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Effect of macrophytes on Phytophilous macroinvertebrate community: A review

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Abstract
Understanding the importance of interaction among various biotic-variables is a prerequisite for analyzing the changes in the environment of an ecosystem. In aquatic ecology, macrophytes play a prominent role in providing stable habitat to various other biota including fish, invertebrates, periphytons and diatoms. The composition of these taxonomic groups is a better predictor of assemblage diversity and indicator of the health of the ecosystem, thereby lending importance to species interaction for spatial coherence.

Macrophytes and invertebrates are bio-indicators of water quality due to their varying degree of sensitivity to pollution. Unlike chemical data, which provides water quality information at a discrete point in time, the biological organisms are long-term indicators of environmental stressors. Moreover the macroinvertebrates are more effective than chemical methods for detecting non-point source pollution. In part, of the wide-spectrum of taxa-specific responses among these organisms to environmental stressors and long-term response to both exposure and recovery has enhanced there use in biomonitoring.

Besides macrophyte morphology plays a decisive role in invertebrate density and diversity by providing a variety of ecological niches. Likewise insect herbivory inflict damage to the structure of macrophytes, thus, both share a two-way relation. Appreciating the essentiality of this association is the key to improvement of aquatic biodiversity that identifies the interactions and understands the pattern of changes in the regional species pool. The present paper is a comprehensive review that highlights the interaction between macrophyte and the associated invertebrate community.

Keywords: invertebrates; macrophytes; entomology; biodiversity

Introduction
Macrophytes play an important role in providing a stable habitat structure to the aquatic ecosystems (Danielle and Barmuta, 2004; McAbendroth *et al.* 2005) [34, 81]. From the past few decades macrophytes are being increasingly used in bio-monitoring the aquatic ecosystems (Moore *et al*., 2012) [84] because they are sessile and cannot escape that environment to avoid unfavorable conditions thereby showing short-, long-term and cumulative hydrological stresses. The structural and functional significance of macrophytes can be demonstrated vis-à-vis their diverse role in primary productivity (Wetzel, 2001; Kalff, 2002; Toft *et al*., 2003) [121, 64, 113] global nutrient cycling (Madsen *et al*., 2001; Camargo *et al*., 2003; Pott and Pott, 2003; Meerhoff *et al*., 2003) [79, 82] improvement of water quality, erosion prevention (Caraco and Cole, 2002; Scheffer 2004) [97] and in providing food, shelter and oxygen to fish fauna (Petry *et al*., 2003; Kelly and Hawes, 2005; Barrientos and Allen, 2008; Bickel and Closs, 2008; Schultz and Dibble, 2012) [93, 66, 5, 9, 99] and macroinvertebrates (Grenouillet *et al*., 2002; Strayer and Malcom, 2007; Chambers *et al*., 2008) [46, 24].

Macrophytes are an essential direct and indirect resource in any aquatic ecosystem ranging from rivers, lakes to wetland and coastal areas. The periphyton inhabiting the plant surface provide a direct food source to the associated macro-fauna (James *et al*. 2000, Hillebrand, 2002) [60, 56]. Due to the high rate of biomass production, macrophytes have primarily been characterized as an important food source for aquatic organisms providing both living and dead organic matter (Thomaz and Cunha, 2010) [111]. Macrophyte beds harbor diverse macroarthropod fauna often containing species of conservation concern (Suutari *et al.,* 2008) [107]. Aquatic macrophytes affect the macroinvertebrate community structure by influencing both physical and biotic characteristics (Feldman, 2001) [41].

The freshwater vegetation is home to a variety of taxa belonging to Arthropoda, Annelida and Mollusca (Gerry and Mullens, 2000; Lysyk, 2007; Habib and Yousuf, 2014) [49]. Many invertebrate taxa referred to as *phytophilous macroinvertebrates* exhibit preferences for aquatic plants (Cattaneo *et al.,* 1998; Linhart, 1999) [21, 72]. This association with macrophytes can either be trophic, spatial or both (Linhart *et al.,* 1998) [73]. This heterogeneous group of invertebrates utilizes plants as a direct food source (Gregg and Ross, 1985) [45], shelter from predators (Harrod, 1964) [52] spawning and attachment sites (Keast, 1984) [65] as well as feeding on periphyton growing on their surfaces (Higler, 1975; Cattaneo and Kalff, 1980) [55, 20].

Invertebrates are one of the most commonly used assessment agents in biomonitoring, either their taxonomic or functional aspects are be employed for the purpose. Taxonomic approach includes species diversity, density, abundance and richness, which have further improved with the increase in availability of standard taxonomic keys. Functional aspect pertains to their role in food web and energy flow (Cummin *et al*., 2005) [33] which are essential to characterize the ecosystem conditions.

Macrofauna assemblages are also categorized on the basis of trophic levels into different feeding groups that include collector / gatherer, collector / filterer, scrapper, shredder and predator. The functional composition of macroinvertebrate communities has an important implication on the ecosystem functioning (Wallace and Webster, 1996) [119]. However, most macroinvertebrates show a high plasticity in the use of food resources (Dangles, 2002) enabling them to occupy every possible niche in the ecosystem thereby making them better adapted competitively.

The alteration in community structure of invertebrates indicates the cumulative ecological effects of various natural and/or anthropogenic activities, as these communities are sensitive to shifts in food resources, which will ultimately generate shifts in trophic structure of the lake (Schneider and Sager, 2007) [98]. Motivated by the widespread role of invertebrates in ecosystem mediated services our review has been based on following four aims: availability of standard method for collection of phytophilous invertebrates; assessment of the relation between macroinvertebrate assemblages and leaf architecture; identification of the effect of insect herbivory on macrophytes, the physico-chemical dynamics of aquatic environment and abundance of macroinvertebrates and the effect of allelochemicals on macroinvertebrate density.

Sampling methods for phytophilous macroinvertebrates

One of the most contentious issues in study of phytophilous invertebrates is the use of standard method. Community structure can be distorted or masked due to lack of adequate sampling technique. The sample comprises mainly macrophytes for the collection of associated macrofauna which is the desired population to be assessed. Separate equipments are to be used during sampling of hard-stemmed and soft-vegetation due to their difference in morphology and community composition.

Generally hand- or sweep- nets are used for semi-quantitative sampling (e.g. Garcia-Criado and Trigal, 2005; Bryant and Papas, 2007; Sychra and Adamek, 2010) [43, 14, 108]. Quantitative sampling can be done by using gerking frame box (Gerking, 1957) [44], composite frame box grappler (Habib and Yousuf, 2014) [49] and many more modifications are considered ideal for collection of all principal taxa. There are various other box samplers like Macan (1949) [77], Minto (1977) [83], Downing (Downing 1979; Rasmussen, 1983) [35, 95] and grab sampler like KUG (Shapovalova and Vologdin, 1979) [100] which are used during quantitative sampling. Of these KUG sampler is considered poorest for collection of submerged macropytes (Downing and Cry, 1985) [36]. However, some of the methods are known to be inefficient for collection of highly active invertebrates dwelling the vegetation e.g. Quadrant method (Linhart, 1999) [72]; Gerking frame box (Sychra and Adamek, 2010) [108].

The efficiency in estimating the abundance of phytophilous invertebrates also depends upon whether the sample is collected in-water or retrieved from water then backwashed in containers. For instance, Capres (2000) compared two methods of submersed macrophyte sampling and found that the in-water sampling produced higher values of total phytophilous species richness and frequency than the boat surveys. Appropriate sample size is another aspect of standard methodology (Cheruvelil *et al.,* 2000) the sample size necessary to detect differences in macroinvertebrate abundance should be appropriate. In order to characterize the total invertebrate assemblages replicate sampling is considered most scientifically suitable (Suren *et al.,* 2008) [106].

Depending on the aims of investigation and the precision required, a standard protocol is to be developed that would take into consideration the problems related to cutting of stem from the substratum and the necessity to capture escaping invertebrates. The protocol adapted should target a certain-habitat type therefore should be flexible and specific enough to adequately represent the community at that site and should be less laborious, less time-consuming and cost-effective.

Macrophyte morphology and its effect on abundance of macroinvertebrate assemblages

Macrophytes play an important role in reducing current velocities which in turn influences the invertebrate micro-distribution (Kershner and Lodge, 1990) [67] by providing a stable habitat. Intricately designed macrophytes are found to be better habitat for invertebrate fauna (Taniguchi *et al*., 2003; Hauser *et al*., 2006; Warfe and Barmuta, 2006) [109, 53, 120] as these provide more number of microhabitats which increases the overall available niche space (Willis *et al*., 2005) [124]. The macroinvertebrate density tends to increase when both macrophyte biomass and habitat complexity increases (Strayer *et al.,* 2003; Balci and Kennedy, 2003; Colon-Gaud *et al.,* 2004; Habib and Yousuf, 2014) [105, 3, 29, 49]. Especially in case of plant species with highly dissected leaves (Cheruvelil, 2002) [27].

Temporal changes in the architecture of macrophytes during the growing season had a substantial influence on habitat use by macroinvertebrates (Lillie and Budd, 1992; Duggan *et al.,* 2001) [70, 37]. Many studies have been carried out that relate plant surface area for colonization with the abundance of invertebrates, for instance, *Ceratophyllum* sp. (Bogut *et al.,* 2007) [10]; *Hydrilla verticillata* (Thorp *et al.,* 1997; Copeland *et al.,* 2012) [112, 30]; *Myriophyllum spicatum* (Cheruvelil *et al*., 2001; Balci and Kennedy 2003; Chase and Knight, 2006; Ali and Soltan 2006) [27, 3, 25, 1]; *Trapa natans* (Feldman, 2001; Strayer *et al.,* 2003) [41, 105]; *Lagarosiphon major* (Kelly and Hawes, 2005) [66]; *Cabomba caroliniana* (Hogsden *et al.,* 2007) *Eichhornia crassipes* (Brendonck *et al.,* 2003) [12] *Stratiotes aloides* (Tarkowska-Kukuryk, 2006) [110] and *Heteranthera dubia* (Balci and Kennedy 2003) [3].

The complex structured plants support higher macroinvertebrate abundance and species thereby making plant morphology an important determinants in invertebrate distribution (Hansen *et al.* 2010) [50]. The abundance (number of species and biomass) of invertebrates is considerably higher in vegetated areas than in non-vegetated areas (Hemminga and Duarte, 2000; Attrill *et al*., 2000) [54, 2]. The magnitude of macroinvertebrate density and diversity is reported higher in the combined mixed vegetation than in mono-dominant beds of single species (Wilson and Ricciardi, 2009) [125]. Besides leaf architecture, water quality is found to be one of the primary determinant for supporting diverse macroinvertebrate taxa (Cheruvelil *et al.,* 2002) [26]. The relationship between macroinvertebrate communities and macrophytes is not only determined by the structural complexity of the plants, but also by the amount of plant available for inhabitation (Attrill *et al.,* 2000) [2].

Besides, macrophyte architecture some independent factors such a plant age, density and the depth of macrophyte beds are responsible for variation in macro-faunal distribution (Moya and Duggan, 2011) [86]. But some of the researchers are of the view that although the macrophyte growth form has an effect on macroinvertebrate abundance but it causes no significant differences in macroinvertebrate species richness and diversity (Walker *et al.,* 2012) [118]. However, macrophyte with dissected leaves have higher surface area and therefore provide more habitat for invertebrate colonization, more periphytons for grazing and better refuge from predation which is one of the most influencing survival factor for any organism.

Influence of invasive macrophyte species on macroinvertebrates diversity

Biological invasion due to introduction of exotic macrophytes species has become a serious threat to biodiversity (Gurevitch and Padilla, 2004; Stiers *et al*., 2011) [48, 104]. Valery *et al.* (2008) [117] defines biological invasion as consisting of "a species acquiring a competitive advantage following the disappearance of natural obstacles to its proliferation, which allows it to spread rapidly and to conquer novel areas within recipient ecosystems in which it becomes a dominant population".

Recently, much attention has been paid to the impact of invasive species, direct or indirect, and positive or negative, on different groups in aquatic native habitats (see review by Schultz and Dibble, 2012) [99]. This increased interest is due to vulnerability of freshwater systems to the effects of exotic species (Sala *et al*., 2000; Lodge 2001; Shea and Chesson 2002) [96, 76, 101]. The introduction of species outside the native ranges can occur intentionally (Williamson, 1996) [123] or unintentionally (Ciutti *et al.,* 2011) [28]. The native macrophytes species are known to support better composition, diversity and abundance than the structurally similar exotic species (Feldman, 2001; Houston and Duivenvoorden, 2002; Toft *et al*., 2003; Wilson and Ricciardi, 2008; Stiers *et al*., 2011) [41, 58, 113, 104].

Native aquatic macrophytes play a key role in the structure and function of freshwater ecosystems by providing food, shelter and oxygen for other aquatic life, including macroinvertebrates (Van den Berg *et al*., 1997; Batzer, 1998) [115, 6]. Alteration from a diverse habitat with different native vegetation to a dense exotic monospecific stand seriously alters the macroinvertebrate assemblages (Boylen *et al*., 1999; Stiers *et al*., 2011) [11, 104]. However, some studies contradict indicating no alteration in invertebrate community as a result of biological invasion (Strayer *et al*., 2003; Phillips, 2008) [105]. Mormul *et al.,* (2011) [85] revealed that, it is the structural complexity of native and invasive plant species that accounts for differences in invertebrate composition.

The basic menace with the biological invasion by exotic macrophyte species is their tendency to form monotypic stands which eventually replace the native vegetation and consequently changes the structure and function of various communities associated with the previous vegetation. For instance, *Myriophyllum spicatum* a native submerged macrophyte to Asia, Africa and Europe was introduced in North America where it turned invasive and outcompeted native vegetation for resources leading to decrease in diversity and density of associated invertebrate and fish species, thereby facilitating alteration in the trophic dynamics (Linden and Lehtiniemi, 2005; Wilson and Riccardi, 2009) [71, 125].

Physico-chemical dynamics of aquatic environment and abundance of macroinvertebrates

The factors that most commonly influence the invertebrate community in freshwater are physico-chemical characteristics and biotic interactions (Smith *et al*., 2003; Brooks, 2004; Willams, 2006) [103, 13]. The physico-chemical properties including the nutrient availability in water are known to have a profound influence on the invertebrate assemblages. Usually a direct link is observed between the environmental gradient and macroinvertebrate assemblages (Cañedo and Rieradevall, 2009) [15]. These variables include primarily light penetration (secchi depth), macrophyte dry weight and water temperature (Cerba *et al.,* 2010) [22]. The density and number of insect families are decreased significantly due to variation in water conditions e.g. Martin and Neely (2001) [80] reported that the incoming clay adversely affects the larval insect population likewise Zrum and Hann (2002) [127] examined the micro- and macroinvertebrate communities associated with submersed macrophytes in experimental enclosures experiencing primary and secondary effects of two manipulations of the trophic cascade that were organo-phosphorus and nutrient addition. Macrophytes play an important role in improving the water quality by suppressing the re-suspension of bottom sediments (James, 2004) [61] that is macrophytes play a pivotal role in enhancing the water clarity.

The water parameters are also influenced by the type of biota inhabiting the system, for example, dense mat of invasive macrophytes, produces anoxic conditions due to limited diffusion of oxygen and excess detritus which negatively affects the macroinvertebrate densities (Stiers *et al.,* 2011; Parsons *et al.,* 2011) [104, 92]. Some of the researchers have reported a positive influence of insect herbivory on macrophytes for example pulmonate snails enhanced the growth of macrophytes via increased availability of plant nutrients of snail origin (PO_4 and NH_3) and also reduced the density of epiphyton that are potentially deleterious to macrophytes (Underwood *et al.,* 1992) [114].

Most of the macroinvertebrates are sensitive to low concentration of dissolved oxygen (Toft *et al*., 2003; Stiers *et al*., 2011) [113, 104]. Kornijow *et al*. (2010) [68] reported greater density of invertebrates in the roots of the floating mats *Trapa* *natans* concluding that the invertebrates find refuge from prevailing hypoxic conditions in the overlaying water by using the oxygen excluded from the roots of the macrophyte. Reduced light penetration also limits the macroinvertebrate community, Cattaneo *et al.* (1998) [21] found two to ten times lower density of invertebrates when the floating mats of *Trapa natans* intercepted light entering the aquatic environment.

Herbivory by invertebrates on macrophytes

Earlier it was assumed that the herbivory by invertebrates on aquatic macrophytes is unimportant as the latter are seldom consumed directly by the former. Conventional wisdom indicated that majority of invertebrates prefer to feed on periphyton colonizing the macrophytes surface. However, recent literature reports that under natural conditions the invertebrate herbivory on macrophytes is more common than thought.

Herbivory by macroinvertebrates are found to significantly affect aquatic macrophyte as they cause substantial reductions in their biomass (Cronin *et al.,* 1998; Nachtrieb *et al.,* 2011; Jacobsen and Sand-Jensen, 1992) [32, 88, 59]. Herbivory by snail is now known to have a strong influence on distribution, abundance and diversity of freshwater macrophytes (Pieczynska, 2003; Elger and Lemoine, 2005; Li *et al*., 2005) [38, 69].

Newman (2004) [89] demonstrated that herbivory by aquatic insects can substantially result in 50-95 % reduction in plant biomass and shifts in macrophyte community structure. Some of the insect species belonging to order Lepidoptera, Diptera, Trichoptera, Coleoptera are found to extensively tunnel in the stems of the plants and, in some cases, cause substantial chewing damage to the leaves (Harms *et al.,* 2011) [51]. Creed *et al.* (1992) [31] while investigating the impact of herbivore insects on milfoil found that the weevil larvae and caterpillar bored the stems that lead to collapse of the milfoil bed and reduced the buoyancy of the plants. Some of the invertebrates are able to graze and decompose macrophytes. It has also been reported that the intense and selective grazing by invertebrates leads to disruption of one type of macrophytes making the other plant species dominant (Carlsson and Lacoursiere, 2005) [18].

Invertebrates can be used as biological control agents to eradicate the nuisance growth of invasive macrophytes. Bennett and Buckingham (2000) [7] found that the herbivores like Chironomidae and Pyralidae larvae foraged on the apical meristem and stem of *Hydrilla verticillata* respectively. However, extensive research is needed in this regard to judge the potential of insects in aquatic weed biological control program. More effort is to be put in the field collection program to build an extensive data base to evaluate the suitability of such program in lake management.

Influence of macrophyte released allelochemicals on invertebrates

The functional performance of any organism is determined by its physiological, behavioral and morphological response to variable environmental factors. These factors may be physical such as temperature, pH and allochthonous nutrient input, as well as biotic such as inter- and intra- specific competition, parasitism and predation. Many aquatic organisms exhibit unique mechanisms that aid them in better adaption in the habitat by providing them competitive edge over other species. Such mechanisms include differential susceptibility to interference; aggressive behavior and potential to produce allelochemicals that hinder the growth of other species.

Allelochemicals are the bioactive chemicals produced by organisms, these chemicals can either alter interactions between the same or among different species. The effect of allelochemicals on flora (Berger and Schagerl 2003, Mulderij *et al*. 2005; Erhard and Gross 2006; Hilt 2006) [8, 87, 40, 57] and fauna (Lindén and Lehtiniemi 2005; Parker *et al*. 2006; Cangiano *et al*. 2002; Van Donk and Van de Bund 2002) [71, 91, 16, 116] has been well documented.

Allelopathy is particularly important in plants manifesting spatial competition with other species occupying the same niche. The liberation of chemicals results in establishment of dense monotypic beds, which in turn alters the macroinvertebrate community structure. This property plays a prominent role during decomposition phase also, the patterns and the use of macrophyte detritus by primary aquatic invertebrates are more related to deterrent chemicals present in aquatic plants than with the low food quality of aquatic macrophytes

(Newman, 1991; Wium- Andersen *et al.,* 1982; Cattaneo 1983; Jasser, 1995; Gross *et al.,* 1996; Marko *et al.,* 2005) [90, 126, 62].

Gab-alla (2007) [42] reported that phytophilous invertebrates avoid *Caulerpa prolifera* (weed) either as a habitat or as feeding grounds because of production of toxic secondary metabolites. Erhard (2005) [39] observed that *Elodea canadensis* and *E. nuttallii* had allelopathic effects on cyanobacteria and lepidopteron larvae that resulted in a competitive advantage over native species, which are depredated by herbivores. Linden and Lehtiniemi (2005) [71] reported that *M. spicatum* changes the epiphytic community by exuding allelopathic compounds, resulting in invertebrates avoiding *M. spicatum* as feeding habitat, which also showed influence on density of insectivorous fish. Baron and Ostrofsky (2010) [4] reported that although the submersed aquatic plants having high surface to biomass ratio support increased macroinvertebrate colonization but many aquatic plants contain defensive compounds (phenolics, alkaloids, etc.) that deter herbivory by macroinvertebrates. This also explains why macrophytes with similar structure support different invertebrate diversity.

Conclusion

In this review, we find that diversity of macrophytes functions as a surrogate indicator for reflecting the diversity of other taxonomic groups. They are of primary importance in shaping the structure of various other environmental variables. Thus, making them a fundamental factor for determining the distribution of invertebrates at all spatial scales. The number of invertebrates found attached to macrophytes are proportional to the leaf surface area available for colonization. However, there are some exceptions in case of plants secreting allelochemicals. The chemicals exudates hamper the growth of other plants making the former better competitors.

Variation in the physical and chemical environment plays a strong role in determining the community structure of any freshwater ecosystem. Unchecked nutrient enrichment leads to excessive growth of algal-blooms which results to shading-out of submerged macrophytes, without which invertebrates are rendered without habitat with no opportunity to graze on periphyton and shelter from predators. Furthermore, implication of the decrease in invertebrate density is manifested in the decline in population of fish species whose mature or juvenile stages prey on macrofauna. Hence, macroinvertebrate community plays a vital role in feedback mechanism which helps to stabilize the aquatic ecosystem.

The study of interaction between macrophytes and macroinvertebrates has implications on the aquatic food webs and the resource management because invertebrates are an integral component linking macrophytes (primary producers), fish that consume them, and piscivoros fish (higher consumers). Thus, play a key role in structuring aquatic communities, therefore research on food web effect of phytophilous macroinvertebrates at multiple trophic levels would help to improve management of aquatic ecosystems.

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