

Factors affecting the distribution patterns of aquatic macrophytes

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Abstract: Aquatic macrophytes constitute important components of many freshwater ecosystems. The manifold role of aquatic macrophytes in freshwater habitats is closely linked to their distribution, which in turn depends on a myriad of factors. Foremost, among these are light, water temperature, water quality changes and nutrient enrichment, sediment composition and fluctuations in water levels. Light and temperature are of paramount importance in determining the distribution (with depth, season and latitude), thereby influencing productivity and species composition as well. Sediment compositions markedly affect the growth rates of macrophytes which in turn have a profound influence on the distribution of aquatic macrophytes. Water quality changes and nutrient enrichment can cause considerable variations in the species richness, composition, and density of aquatic vegetation. The reduction in water levels could bring drastic changes in the species composition and distribution of macrophytes. Factors associated with competition, herbivory, land use and land cover changes etc. also play an important role in shaping macrophyte distribution and community structure. In this review we examine both biotic and abiotic factors that influence the structural attributes like species composition, distribution, abundance and diversity of aquatic macrophytes.

Key words: Abiotic and biotic factors, aquatic macrophytes, competition, freshwater ecosystems, species composition

Introduction

Aquatic macrophytes are considered photosynthetic organisms of freshwater habitats, comprising vascular plants, aquatic bryophytes and macroalgae growing permanently or temporally in aquatic environments (Jones et al. 2010). They play an important role in the structure and functioning of freshwater ecosystems (Wetzel 2001; Hrivnak et al. 2009; Tamire and Mengistou 2012). The macrophytes serve as a base of aquatic food-chains, besides they also actively contribute to the promotion and maintenance of food webs and services in freshwater ecosystems (Scheffer and Jeppesen 2007; Smith 2011). Aquatic macrophytes also act as important bioindicators of environmental conditions and long-term ecological changes in water quality (Lacoul and Freedman, 2006; Solimini et al. 2006). The function of macrophytes in these ecosystems is related to their structural attributes like species composition, distribution, abundance and diversity which in turn relies on various environmental factors such as light, water temperature, substrate composition, disturbance, competitive interactions, herbivory, epiphyte loading, water levels, quality of the lake water and sediment nutrients (Kaul et al. 1978; Pandit 1984, 1992; Barko and Smart 1986; Duarte et al. 1986; Lodge 1991; Cronk and Fennessey 2001; Wetzel

2001; Capers 2003; Pankhurst 2005; Jaikumar et al. 2011; Siraj et al. 2011; Feldmann 2012; Tamire and Mengistou 2012). Apart from these, factors such as composition and properties of sediments also seem to have significant effect on the diversity and distribution of certain macrophytic species (Dawson and Szoszkiewicz 1999; Heegaard et al. 2001; Makela et al. 2004). Vegetative and clonal reproduction is considered to be the major mechanism for population growth and dispersal of macrophytes because sexual reproduction and genetic recombination are often subordinate strategies (Wetzel 2001). The efficient reproduction strategies and good dispersal capabilities are the two factors that help some aquatic macrophytes to become cosmopolitan in distribution and display high levels of polymorphism and phenotypic plasticity in response to variations of environmental factors. (Sculthorpe 1967; Barrat-Segretain 1996; Santamaria 2002).

In view of the significant role played by macrophytes in freshwater ecosystems, understanding and quantifying the environmental factors that influence the distribution patterns of macrophytes is indispensable for integrated management practices of these ecosystems. The present paper, therefore, attempts to document the historical review of the factors that significantly govern the distribution patterns of aquatic macrophytes in freshwater ecosystems.

A brief overview of the factors that affect the distribution of macrophytes is given as under.

I. Abiotic factors

Light

The distribution pattern of macrophytes is largely controlled by water clarity and the amount of light that reaches the plant. A number of studies have found these to be the most significant factors governing the abundance, composition and distribution of macrophytes (Bini et al. 1999; Loughheed et al. 2001; Pandit 2002). It is well documented that the underwater light plays an important role in determining the depth distribution of different groups of aquatic macrophytes (Sculthorpe 1971; Chambers and Kalff 1985; Dale 1986; Chambers and Prepas 1988; Hrivnak et al. 2006). Water level is closely related to light transmission, with deeper water hindering the processes of scattering and absorption (Wetzel 1988; Sand-Jensen and Borum 1991). A number of reports indicate that certain species of aquatic macrophytes, mostly submerged ones, usually extend into the depths in order to maximize their absorption of the light and CO₂ needed for photosynthesis; for example, *Hydrilla* sp. is very effective in elongating its shoots (Barko and Smart 1981; Maberly and Madsen 2002). Submerged macrophytes have also been reported to grow to a depth of two to three times the Secchi depth (Chambers and Kalff 1985). Sand-Jensen (1990) found that epiphyte shading plays significant role in determining the depth distribution of submerged aquatic macrophytes. Chambers and Kalff (1985) and Dennison et al. (1993) obtained a positive relationship between Secchi depth and rhizophytes. They found that this relationship is probably related to light availability-dependent habitat heterogeneity for submerged species. Certain studies indicate that the climatic difference associated with geographic latitude seems to have a strong influence on the relationship between water transparency and depth distribution of submerged plants (Duarte and Kalff 1987).

Temperature

In most aquatic systems, seasonal variations in photoperiod and incident solar radiation trigger corresponding changes in water temperature (Barko et al. 1986). It is generally known that light and temperature act together in affecting growth, morphology, photosynthesis, chlorophyll composition and reproduction of macrophytes (Sastroutomo 1980, 1981; Barko et al. 1982, 1986; Chambers 1982; Nekrasova et al. 2003; Ronzhina et al. 2004; Robledo and Freile-Pelegrin 2005). Although temperature within the thermal tolerance promotes growth and reproduction in aquatic plants, decrease in water temperature may be one of the factors that are responsible for depth-related reductions in the seasonal growth of macrophytes (Barko et al. 1986). It is believed that the temporal changes in distribution of certain species of macrophytes are mainly temperature-dri-

ven (Heikkinen et al. 2009; Alahuhta 2011; Kors et al. 2012). The variations that occur in the species composition and distribution of certain species of aquatic macrophytes, mostly submerged ones due to thermal changes, indicate that temperature is as important as light in influencing competitive interactions among coexisting species (Anderson 1969; Allen and Gorham 1973; Barko et al. 1986). Recent studies have found that the increased nutrient concentrations, derived from diffuse pollution due to increased precipitation in future can hinder temperature driven distribution changes of macrophytes (Jylha et al. 2004; Rosset et al. 2010).

Water quality and sediment related characteristics

A lot of research has been done from time to time to evaluate the effects of water quality, sediment characteristics and geological formations on aquatic macrophyte distribution (Kaul 1971; Chambers 1987; Gopal 1987; Barko et al. 1991; Heegaard et al. 2001; Loughheed et al. 2001; Mir 2009; Birk and Willby 2010; Alahuhta 2011; Uedeme-Naa et al. 2011; Tamire and Mengistou 2012; Gecheva et al. 2013; Sossey-Alaoui and Rosillon 2013). Riis et al. (2000) while examining the relationship between environmental factors and aquatic plant composition in Danish streams found that alkalinity was the most important factor in predicting plant distribution. The factors associated with sediments such as high organic matter content, poor oxygen availability, nutrient limitation and granulometric composition are known to influence the distribution and diversity of aquatic macrophytes to a varied extent (Drew and Lynch 1980; Sikora and Keeney 1983; Lachavanne 1985; Barko and Smart 1986; James and Barko 1990; Barko et al. 1991; Sand-Jensen 1998; Armstrong et al. 1999; Boedeltje et al. 2001). A few studies have indicated that the growth of rooted aquatic plants is favoured over phytoplankton due to higher concentration of phosphorus in the sediments (Scheffer et al. 1993). The distribution of macrophytes in freshwater ecosystems also seems to be influenced by the nature of the geological formations and the degree and nature of the pressure exerted on these environments (Sossey-Alaoui and Rosillon 2013).

Nutrient enrichment

It has been well emphasized that the distribution and growth of aquatic macrophytes are associated with nutrient rich environments particularly nitrate and phosphate which have been noted to favour macrophytes growth (Frankouich et al. 2006). Several studies have established that the nutrient enrichment can cause significant changes in the density, species composition and richness of aquatic vegetation in lakes (Toivonen and Huttunen 1995; Findlay and Houlahan 1997; Bini et al. 1999; Magee et al. 1999; Loughheed et al. 2001; Rosset et al. 2010; Alahuhta 2011). There is a possibility that the elevated nutrient concentrations might hamper climate-driven distribution patterns of macrophytes (Rosset et al. 2010). Nutrient enrichment of waters due to clay soils probably resulted in a positive relationship between helophyte vegetation distribution and fi-

ner grained soils and less acidic bedrocks. Clay soils can promote littoral overgrowth both at the lake and habitat levels in boreal catchments (Partanen et al. 2009). Recently, Shah and Reshi (2014) linked the distribution of alien aquatic flora in different aquatic ecosystems of Kashmir Himalaya to their trophic status.

Hydrological variations

It has been established that the hydrologic and hydrodynamic conditions affect the distribution patterns of macrophytes mainly in two ways: (i) by the fluctuating water level (Makin et al. 1976; Spence 1982; Coops et al. 1996; Schwarz and Hawes 1997; Fernández-Aláez et al. 1999; Kors et al. 2012), and (ii) by mechanical stress caused by waves and water flow (Spence 1982; Idestam-Almquist and Kautsky 1995; Rea et al. 1998). Several studies have found that the variations in water depth lead to variations in species zonation, distribution, biomass and richness (Khedr and El-Demerdash 1997; Fernandez-Alaez 1999; Arts 2002; Lacoul and Freedman 2006). The turbidity of water also seems to determine the extent of colonization of submerged aquatic plants (Kaul et al. 1978; Kaul 1982; Pandit 1992, 2008; Scheffer et al. 1992). Nurminen (2003) noted that higher turbidity, fluctuations in water level and other factors seem to limit the macrophyte distribution to mainly turbidity tolerant species (e.g., *Nymphaea*, *Nelumbo* and emergents). Low water levels may have a greater impact on the submerged vegetation in comparison to the lower lakes, due to the steeper shorelines (Pankhurst 2005). It is believed that the reduction in water level and change in limnology of lake waters could change considerably the composition of macrophytes over decades (Deribessa 2006; Beneberu and Mengistou 2010). Kumar and Pandit (2008) while studying the effect of water level fluctuations on distribution of emergent vegetation in Hokersar wetland (Kashmir) maintained that water depth plays an important role in the presence, distribution and diversity of the emergent species. Day et al. (1988), however, found that water depth, the effects of spring flooding in removing litter and the fertility gradient produced by flowing water are the three main factors affecting vegetation composition.

Exposure to wind and waves

A number of studies have indicated that the exposure to wind and waves largely influences the distribution of aquatic plants in shallow waters (Chambers 1987; Vermaat and De Bruyne 1993; Pankhurst 2005). Hudon et al. (2000) found the biomass and distribution of submerged macrophytes to be influenced by site exposure and differences in species distribution attributable to growth form. Sand-Jensen (1989) held decrease in water depth responsible for increase in the wave-induced turbulent forces on the bottom. Spence (1982) found that the helophyte zone and especially the zone of floating-leaved plants decrease with the increasing lake area due to wind stress related to the height and strength of waves. He also obtained positive

relationship between the lake area and helophytes in small and middle sized lake surfaces. A few studies have indicated that this relationship probably originates from habitat heterogeneity - as larger lakes encompass more microhabitats more species are able to find a suitable habitat with increasing area (Rorslett 1991; Jones et al. 2003; Heegaard 2004; Capers et al. 2010).

II. Biotic factors

Many authors have reported that the competitive interactions among plants, herbivory by invertebrates and vertebrates etc. are the major biological factors that shape aquatic vegetation composition and distribution in freshwater ecosystems (Chambers and Prepas 1990; Connors et al. 2000). Several studies have found that competitive interactions between naturally occurring species may play a larger role in shaping macrophyte distribution and community structure (Chambers and Prepas 1990; Pankhurst 2005; Hrivnak et al. 2009; Kors et al. 2012). There is some evidence that certain biotic factors such as grazers, pathogens etc. also influence the distribution patterns of submerged macrophytes (Nichols and Shaw 1983). It has been long believed that the introduction of exotic species by humans (e.g., *Orconectes rusticus* and *Myriophyllum spicatum*) can significantly reduce the population of native freshwater macrophytes (Lodge and Lorman 1987; Boylen et al. 1999; Wilson 2002).

III. Other factors

Apart from these, factors such as latitudinal and altitudinal pattern, dispersal, soil, bedrock and land cover and land use (LCLU) are also known to play an important role in macrophytes distribution and richness between lake catchments (Sand-Jensen et al. 2000; Jones et al. 2003; Heegaard 2004; Lacoul 2004; Edvardsen and Okland 2006; Lacoul and Freedman 2006; Chambers et al. 2008; Partanen et al. 2009; Capers et al. 2010; Alahuhta 2011). Certain studies have reported that the land use patterns generally have a strong influence on the distribution of macrophytes at finer extents (Luoto et al. 2007; Heino and Toivonen 2008; Alahuhta 2011). Lambert (2007) maintained that the distribution of charophytes is significantly affected by substratum type and topology (slope inclination of littorals and lake edges).

Conclusion

It is now evident that biotic as well as abiotic factors lead to considerable variations in distribution, diversity and abundance of aquatic macrophytes in freshwater ecosystems. The availability of light and temperature appears to be the most important factors in determining the macrophyte distribution (with depth, season and latitude), there-

by influencing productivity as well as species composition of submerged macrophytes.

However, it is not easy to discriminate between the effects of these environmental variables on overall distribution patterns of aquatic macrophytes. Therefore, future research should focus on the influence of potential environmental variables (anthropogenic pressures, climatic change through human development and global warming) leading to change in the community structure and productivity of macrophytes. Moreover, emphasis should be given to the impact of eutrophication on distribution, diversity and density as well as productivity of macrophytes-making an important component of aquatic ecosystem.

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