ponds and lakes). These habitats can also be viewed as erosional habitats frequently colonize lake shorelines. Similarly, many species of depositional habitats are common in flood plain pools and backwaters. The habitats for the aquatic insects can be visualized within the framework of various spatial -temporal scales. At a spatial scale, it ranges in size from particles of few millimeters to the entire drainage basin, which extends to squares of kilometers. Temporally, the changes in the habitats can be visualized from days to thousands of years. The permanence of the physical structures of the habitats varies with the spatial scale. This ranges from few days for individual grain and microhabitat to thousands of years for the drainage network. Insect communities of the wetlands respond to this spatial temporal variation as well. Within a given habitat, aquatic insects maintain their location by clinging, swimming, skating or burrowing into the habitat (Hershey *et al*., 2010).

Distribution of aquatic insects within a habitat is determined by intricate interplay between substrate, flow, turbulence and food availability. The habit (mode of locomotion, attachment or concealment) of a given species determines the frequency of movement within the habitat Substrate, an important physical component of habitat is very complex. The water current and the nature of the available parental material determine the physical nature of the substrate. The organic detritus adds complexity to the substrata and can strongly influence the organism’s response to the substrate. It has been established across continents and biomes that the faunal composition changes with the substrate. Sand is a relatively poor habitat with low (streams and rivers) or depositional (ponds and lakes). Both stream/ river currents and lake shoreline waves create erosional habitats while lake basins, river flood plain pools and stream/river backwaters provide depositional conditions. Species adapted to erosional abundance and diversity (Subramanian and Sivaramakrishnan, 2007). Relatively, the diversity is high in silty sand and biomass may be high and diversity low in muddy substrata. The presence of sand and silt reduces and changes fauna. At least in stony substrata it is known that the space available for colonization determines species abundance. In general, diversity and abundance increase with substrate stability and the presence of organic detritus (Collins, 2012).

Societal benefits of aquatic insects

A high diversity of aquatic insect species is of value to humans and animals for a variety of reasons, out of which four are particularly important. They are the role of these insects in food webs, biomonitoring, fishing, and controlling noxious weeds (Nair *et al.,* 2015).

Food webs: A high abundance (or density) of aquatic insects helps assure the processing of large amounts of nutrients. A high diversity (or taxa richness) of aquatic insects helps assure diversity of resources and ecosystem services (e.g., nutrients, habitats) and effective use of all available resources in both space and time.

Aquatic insects in biomonitoring: Biological monitoring or biomonitoring is the systematic use of living organism or their responses to determine the health of aquatic ecosystem. Fish, algae, protozoans, and other groups of organisms is being used in water quality assessment but macro invertebrates which largely consist of insects are more frequently used. They are suitable and sensitive indicators of water quality and ecosystem health because: (1) they are ubiquitous and, consequently affected by perturbations in many different aquatic habitats; (2) the large number of species respond to a range of environmental stress; (3) their sedentary nature relative to other aquatic organisms permits effective determination of spatial extend of perturbation; and (4) long life cycles allow to examine temporal changes in abundance and age structure (Bonada *et al*., 2006).

Aquatic insects allow us to know about the health of a stream, pond, river or a lake. Aquatic insects are good indicators of water quality because they are affected by the physical, chemical, and biological conditions of the water body. They cannot escape pollution and show the collective effects of short- and long-term pollution events. They are particularly sensitive to the water quality like the amount of dissolved oxygen. Aquatic ecosystems are under increasing pressure from various kinds of disturbances (Tachet *et al.,* 2003).

Mayflies are considered as "keystone" species and their presence is believed to be an important indicator of oligotrophic to mesotrophic (low to moderately productive) condition in running waters. Presence of saprophilic species of diptera indicates that water bodies are grossly polluted with poor water quality characterized by low oxygen and high nutrient concentration (eutrophic). Large numbers of pollution tolerant chronomids are often indicative of poor water quality (characterized by low dissolved oxygen and high nutrient concentrations). Excellent water quality conditions are often characterized by relatively low densities and high species diversity. The high abundance of *Chironomu*s sp. in aquatic body indicates eutrophic nature of water body. These bugs, since they can survive in heavily polluted areas, are often used to gauge the toxins in an environment (Papacek, 2001; Wollmann, 2001). The members of family Gyrinidae (whirling beetles) are found in fresh water ponds, lakes, open flowing streams etc. The members of Haliplidae (crawling water beetles) live among aquatic vegetation along the edges of ponds, lakes, streams and creeks.

Fishing of aquatic insects: Aquatic insect biodiversity is of considerable interest to society because these animals are so important in the diets of many fish species, including species that are commonly consumed by humans for food. People who fish with natural or artificial baits have long had particular interest in them. Anglers for centuries have attempted to imitate the form and colour of various aquatic insects on hooks (or angles) in the hope of tricking fish to swallow them and become snagged. Mayflies, caddisflies, stoneflies and non-biting midges have been grouping whose species are most commonly imitated. Larvae, pupae and adults are imitated and presented to the fish in ways intended to replicate the behaviour of those forms as they grow on the bottom substrate, drift in the current, emerge from the water surface, or return to the water as egg-laying females or dying adults. A high diversity of these insects in a particular stream, each with its own specific emergence time, assures that food is available to the fish through much of the year and through different times of day.

Control of noxious weeds: Several species of noxious, invasive weeds have become problems in parts of the world where they out-compete native species, clog otherwise navigable waters and water-intake structures, and exclude food-fish species. Herbicides often are employed to control these weeds, but some success also has resulted from the introduction of insect herbivores. For example, in the USA, alligator weed (*Alternanthera philoxeroides*), an invasive species from South America, has been controlled successfully by three important herbivores: alligator weed stem borer, alligator weed flea beetle and alligator weed thrip. Another example is the successful control of commo water hyacinth (*Eichhornia crassipes*) an invasive species from Brazil, by two imported species of weevils (Coleoptera: Curculionidae) and one species of imported moth. Studies can be attempted to discover species of aquatic insects that may help reduce or eliminate weeds.

Forensic Entomology: The importance of aquatic insects in terms of Forensic Investigation can be very much useful in Drowning cases like death due to submersion which is substantial which is most probably accidental. Aquatic insects like Anax Parthenope, Lestes Sponsa, Scarlet Skimmer, etc. are a few which are very much useful in a death investigation. The investigation of submerged bodies in context with aquatic insects usually requires a coordinated effort and the expertise of multiple agencies especially dealing with natural water bodies. Insects mostly involved in the forensic investigations are true flies or Diptera. The predominant species in this order are Calliphoridae (blow flies), Sacrophagidae (flesh flies) and Muscidae (house flies). Calliphoridae (blow flies), Sacrophagidae (flesh flies) may arrive within minutes following death. Muscidae (house flies) delay colonization until the body reaches bloat stages of decomposition (Joseph *et al*. 2011).

Environmental threats to aquatic insects

Aquatic insects are also vulnerable to a wide range of human-induced factors. Because they live for several years under water, many of these insects are extremely sensitive to water quality. In fact, the assemblage of species present can serve as an indicator of the stream's health, and scientists can monitor stream quality using what is called a biodiversity index. For example, stoneflies are known to have low tolerance to poor water quality, so the presence of stoneflies indicates a healthy stream. If the stream only contains worm-like animals and fly larvae, however, it may be experiencing pollution problems, as these animals have high tolerance to poor water quality. Some factors that can reduce water quality include trash dumping near streams, runoff from areas with improper drainage, city storm drains where people dump a variety of liquids, and changing habitat around the stream.

Pesticides (water pollution): Agricultural areas can be especially problematic, as fertilizers and pesticides may leach into the stream, and rain may wash an excess of sediments into the stream. As these sediments cover the streambed and darken the water, they make it difficult for insects to breath, hunt, and access shelter. Furthermore, changing the habitat around the stream can alter the stream's ecosystem. When a forest is cleared and leaf litter ceases to enter the system, there may be less decaying organic matter in the stream, changing the natural flow of the food chain.

Industrial pollution: In recent years, freshwater ecosystem has experienced serious threats from human activities such as industrial effluents, agricultural activities, urban waste management issues, and increase in urbanization (Meijide *et al.*, 2018; Zhu *et al.*, 2018). In addition, climate change impacts resulting changes in abiotic factors such as precipitation and temperature levels have affected the normal function of aquatic ecosystems including reproduction and feeding. These pollution levels have also affected the habitats of aquatic flora and fauna (Schmeller *et al.*, 2018). Relationship between some aquatic insect species (Ephemeroptera, Plecoptera,Trichoptera and Odonata) and some heavy metals (cadmium, lead, copper, zinc, nickel, iron and manganese) and boron studied by Girgin *et al*. (2010) and reported that if contamination was high due to this heavy metals there may be absence of this insect orders in aquatic condition (Figure 2).

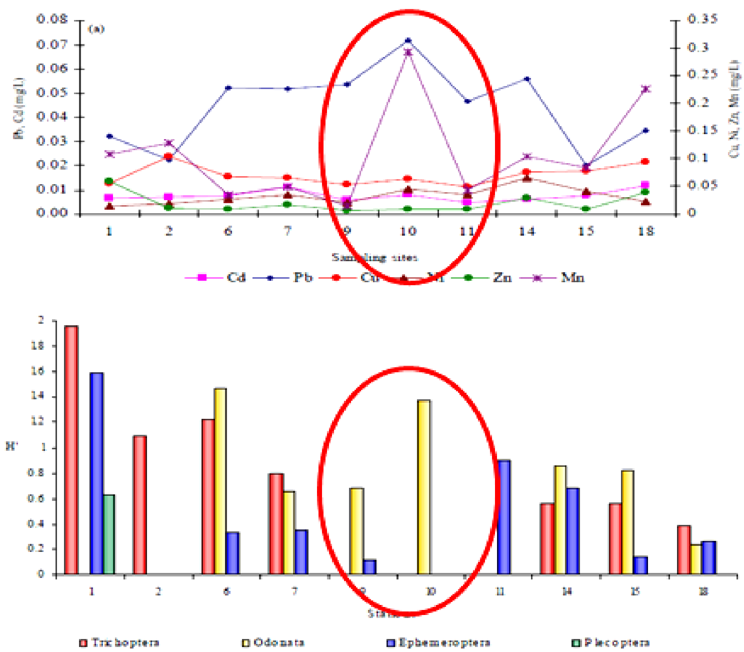

Figure 2. Relationship between heavy metals and aquatic insects (Girgin *et al*., 2010).

Climate change as a potential threat: Changes in climate occur as a result of internal variability of the climate system and external factors (both natural factors such as solar radiation, cloud formation, and rainfall and those resulting from human activities, including increased concentrations of greenhouse gases) in the atmosphere (Figure 3). Impacts of human activities also extend to other aspects of climate, including ocean warming and sea level rise, continental average temperatures, temperature extremes and wind patterns (IPCC, 2007) Aquatic systems are influenced by the changing climatic conditions which in turn determine the ecological distributions of organisms (Vannote and Sweeney, 1980; Li *et al*., 2013). The effects of climate variations on species diversity depend on the nature of variation, whether it is predictable or unpredictable. The latter could have more complicated effects on species richness and the systems. The degree and extent of the ecological consequences of climate change in freshwater ecosystems depend largely on the rate and degree of change in three primary environmental drivers: the timing, degree and duration of the runoff regime; temperature; and alterations in water chemistry such as nutrient levels and particulate organic matter loadings (Rouse *et al*., 1997; Vincent and Hobbie, 2000; Poff *et al*., 2002). Aquatic insects are affected by alternations in temperature and hydrological regime during their entire life cycle (Chen *et al*., 2011; Sandin *et al*., 2014). Plecoptera as nymphs generally prefer cool and clear streams with high dissolved oxygen content and substrates that vary from leaf litter, cobbles, and rocks. However, the specific microhabitat depends on a variety of environmental factors such as the nature of the substratum, current regime, presence of other organisms, and local variations in water chemistry and temperature (Jonsson *et al*., 2013). Refugial habitats characteristic of thermal stability with low-nutrient and oxygen rich waters are under threat owing to the effect of the undue raise in global mean temperature (Fonnesu *et al*., 2005). Though most of the freshwater organisms are adapted with specific traits to survive the conditions caused by naturally occurring mild to moderate climate variations, it is not always possible for certain sensitive species.

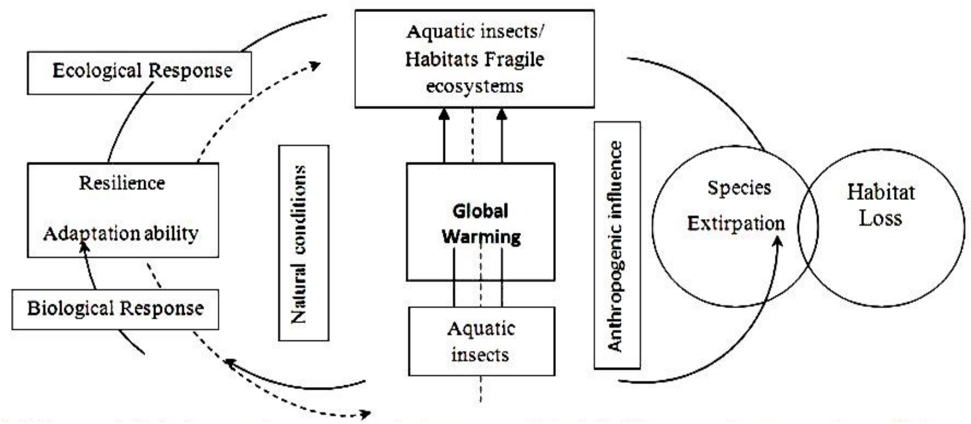

Figure 3. Effects of global warming on aquatic insects (Sundar and Muralidharan, 2017).

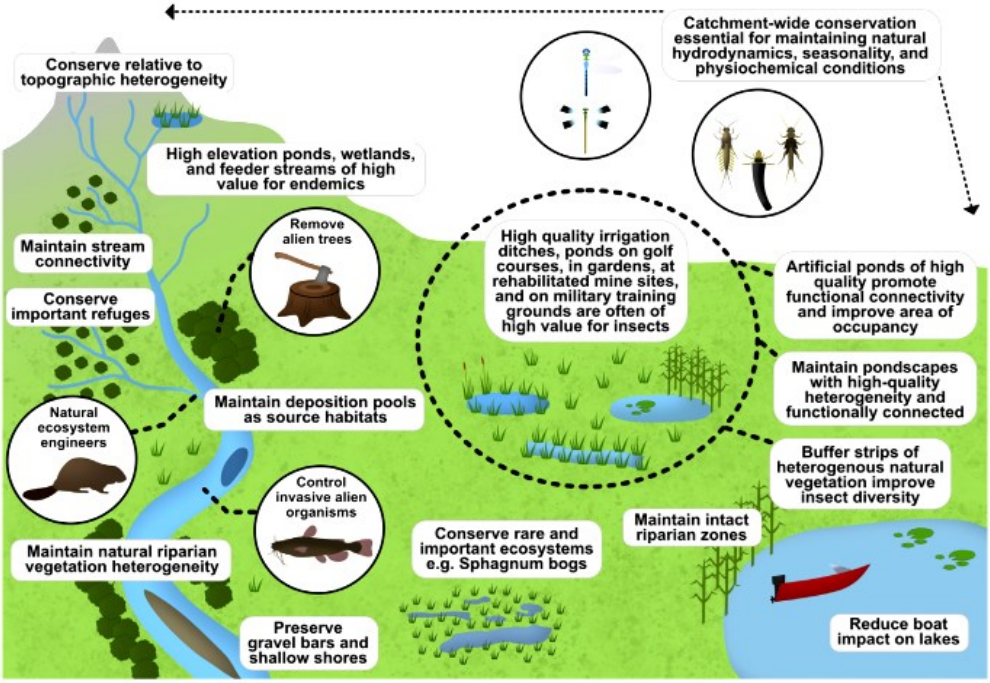

Figure 4. Essential components for aquatic insect conservation (Samways *et al*., 2020).

Dispersal ability and rate are essential traits in adapting to environmental changes, aquatic insects are said to have dispersal rates that may be sufficient to keep up with climate change (Havel and Shurin, 2004). However, the dispersal rates of many other freshwater invertebrates across drainages appear to be very slow (Strayer, 2006) almost surely too slow to keep up with the pace of climate change that current models predict.

Approaches of aquatic insects conservation

Catchment-wide conservation of freshwater systems is an important management objective. At the local level, conservation of headwater streams is particularly important, as are high-elevation ponds for endemic insects. Maintenance of historic river dynamics is essential, including historic seasonality and physiochemical water conditions (Figure 4). Also important are location-specific factors such as consideration of river network connectivity, sensitive land use, topographic heterogeneity, and biotic interactions, as well as promotion of macrophyte and riparian/bank vegetation quality and diversity for adult aquatic insects as well as protecting the areas of open water. Channelization should be avoided as it greatly reduces insect diversity and causes local hydrological drought. On the positive side, artificial, shallow and well vegetated shorelines should be created, while also maintaining substrata that are rich in organic matter, both of which increase insect diversity. Historic vertebrate engineers, especially beavers, should be recovered. Although alien trees sometimes can be a substitute for loss of indigenous trees, in general alien trees must be removed, leading to considerable insect habitat improvement. Maintenance of floodplains and ensuring gravel bars are intact has become crucial for many terrestrial as well as aquatic insects, as is maintaining or restoring intact hydrology, and careful management of saline systems (Samways *et al*., 2020).

Connectivity is important for freshwater systems as it is for other systems, most importantly for many ponds making up a pondscape network. Pondscapes should be of high quality, with high pond heterogeneity, connectivity and size variation, as well as high functional connectivity among each other and to deposition pools of streams and rivers. It is important to maintain natural dynamics of freshwater systems in general for improved vegetation and insect heterogeneity. However, as some aquatic insect species are adapted to short hydroperiods, it is necessary to retain a variety of both permanent and ephemeral ponds and deposition pools of streams as part of pondscape heterogeneity. In turn, for some aquatic insects, permanent ponds and pools can be source habitats from which to colonize ephemeral ponds. Buffer strips instigated around ponds mitigate the effects of agriculture.

In turn, well-designed artificial ponds can provide valuable supplementary habitat, as can high-quality irrigation ditches for marshland insects, and storm water ponds for aquatic insects. Increased natural vegetation heterogeneity benefits both agricultural and urban ponds, with city ponds having the added benefit of increasing insect conservation awareness. In turn, there is great opportunity for improving artificial ponds, and doing so greatly improves pond functional connectivity across the landscape (i.e. improves the pondscape). Certain human-designed landscapes provide a great opportunity for aquatic insect conservation, including garden ponds, roughs of golf courses, and military training areas. There are also some special cases significant for aquatic insect conservation. These include reducing ship and boat wave impact, introducing biological control of invasive water plants, preservation of river-lake ecotones, rehabilitation of mining pools, retention of well managed Sphagnum bogs, removal of alien predators such as fish, erection of physical diversion structures to deflect certain threatened flying adults, and in some special habitats reducing tourist impact through use of designated paths and duckboards (Sivaramakrishnan *et al*., 2014; Samways *et al*., 2020).

Conclusion

Conservation of natural resources and biodiversity has become urgent issues in recent years for attaining an environmentally sustainable future. While a lack of data has historically excluded the use of many taxa as possible indicator. Growing number of studies on the habitats and distributional pattern of certain aquatic insects is making their use increasingly suitable. Aquatic insects are used for monitoring the health of aquatic environments because of their differential responses to stimuli in their aquatic habitat and determining the quality of that environment. The improvement and development of existing and new biomonitoring tools using aquatic insects are a major effort among aquatic entomologists.

References

Amaravathi, D., Raja Sekhar, P.S. and Rama Rao, K. (2018). Entomofaunal diversity in Kondakarla freshwater lake ecosystem at Visakhapatnam, Andhra Pradesh, India. *Journal of Entomology and Zoology Studies*, 6(6): 880-886.

Bohonak, A.J. and Jenkins, D.G. (2003). Ecological and evolutionary significance of dispersal by freshwater invertebrates. *Ecology letters*, 6(8): 783-796.

Bonada, N., Prat, N., Resh, V.H. and Statzner, B. (2006). Developments in aquatic insect biomonitoring: a comparative analysis of recent approaches. *Annual Review of Entomology*, 51: 495-523.

Buck, J. (1962). Some physical aspects of insect respiration. *Annual Review of Entomology*, *7*(1): 27-56.

Chen, I.C., Hill, J.K., Shiu, H.J., Holloway, J.D., Benedick, S., Chey, V.K., Barlow, H.S. and Thomas, C.D. (2011). Asymmetric boundary shifts of tropical montane Lepidoptera over four decades of climate warming. *Global Ecology and Biogeography*, 20(1): 34-45.

Collins, N.M. (Ed.). (2012). *The conservation of insects and their habitats*. Academic Press.Fonnesu, A., Sabetta, L. and Basset, A. 2005. Factors affecting macroinvertebrate distribution in a Mediterranean intermittent stream. *Journal of Freshwater Ecology*, 20: 641-647.

Girgin, S.Ö.N.M.E.Z., Kazanci, N. and Dügel, M. (2010). Relationship between aquatic insects and heavy metals in an urban stream using multivariate techniques. *International Journal of Environmental Science & Technology*, 7(4): 653-664.

Girgin, Z., Kazanci, N. and Dügel, M. (2010). Relationship between aquatic insects and heavy metals in an urban stream using multivariate techniques. *International Journal of Environmental Science & Technology*, 7(4): 653 664.

Havel, J.E. and Shurin, J.B. (2004). Mechanisms, effects, and scales of dispersal in freshwater zooplankton: a synthesis. *Limnology and Oceanography,* 49: 1229-1238

Hershey, A.E., Lamberti, G.A., Chaloner, D.T. and Northington, R.M. (2010). Aquatic insect ecology. In Ecology and classification of North American freshwater invertebrates, Academic Press, pp. 659-694.

IPCC (2007). Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J., Hanson C. E. (eds) Climate change 2007: impacts, adaptation and vulnerability, Cambridge, UK: Cambridge University Press, pp. 976.

Jonsson, M., Deleu, P. and Malmqvist, B.(2013). Persisting effects of river regulation on emergent aquatic insects and terrestrial invertebrates in upland forests. *River Research and Applications*, 29: 537–547

Joseph, I., Mathew, D.G., Sathyan, P. and Vargheese, G. (2011). The use of insects in forensic investigations: An overview on the scope of forensic entomology. *Journal of Forensic Dental Sciences*, 3(2): 80-89.

Lancaster, J. and Downes, B.J. (2013). Aquatic entomology. OUP Oxford.

Li, F., Chung, M., Bae, M., Kwon, Y., Kwon, T. and Park, Y. (2013). Temperature change and macroinvertebrate biodiversity: assessments of organism vulnerability and potential distributions. *Climatic Change,* 119: 421–434

Medona Mary, R., Nirmala, T. and MR, D.R. (2015). Diversity and distribution of aquatic insects in sothuparai reservoir, at Periyakulam, Theni district, Tamilnadu, India. *International Journal of Current Research and Review*, 9(7): 10-15.

Meijide, F.J., Da Cuna, R.H., Prieto, J.P., Dorelle, L.S., Babay, P.A. and Lo Nostro, F.L. (2018). Effects of waterborne exposure to the antidepressant fluoxetine on swimming, shoaling and anxiety behaviours of the mosquitofish *Gambusia holbrooki*. *Ecotoxicology and Environmental Safety*, 163: 646– 655.

Merritt, R.W. and Wallace, J.R. (2001). The role of aquatic insects in forensic investigations. Forensic entomology: the utility of arthropods in legal investigations, pp. 177-222.

Nair, G.A., Morse, J.C. and Marshall, S.A. (2015). Aquatic insects and their societal benefits and risks. *Journal of Entomology and Zoology Studies*, 3(3): 171-177.

Papacek, M. (2001). Small aquatic and ripicolous bugs (Heteroptera : Nepomorpha) as predators and prey: The question of economic importance. *European Journal of Entomology*, 98(1) : 1-12

Poff, N.L., Brinson, M.M. and Day, J.W (2002). Aquatic Ecosystems and Global Climate Change. Pew Center on Global Climate Change, Arlington, VA, pp. 45

Pritchard, G., Harder, L.D. and Mutch, R.A. (1996). Development of aquatic insect eggs in relation to temperature and strategies for dealing with different thermal environments. *Biological Journal of the Linnean Society*, 58(2): 221-244.

Ramírez, A. and Gutiérrez-Fonseca, P.E. (2014). Functional feeding groups of aquatic insect families in Latin America: a critical analysis and review of existing literature. *Revista de Biología Tropical*, 62: 155-167.

Rao, K.R., Prasanna, D. and Amaravathi, D. (2020). Aquatic entomofauna diversity in lower Manair Dam, Karimnagar Dt. Telangana state, India. *Journal of Entomology and Zoology Studies*, 8(2): 1144-1149.

Rouse, W.R., Douglas, M., Hecky, R., Hershey, A., Kling, G., Lesacle, L., Marsh, P., Mc Donald, M., Nicholson, B., Roulet, N. and Smol, J. (1997). Effects of climate change on the fresh water of Arctic and Subarctic, North America. *Hydrological Processes*, 11: 873-902.

Samways, M.J., Barton, P.S., Birkhofer, K., Chichorro, F., Deacon, C., Fartmann, T. and Cardoso, P. (2020). Solutions for humanity on how to conserve insects. *Biological Conservation*, 242: 10-27.

Sandin, L., Schmidt-Kloiber, A., Svenning, J., Jeppesen, E. and Friberg, N. (2014). A trait-based approach to assess climate change sensitivity of freshwater invertebrates across Swedish ecoregions. *Current Zoology,* 60(2): 221–232

Schmeller, D.S., Loyau, A., Bao, K., Brack, W., Chatzinotas, A., De Vleeschouwer, F. and Vredenburg, V.T. (2018). People, pollution and pathogens–Global change impacts in mountain freshwater ecosystems. *Science of the Total Environment*, 622: 756-763.

Sharma, K., Lodhi, R.K. and Rao, R.J. (2020). Study on diversity of aquatic insects in ramaua reservoir of gwalior district (MP)." *International Journal of Research-granthaalayah,* 8(2): 140-146.

Sivaramakrishnan, K.G., Janarthanan, S., Selvakumar, C. and Arumugam, M. (2014). Aquatic insect conservation: a molecular genetic approach. *Conservation Genetics Resources*, 6(4): 849-855.

Smock, L.A. (1980). Relationships between body size and biomass of aquatic insects. *Freshwater biology*, *10*(4): 375-383.

Strayer, D.L. (2006). Challenges for freshwater invertebrate conservation. *Journal of North American Benthological Society*, 2(2): 271–287.

Subramanian, K.A. and Sivaramakrishnan, K.G. (2007). Aquatic Insects of India-A Field Guide. Ashoka Trust for Ecology and Environment (ATREE), Bangalore, India. pp. 50-62.

Sundar, S. and Muralidharan, M. (2017). Impacts of climatic change on aquatic insects and their habitats: A global perspective with particular reference to India. *Journal of Scientific Transactions in Environment and Technovation*, 10(4): 157-165.

Tachet, H., Richoux, P., Bourneau, M. and Usseliopolatera, P. (2003). Invertebratesd" eaudouce; systematique, biologie, ecologie. Fresh water invertebrates; systematic, biology, ecology. CNRS edition, Paris.

Thorpe, W.H. (1950). Plastron respiration in aquatic insects. *Biological Reviews*, 25(3): 344-390.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. and Cushing, C.E. (1980). The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences,* 37: 130–137.

Vincent, W.F. and Hobbie, J.E. (2000). Ecology of arctic lakes and rivers. In*:* Nuttal, M. Callaghan, T.V. (eds.). The Arctic: Environment, People, Policy. Harwood Academic Press, Chur, Switzerland, pp. 197–231

Voshell, J.R. (2002). A guide to common freshwater invertebrates of North America (No. Sirsi) i9780939923878). McDonald & Woodward Pub.

Wollmann, K. (2001). Corixidae (Hemiptera, Heteroptera) in acidic mining lakes with pH ≤ 3 in Lusatia, Germany. *Hydrobiologia*, 433(3): 181-183.

Zhu, S., Zhang, Z. and Zagar, D. (2018). Mercury transport and fate models in aquatic systems: A review and synthesis. *Science of the Total Environment*, 639: 538– 549.

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