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Macro-Invertebrate Diversity in Relation with Habitat Ecology with Special Reference to Fresh Water: A Review

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Abstract: Insects make up a significant portion of animal species. Freshwater invertebrates, with insects making up the majority, account for over 100,000 identified species. Various insects play important roles as bio-indicators, predators and consumers of organic material and algae in aquatic ecosystems. The occurrence and distribution of aquatic invertebrates are regulated by several parameters, including current speed, temperature, pH, substratum, and vegetation. Ecological factors, such as habitat structure, affect the community composition of macro-invertebrates in aquatic systems. The rate of species extinction is accelerating due to human activities, with tropical freshwater habitats being amongst the most vulnerable to biodiversity loss. Changes in land utilization pose the most significant threat to aquatic biodiversity, including the introduction of exotic species and contamination of aquatic ecosystem. Climate change is also predicted to have a negative impact on freshwater macro- invertebrate biodiversity. Owing to the various ecological roles of aquatic macro-invertebrate in freshwater ecosystems, conserving aquatic macro-invertebrate biodiversity is essential. The conservation efforts should include taxonomy advances, classification modifications, and IUCN Red List assessments, as well as habitat restoration and creation of new protected regions. Remediation methods, such as river channel re-meandering and increasing flood plain areas, can also help to restore river ecosystems.

Keywords: Macro-invertebrates, Biodiversity, Invertebrate, Extinction, Conservation

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Introduction

Freshwater ecosystems are home to a wide range of macro-invertebrate species, including worms, molluscs, crustaceans, and insects. The taxonomic richness of these organisms is a key indicator of freshwater ecosystem health and serves important ecological functions. The physico-chemical status of an aquatic system, including temperature, season, altitude, current speed, vegetation, dissolved substances, substratum, and zoogeography, influences the diversity and quantity of benthic residents. However, macro-invertebrate biodiversity is declining globally due to various anthropogenic activities, including habitat loss, pollution, and climate change. The main objective of this review was to focus on ecological status and importance of macro-invertebrates. In this review, in order to fulfill the objective, we will discuss the taxonomic richness of macro-invertebrates, ecological factors that affect their biodiversity, the threats they face, and conservation strategies to protect and restore their populations.

The organisms that reside on or in the bed of a water body are known as macro benthos. Benthic animals span all phyla and are incredibly diverse, ranging from protozoan to giant macro-invertebrates to vertebrates (Wetzel, 2001). Aquatic macro-invertebrates, which are amongst the most common (Voelz *et al*., 2000) and diverse (Strayer, 2006) creatures in fresh water, also serves crucial ecological function in aquatic habitat (Boulton, 2003). The many aquatic macro-invertebrates includes various species of worms, such as flatworms, eelworms, and segmented roundworms, as well as molluscs like bivalves and snails, crustaceans like crayfish, shrimp and other groups that resemble mites, shrimp, and most importantly, insects.

The physio-chemical status of an aquatic system, which does exhibit seasonal variations, has a noteworthy impact on the diversity and quantity of benthic residents of that water body (Kumar, 2006). The presence and precise distribution of invertebrates that live in streams are influenced by a variety of variables. The most significant of these are temperature (Castella *et al*., 2001; Li *et al*., 2001; Sullivan *et al*., 2004), together with the effect of season and altitude (Miserendino *et al*., 2003; Waite *et al*., 2004; Sporka *et al*., 2006; Joshi *et al*., 2007), current speed (Younes-Baraille *et al*., 2005; Donohue *et al*., 2006), vegetation (Subramanian and Sivaramakrishnan, 2005), dissolved substances (Azrina *et al*., 2006) and, the substratum (Munoz 2003). Additional crucial elements include susceptibility to drought and flooding, food, species competition, shade, and of course zoogeography (Negishi *et al*., 2002).

Freshwater ecosystem biodiversity has significantly decreased in recent decades as a result of anthropogenic disturbances which harmed ecosystem structure and function. Over the past several centuries, anthropogenic disturbances like urbanisation, pollution and damming, have expanded significantly, severely harming the structure of freshwater ecosystems and reducing biodiversity (Zhang *et al*., 2019). According to the World Wide Fund for Nature (WWF, 2018), since 1970, about 83% of all freshwater species worldwide have decreased, with the Neo tropics, Indo-Pacific, and Afro tropics experiencing the greatest biodiversity loss. In particular, similar decline in aquatic insects is likely to be observed as of freshwater species in general, and the International Union for Conservation of Nature (IUCN) Red List assessment reported that 15% of damselflies (Odonata) and dragonflies were experiencing extinction threat (Collen *et al*., 2012; IUCN, 2012).

Aquatic biodiversity continue to get less focus than its terrestrial counterparts despite the downward trend in aquatic macro-invertebrates, especially in tropical areas (Boyero *et al*., 2009; Godet *et al*., 2018). Given the need to maintain freshwater ecosystems as the benefits they offer, this lack of focus is unexpected (Table 1) (Dudgeon *et al*., 2006; Heino *et al*., 2009; Woodward *et al*., 2010; Poff *et al*., 2012). In order to slow the decrease of aquatic macro invertebrates and the deterioration of aquatic ecosystems, certain strategies to improve taxonomy, establish protected areas, document species status, and restore habitats can be implemented.

***Taxonomic Richness and Ecological Roles of Macro-Invertebrates*:**

Insects make up roughly 7,51,000 recognised species, or nearly one-fourth of all known animal species (Voshell, 2002; Balaram, 2005). A total of 107,295 different species of freshwater invertebrates have been identified, with insects

Table 1: Ecosystem goods and services provided by aquatic macro-invertebrates

Type of ecosystem service	Goods or Services provided	Examples of goods or services
Provisioning	Production (food); therapeutic uses; resources (e.g. genetic, ornamental)	Freshwater crustaceans, molluscs, and insects are significant sources of protein, vitamins, minerals, and income for people and animals (Williams and Williams, 2017). In some traditional communities, dragonflies are consumed, have decorative significance, and are utilised in traditional medicine (Simaika and Samways, 2008). Dog bites are treated with water striders (Gerridae: Hemiptera), while mental illness is treated with various hemipterans (Srivastava *et al*., 2009)
Regulating and maintenance	Disease control and suppression of pathogens; water purification and regulation; nutrientcycling regulation; decomposition regulation	Dragonflies serve as hosts for parasites and act as disease vectors for both people and livestock (Simaika and Samways, 2008). Aquatic macroinvertebrates are essential to the cycling of nutrients (Yuen and Dudgeon, 2016). Bugs, dragonfly, beetles, and damselfly larvae control the abundance of pests and disease-vector mosquitoes (Benbow *et al*., 2014).
Cultural	Aesthetics; cultural heritage and sense of place; educational; recreational; spiritual and religious	Macro-invertebrates are appropriate for use in science education programmes or citizen science initiatives due to their high abundance and variety of forms (Suter and Cormier, 2015). Dragonfly parks, trails, kid's activities and field guides all attest to the importance of dragonflies in many different civilizations. Dragonflies also hold religious significance in Japan (Simaika and Samways, 2008).

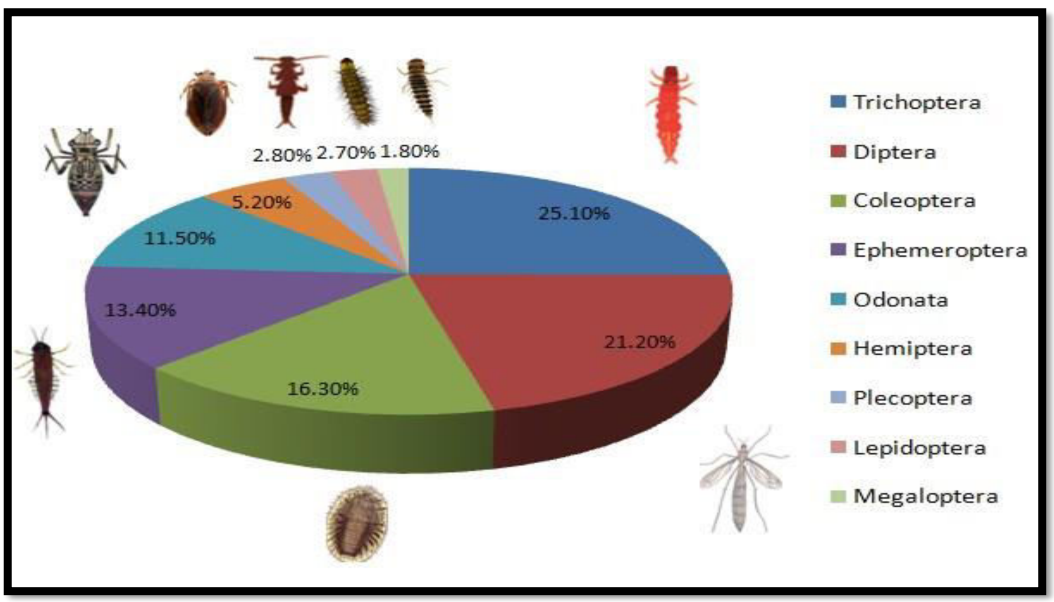

Fig. 1: Percentage composition of macro-invertebrate community.

accounting for the majority (60.4%) of them (Fig. 1). Crustaceans (10%), molluscs (4%) and annelids (1.4%) are the next most prevalent groups (Balian *et al*., 2008). Around 3% of all insect species possess aquatic life cycles. In certain freshwater biotopes, around 95% of all macro-invertebrate species or individuals may be insects. Average percentage of diversity of various insect orders was reported as true flies (Diptera, 21.2%), caddisflies (Trichoptera, 25.1%), damselflies and dragonflies (Odonata, 11.5%), mayflies (Ephemeroptera, 13.4%), beetles (Coleoptera, 16.3%), true bugs (Hemiptera, 5.2%), moths (Lepidoptera, 2.7%), stoneflies (Plecoptera, 2.8%), and alderflies and dobsonflies (Megaloptera, 1.8%) (Dudgeon, 2008).

Individuals from the orders Odanata, Diptera, Hemiptera, Coleoptera, Ephemeroptera, Plecoptera, Trichoptera, Lepidoptera, and Megaloptera typically make up aquatic insects. Each of these orders fulfils a distinct ecological function in the aquatic ecosystem. Odonata abundance may reflect the diversity of other macro-invertebrates and macrophytes (Bried and Ervin, 2005). In the tropics, dipterans are the most common group of macro benthic invertebrates and prefer lentic settings for breeding and early life stages (Majumder *et al*., 2011). Important predators are frequently aquatic hemiptera (Saha *et al*., 2007). It is thought that the predatory aquatic bug species of the superfamily Nepoidea, of Hemiptera, which includes the families Belostomatidae and Nepidae, are efficient predators of mosquito larvae and fresh water snails (Ohba and Nakasuji, 2006). There are almost 30 families and 18,000 species of aquatic coleopterans, which are incredibly diverse in terms of colour, structure, and life pattern (Vazirani, 1977). Ephemeroptera (mayfly nymphs) are extremely vulnerable to habitat deterioration brought on by pollution and eat fine particle organic materials and epiphytic algae (Francis *et al*., 2010). The delicate order of aquatic insects known as Plecoptera is confined to areas with low human influence, crystal-clear water, and high dissolved oxygen levels. Due to the ecological diversity of trichopterans and their capacity to make silk, caddisflies have been able to successfully exploit a variety of aquatic habitats. Based solely on case-building activity, among the three super families constituting Trichoptera, five groups have been categorized (Malick, 2010).

Factors affecting macro-invertebrate community:

In terrestrial, marine, and freshwater ecosystems, macro-invertebrates community composition is highly influenced by habitat structure, with habitat diversity and heterogeneity thought to increase species abundance and diversity (Tews *et al*., 2004). The occurrence and precise distribution of aquatic invertebrates are regulated by a variety of parameters, including current speed, temperature, pH, substratum, and vegetation.

Temperature highly influences the emergence pattern, metabolism, growth rate, reproduction, and body size in macro-invertebrates (Angelier, 2003). The range of temperatures that different species can endure varies, although some are capable of withstanding temperatures above their tolerance range (Sullivan *et al*., 2004). Evolution in many benthic macro-invertebrates allows them to exist in a specified range of temperature, which has a considerable impact on both the community structure and distribution of aquatic macro-invertebrates. Ecology of macro invertebrates in aquatic systems has been discovered to be significantly impacted by pH, one of the most significant water quality indicators. Although pH sensitivity in benthic macro-invertebrates varies (Yuan, 2004), values between 5.0 and 9.0 are regarded as hazardous. Low pH levels result in decreased emergence rates in benthic macro-invertebrates and are linked to poorer diversity in these organisms (Thomsen and Friberg, 2002). Low pH has also been linked to physiological issues in macro- invertebrates, including egg failure, and trouble faced in sustaining ions in their system and calcium absorption, required for exoskeletons. Some researchers have noted that amphipods, snails, isopods, bivalves, and crayfish are widespread in hard waters compared to soft waters (Willoughby and Mappin, 1988).

The macro-invertebrate fauna is significantly impacted by the existence of vegetation. Studies have revealed that invertebrate abundance and distribution fluctuate significantly with time and that certain plants can sustain more organisms than others in terms of quantity, diversity, and biomass (Chilton, 1990). The width and the morphology of leaves of a plant may possess a

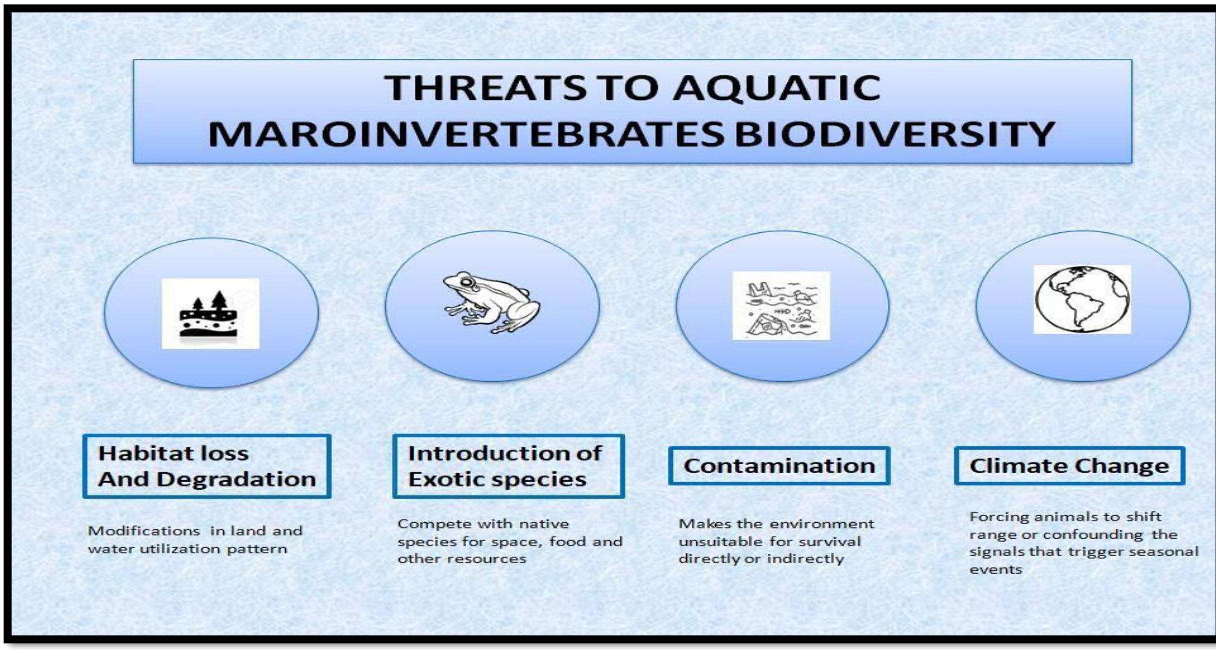

Fig. 2: Factors driving declines of freshwater macro-invertebrate biodiversity.

significant impact on its capacity to support aquatic macro-invertebrates, and secretion of certain chemicals by plants can also have an impact on the abundance of invertebrates that may be present (Krull, 1970). It has been demonstrated that the food quantity and quality available for macro-invertebrates is directly affected by riverside forests, through access of particulate matter (wood, leaf litter, etc.) and indirectly by modifying the dissolved organic carbon and nutrients levels (LeCraw *et al*., 2010). Benthic fauna also prefers stable substratum that is generally coarse and tightly organized since these areas see little disturbance from floods. Many studies have revealed significant correlations among substrate properties, micro hydraulic parameters, and the richness, variety, and species attributes of benthic invertebrates (Silveira *et al*., 2006; Pandit *et al*., 2007).

Threats to Macro-Invertebrate Diversity:

According to several studies (Barnosky *et al*., 2011; Ceballos *et al*., 2017; IPBES, 2019), current extinction rates of species is speeding 1000 times than extinction rates experienced in the past and are closer to those of earlier mass extinction events. This is because human impacts on the environment are increasing globally. Tropical freshwater habitats are among the most endangered, with alarming rates of biodiversity loss (Boyero *et al*., 2009; Antunes *et al*., 2016; Allan *et al*., 2021). Deforestation, habitat degradation, habitat fragmentation, over-exploitation, eutrophication, pollution, siltation, channel impoundment, climate change, and the introduction of exotic species are some of the challenges to these habitats (Fig. 2) (Dudgeon *et al*., 2006).

Habitat loss and degradation:

According to certain studies, modifications in land utilization pose the biggest risk to biodiversity globally and are a chief factor in determining the kind and abundance of benthic macro-invertebrates (Cooper *et al*., 2013; Cuevas *et al*., 2014). In addition, alterations to the physical and chemical environment as well as alterations in land use have a direct impact on the ecosystem of aquatic community, by affecting food sources and quality of habitat. It has been predicted that throughout the past 20 years, the natural forests area has shrunk to one third in several Mediterranean regions (Nahuelhual *et al*., 2012), which includes fruit trees and some exotic tree plantation, such as eucalyptus and pine. As a result, macro-invertebrate taxa and sensitive fish have demonstrated indicators of population reduction (Figueroa *et al*., 2007; Fierro *et al*., 2017).

The lower to mid portions of basins have been impacted by other alterations in land utilization pattern, such as gravel extraction and canal construction. The disturbances caused by increases in downstream deposit of fine sediment from regions of gravel extraction, have the potential to change the hydrobiology and geomorphology of rivers (Zawiejska *et al*., 2015). According to certain studies, fine sediments can harm freshwater fauna, particularly benthonic species (Wyzga *et al*., 2009). Additionally, by limiting movement and respiration due to high turbidity and physical alterations to streams, invertebrate biomass and abundance has shown alterations. River dredging too can have an impact on macro-invertebrate functional feeding groups as well, since the amount of inorganic material is increasing (Mori *et al*., 2011). Moreover, the variety of macro-invertebrates recorded was lower downstream of a river dam than it was upstream (Moya *et al*., 2002).

Introduction of exotic species:

Invasive species are amongst the biggest dangers to aquatic biodiversity. By the year 2100, they are probably going to be the main cause of biodiversity depletion in aquatic ecosystems, after changes in climate and land utilization pattern (Sala *et al*., 2000). For instance, in the streams of Brazilian Atlantic Forest, shredding insect's growth and existence are significantly impacted by the long-term eating of invasive Eucalyptus leaves (Kiffer *et al*., 2018).

Invasive species Didymo algae (*Didymosphenia geminate*) is thought to increase the homogenization of the invertebrate population in Chile by causing an increase in Chironomid and oligochaete worm density (Kilroy *et al*., 2009). Both the invasive species in the Mediterranean region, African clawed frog (*Xenopus laevis*) and the red-eared slider (*Trachemys scripta elegans*), which eat invertebrates, pose major challenges to aquatic environment. This dietary pattern is a persistent source of concern for the aquatic macro-invertebrates in the Mediterranean region (Lobos and Measey, 2002).

Contamination of aquatic system:

Recent development of anthropogenic activities such as residential, agricultural and industrial operations has increased the contamination level in aquatic system (Pauchard *et al*., 2006; Azócar *et al*., 2007). Mining has a tremendous impact on freshwater benthic communities all over the world. Macro-invertebrate assemblages, for instance, have seen effects such as an increase in the number of Dipterans and a decrease in species diversity (Smolders *et al*., 2003). By influencing the water quality of river ecosystems, illegal gold mining also has a negative impact on the biodiversity of macro-invertebrates in high-elevation rainforest streams (Kasangaki *et al*., 2008; Chula *et al*., 2013). Reduced macro-invertebrate diversity and abundance in rivers exposed to higher natural levels of heavy metals has been reported (Alvial *et al*., 2013).

Climate change:

Attributing to changes in natural hydrological and physicochemical regimes, climate change is predicted to negatively impact the biodiversity of tropical freshwater macro invertebrates (Doln *et al*., 2012; Pearson, 2014; Taniwaki *et al*., 2017; Tonkin *et al*., 2017; Gutiérrez-Fonseca *et al*., 2018). Certain studies have examined how macro-invertebrate distribution and survival are impacted by change in climate of tropical areas(Simaika and Samways, 2015; Jourdan *et al*., 2018). Given their wide physiological tolerances, generalist species only persists as a result of climate change homogenizing the diversity of local benthic macro-invertebrates (Pecl *et al*., 2017). Since the availability of water in the tropics is predicted to vary significantly (Rodell *et al*., 2018), as is already the case of forest in the Brazilian

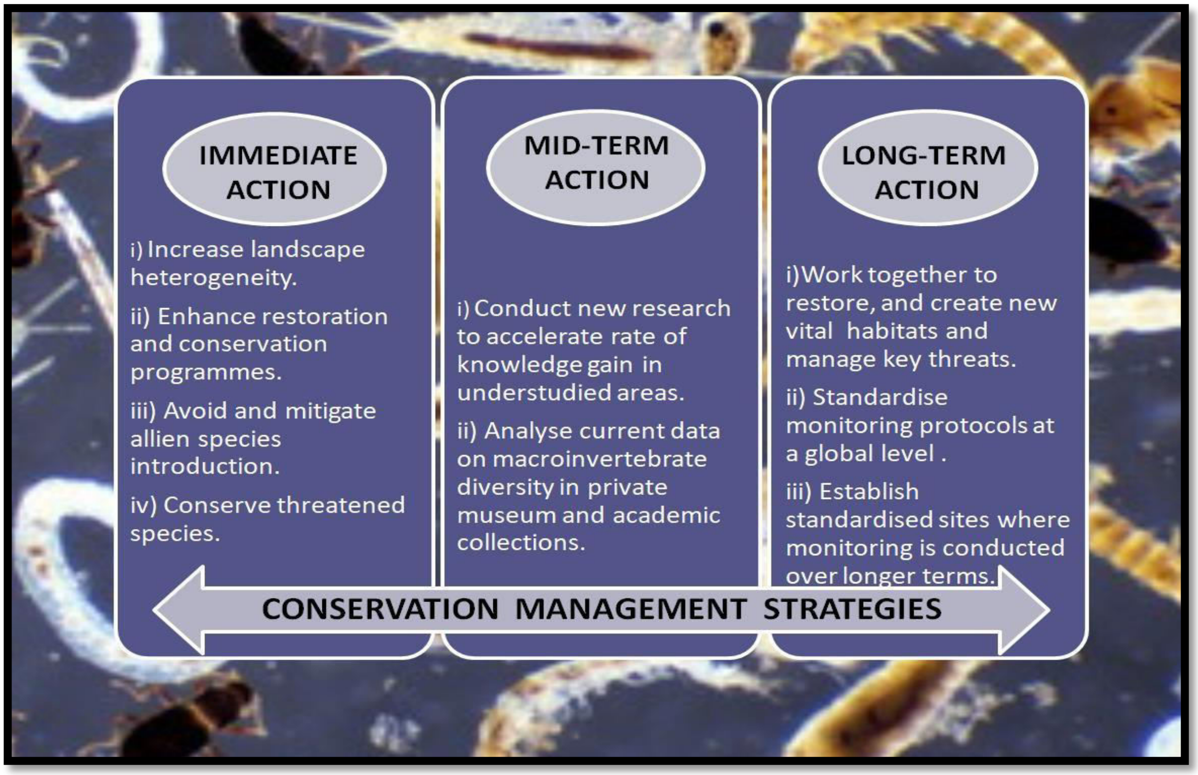

Fig. 3: Approaches to aquatic macro-invertebrate conservation.

Atlantic region, the impact of change in climate on freshwater fauna are frightening (Dobrovolski and Rattis, 2015).

Conservation Management:

Attributing to the intrinsic, ecological, genetic, social, scientific, educational, economic, recreational, cultural, and aesthetic aspects, the conservation of aquatic macro-invertebrate biodiversity is a crucial job. In freshwater ecosystems, macro-invertebrates carry out a wide range of tasks, such as nutrient cycling and the organic matter decomposition (shredders) (Wallace and Webster, 1996), the cellular fluid consumption of individual algae cells (piercers), the processing of organic matter (collectors); and the energy transfer to higher trophics (predators) (Drysdale, 1998; Swanson *et al*., 2007). A significant food supply for terrestrial eaters (such as spiders, birds, lizards, and turtles) is aquatic macro-invertebrates with an emerging adult stage (Recalde *et al*., 2016). Macro-invertebrates are excellent bio-indicators of the effects of humans due to their wide range of roles and abiotic tolerances.

The loss of aquatic biodiversity can be lessened by implementing specific conservation techniques (Fig. 3). An important part of the conservation effort will be the advances of taxonomy, changes in understanding of taxonomy, and modifications in classification (Thomson *et al*., 2018). Any plan for protecting freshwater macro invertebrates in tropical climates should be built on the creation of new protected regions and enhancing those that naturally exist. Localization of areas of concern for macro- invertebrate conservation requires the classification of macro-invertebrates based on their extinction risk, the documentation of endangered and threatened aquatic macro-invertebrate genus, and IUCN Red List assessments (Simaika and Samways, 2009, 2011; Cardoso *et al*., 2011; Cardoso *et al*., 2013).

Certain remediation methods can also be implemented to improve the aquatic macro invertebrates conservation. Habitat restoration has become a crucial endeavour all over the world to lessen and stop the deterioration of river ecosystems (Geist and Hawkins 2016; Kail *et al*., 2016). In some projects, a restoration strategy like river channel remeandering is used to indirectly modify the heterogeneous river ecosystem (Garcia *et al*., 2012; Lorenz *et al*., 2016). In order to directly restore the river ecosystem, increasing flood plain areas are frequently incorporated into urban river restoration schemes (Bernhardt *et al*., 2007, Palmer *et al*., 2014, Martin *et al*., 2018).

Conclusion

Insects make up a significant proportion of all known plant and animal species, with nearly one-fourth of all recognized species being insects. Freshwater invertebrates account for over 100,000 identified species, with insects making up the majority of these. Around 3% of all insect species have aquatic life cycles, and in some freshwater environments, insects make up 95% of all macro-invertebrate species. Various insect orders play distinct ecological roles in aquatic ecosystems, including predators and consumers of organic material and algae. Specific insect orders, such as Plecoptera and Trichoptera, have more specific habitat requirements and are more susceptible to habitat deterioration.

Various ecological factors affect the community composition of macro-invertebrates in aquatic systems in certain ways. Habitat structure, including diversity and heterogeneity, is suggested to increase species abundance and diversity, allowing for more species to coexist. The occurrence and distribution of aquatic invertebrates are regulated by multiple parameters, including current speed, temperature, pH, substratum, and vegetation. Benthic macro-invertebrates have evolved to exist within a specified range of temperature and prefer stable substratum that sees little disturbance from floods. The existence of vegetation significantly impacts invertebrate abundance and distribution, and pH levels also play a significant role, with low pH levels resulting in decreased emergence rates and poorer diversity in macro-invertebrates.

The current rate of species extinction is increasing at an alarming rate, many times faster than the natural extinction rate, primarily due to human activities such as deforestation, habitat degradation and fragmentation, overexploitation, pollution, and climate change. Tropical freshwater habitats are amongst the most threatened, with the highest rates of biodiversity loss. Modifications in land utilization pose the biggest risk to aquatic biodiversity, with alterations in the physical and chemical environment, including the introduction of exotic species and contamination, also having a significant impact. Finally, climate change is predicted to negatively impact the biodiversity of tropical freshwater macro-invertebrates by altering natural hydrological and physicochemical regimes.

The conservation of aquatic macro-invertebrate biodiversity is crucial due to their various ecological roles in freshwater ecosystems, including nutrient cycling, organic matter decomposition, and serving as food for terrestrial eaters. They also serve as bio-indicators of the impacts of humans. To protect them, conservation efforts should include taxonomy advances, classification modifications, and IUCN Red List assessments, as well as habitat restoration and creation of new protected regions. Remediation methods such as river channel re-meandering and increasing flood plain areas are also effective ways to restore river ecosystems.

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