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Aquatic insect ecology, threats and challenges for its conservation-A Review

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Abstract
Aquatic insects are an important part of the aquatic ecosystem providing varied ecosystem services as provisioning services (feed for fish and other organisms including humans), supporting the aquatic ecosystem in decomposition, nutrient cycling, etc., and being regularly used in biomonitoring studies. Although the benefits provided by aquatic insects are diverse and wide-ranging, they are rarely appreciated in the public domain and by policymakers. The ignorance stems from the lack of knowledge about the aquatic insect community as a whole. Here we try to provide basic information about aquatic insects so that it may be easier to understand their ecology, habitat, population dynamics, and to engage directly with the common people to raise awareness thereby making it easier to take appropriate measures for future research and conservation planning.

Keywords: aquatic insects, species, habitat, diversity, biodiversity decline

Introduction
Less than 1% of our planet is covered by inland waters but it bears more than 10% of all known animal species (Strayer and Dudgeon, 2010) [17, 46], of which 60% is composed of aquatic insects (Dijkstra et al., 2014) [18]. The described species of this diversity numbers close to 100,000 (Balian et al., 2007) [7] which is estimated at 200,000 species which makes up almost 80% of aquatic animal diversity (Dijkstra et al., 2014) [18]. Aquatic insects may be defined as insects that spend one or more stages of their life cycle or all development in water (Koroiva and Pepinelli, 2019; Dijkstra et al., 2014) [31, 18]. As Suter and Cormier (2014) [49], put it, "*Researchers who study aquatic insects and applied environmental scientists who include them in monitoring programs and assessments, know that they are important. However, researchers and assessors often find themselves explaining and justifying the use of these organisms to everyone from friends and family to research funders and environmental managers.*" Thus in this review, we put forward the basics for understanding aquatic insects viz. its habitat and distribution, population dynamics, threats and cause of its biodiversity decline, and challenges for its conservation.

Methodology
For the literature survey, a flexible systemic review search protocol was performed (Macadam and Stockan, 2015; Pereznieto and Taylor, 2014; Devkar et al., 2013) [35, 41, 15]. It follows traditional full systematic reviews while allowing for flexibility to modify the process towards improving the quality of the findings (Macadam and Stockan, 2015) [35]. The search, using the combination of relevant keywords such as: ("aquatic insects", "diversity", "habitat", "biodiversity", "population dynamics", "population decline", "conservation") were performed in the web of science using years (1970 -2020) and all publication types. The abstracts of preliminary search results were screened and included if they provided the required details related to the combination of relevant keywords. Thus this review contains relevant papers from the past half-century, which help in our understanding of the aquatic insects.

Habitat and distribution of aquatic insects
Most aquatic insects are grouped into 11 taxonomic orders. They are (I) Collembola (Springtails), (II) Ephemeroptera (the Mayflies), (III) Odonata (Dragonflies and Damselflies), (IV) Plecoptera (the Stoneflies), (V) Hemiptera (True Bugs), (VI) Megaloptera (Dobsonflies and Alderflies) (VII) Neuroptera (Spongilla flies), (VIII) Trichoptera (caddish flies), (IX) Lepidoptera (some of the butterflies and moths), (X) Coleoptera (some Beetles) and (XI) Diptera (some stages of true flies). They are divided into fully and partially aquatic orders (Lancaster and Downes, 2013) [33]. Fully aquatic orders (Ephemeroptera, Odonata, Plecoptera, Trichoptera, and Megaloptera) have juvenile stages that are aquatic and adult stages that are terrestrial. In semi-aquatic orders (Hemiptera, Lepidoptera, Diptera, Neuroptera, and Coleoptera) few have aquatic juveniles and some have air-breathing, aquatic adults (Lancaster and Downes, 2018) [34]. As a result of which they exhibit adaptive variability in morphology, development, physiology, and ecology which allows them to inhabit most freshwater habitats including winter freezing streams and lakes (Hershey et al., 2010; Koroiva and Pepinelli, 2019) [23, 31], geothermal or hot springs (Ward, 1992) [52] and groundwater (Huryn, 2009) [27]. On the other hand, aquatic insects have had only very limited success in marine environments, with only a few such as water striders of genus Halobates being an oceanic taxon (Andersen and Cheng, 2004). Freshwaters are highly diverse, which includes ponds, lakes, springs, streams, rivers, wetlands, reservoirs, etc. (Wetzel, 2001) [53]. Thus setting aside the specialized habitats mentioned above, the major habitats of aquatic insects can be divided into lentic systems or standing water (ponds, lakes, wetlands, reservoir,

etc.) and lotic systems or running water (streams, rivers) (Huryn, 2009; Hershey et al., 2010; Koroiva and Pepinelli, 2019) [27, 23, 31].

Lentic habitat communities

Lakes and ponds

Lakes, ponds offer varied arrangements of habitats for aquatic insects to exploit. They may be further subdivided into a) the surface film – mostly inhabited by organisms that live on the water surface as water striders (Hemiptera), whirligig beetles (Coleoptera), spring tails (Collembola), or organisms such as mosquito larvae (Diptera) (Huryn, 2009) [27]. b) Littoral zone – they have a diversity of aquatic due to good penetration of light, well-oxygenated, having rooted macrophytes and benthic algae. Lentic communities colonizing the littoral zone are constituted by nearly all aquatic insect orders (Hershey et al., 2010) [23], and typically include Coleoptera (adult and larva of many families), Ephemeroptera (Baetidae, Caenidae most commonly), Trichoptera, Plecoptera, Megaloptera, Odonata (from most families), Neuroptera, Diptera (especially Chironomidae) and Hemiptera (Ward, 1992; Doughty, 1994; Merritt et al., 2008; Huryn 2009; Hershey et al., 2010) [52, 20, 37, 27, 23]. c) Profundal zone – characterized by low light penetration, low O2 (eutrophic condition), or high O2 (oligotrophic condition) with soft minerals and organic sediments. Taxonomic richness is low but may contain an abundant population in organic sediments (Huryn, 2009) [27]. It is dominated by Chironomidae (Diptera) (Hershey et al., 2010) [23], although reports of Ephemeridae (Mayflies) are also present (Huryn, 2009) [27]. d) Limnetic zone – the photic zone, lies beneath the profundal zone contains Nektonic (Coleoptera, Hemiptera) and planktonic insects (Diptera) (Merritt and Wallace, 2009; Huryn, 2009) [38, 27].

Wetlands and others (temporary ponds, pools, artificial habitats)

Wetlands are complex ecosystems having variable hydrology, organic sediments that are represented by both freshwater and saline environment, marshes, freshwater swamps, peatlands, mangroves, deltas, etc. These various types of wetlands support a diverse array of aquatic insects. The insect families most commonly encountered are Chironomidae, Culicidae, Ephydridae (Diptera); Dytiscidae, Hydrophilidae (Coleoptera); Corixidae (Hemiptera); Odonata; Ephemeroptera; Trichoptera (Armitage et al., 1995; Huryn, 2009; Batzer and Ruhi 2013; Keleher and Sada, 2012; Batzer and Boix, 2016) [4, 21, 28, 12]. Temporary pools have varied coleopteran and dipteran communities, whom along with mosquito larvae are the dominant residents (Batzer and Wissinger, 1996) [13]. Artificial habitats generally feature generalist species such as mosquitoes, usually, they exhibit one or more extreme abiotic components (Koroiva and Pepinelli, 2019) [31].

Lotic habitat communities

Streams and rivers are the prime natural environment for aquatic insects under this category. Ephemeroptera, Plecoptera, Trichoptera, and Diptera are the major orders, closely followed by Odonata, Megaloptera, and Coleoptera (Battle et al, 2007; Huryn, 2009; Masson et al., 2010; Cummins, 2016; Allan et al., 2020) [10, 27, 36, 14]. The lentic insect communities differ from their lotic counterparts mainly because of the different physical and physicochemical challenges of the lotic ecosystem. The prominent example is the streamlining and dorsoventral flattening of the body (a morphological adaptation), due to hydraulic stress of the flowing water (Ephemeroptera – Heptageniidae, Ephemerellidae; Plecoptera – Perlidae; Coleoptera – Psephenidae, Koroiva, and Pepinelli, 2019) [31]. Other modifications include reduction in body structures, possessing suckers, friction pads, hooks, etc. (Subramanian and Sivaramakrishnan, 2007).

Population dynamics

Aquatic insects show immense diversity in their life history strategies, which serve to separate taxa seasonally and spatially thereby providing the basis for the varied and dynamic nature of aquatic insect community composition (Hershey et al., 2010) [23]. Although large scale variables such as climate change, speciation, diversification can substantially affect and be more pronounced for some aquatic insects (Tolonen et al., 2016) [50], variables such as substrate heterogeneity, land use, abiotic factors, aquatic macrophytes, and water current speed are important drivers of aquatic insects' distribution and diversity (Bae et al., 2011) [6] along with factors such as mortality, competition, resource limitation and their relationship with density affect the population dynamics (Lancaster and Downs, 2018). Density independent processes such as changes in abiotic conditions (most importantly physicochemical properties of the water) can bring about direct responses in aquatic populations. Variations in water chemistry are associated with changes in population size along with the presence or absence of species (Hildrew et al., 1984; Wurtsbaugh, 1992). Water quality changes due to pollution caused by human activities may produce direct physiological changes in the individual's growth and development (Doughty, 1994; Pestana et al., 2009) [20, 42]. The chemical composition of the water has been shown to affect the oviposition selection site for aquatic insect species (Rebora et al., 2013) [44], thereby impacting population dynamics. Variation in water temperature along with frequency and magnitude of physical disturbances such as drought, floods can reduce population size (Vannote and Sweeney, 1980; Giller et al., 1991; Miller and Golladay, 1996.) [51, 21, 39]. Density-dependent processes such as food resource limitations, intra and interspecific competition (including cannibalism), prey-predator relations, and parasitic interaction provide a mechanism for maintaining and regulating aquatic insect populations (Hildrew et al., 2004; Kohler, 2008; Grabner, 2017; Lancaster and Downs, 2018) [25, 30, 22].

Causes of biodiversity decline of aquatic insects and challenges for conservation planning

The loss of biodiversity faced by the world is a major global issue, and going by the current rate of decline in species population – which has been forecasted for progressing into extinction are unparalleled in history (Pimm and Raven, 2000; Barnosky et al., 2011) [43, 8]. As indicated by Sanchez – Bayo & Wyckhus Kris (2019) [45], the degree of the current extent of insect species decline is 41% which is twice that high of vertebrates, and the speed of local species destruction which is at 10% is multiple times higher, affirming the past findings (Dirzo et al., 2014) [19]. At present, about a third of all insect species are threatened with extinction, which sees a biodiversity decline resulting in an annual 2.5% loss of biomass worldwide (Sanchez –

Bayo and Wyckhus Kris, 2019) [45]. Aquatic insects also form a part of the declining insect community. The threats to the freshwater ecosystem in which the majority of aquatic insects reside include but are not limited to habitat degradation, pollution, overexploitation, eutrophication, siltation, channel confinement, non-native species invasion, fisheries, salinity, and climate change (Dudgeon et al., 2006; Sundar et al., 2020) [48]. Aquatic insects are particularly sensitive to habitat change, flow alterations, habitat fragmentation, pollution, and invasive species (Zwick, 1992; Allan and Flecker, 1993; Sanchez – Bayo & Wyckhus Kris, 2019) [55, 45]. All these factors along with anthropogenic pressure are pushing the insect communities towards local species decline, extinctions, and replacement of susceptible species with tolerant ones (Karatayev et al., 2009) [32]. Species loss will steadily lead to a loss in insect mediated ecosystem services thereby interfering with the proper functioning of the freshwater ecosystem (Davis et al., 2004; Kreutzweiser et al., 2007; Aizen et al., 2009; Bartomeus et al., 2014) [16, 29, 5, 9]. The data available (biological and ecological) are affected due to lack of proper description of species concerned and lack of knowledge about the distribution pattern (Hortal et al., 2015; Oliveira et al., 2016) [26, 40] together with the gap in studies of genetic relationships, ecological interactions among one another and overall understandings of their ecological roles, prove to be a major challenge in planning their conservation strategies (Sundar et al., 2020) [48].

Conclusion

Aquatic insects are among the most important components of the freshwater ecosystem and are a familiar concern for ecological research and environmental monitoring assessment. However, the important role they play in managing the aquatic ecosystem is often not recognized mainly because their benefits and ecosystem services provided by them are not apparent to the policy administrator or the public in general (Suter and Cormier, 2014) [49]. Thus there is an urgent need to plug the knowledge gaps about these important organisms, to be better prepared to answer the questions that arise when creating awareness and advocating the need for their conservation.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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