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Status of Aquatic Macrophytes in Changing Climate: A Perspective

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ABSTRACT

Increased emissions of greenhouse gases such as carbon dioxide (CO_2) and associated increase in Earth's surface and water temperature has been seen as the major climatic change of the last decade. Aquatic macrophytes form a major part of highly productive aquatic ecosystems. Increased eutrophication, acidification and salination of water adversely affect the growth and development of aquatic macrophytes via phenological and metabolic alterations. Predicted increases in temperature and increase in rainfall suggest the enhancement in the growth of emergent aquatic macrophytes. The changes in the growth profile of aquatic macrophytes, distribution and abundance are supposed to ultimately cause a strong ecological impact on the structure and function of aquatic ecosystems globally.

Key words: Aquatic, climate, macrophytes, productivity, temperature

INTRODUCTION

Aquatic macrophytes comprise of vascular (emergent, floating or submersed) plants, bryophytes and macroalgae growing in aquatic environments. Seagrasses are plant communities which represent diverse plant forms growing intermingled with algae and phytoplankton. Aquatic macrophytes form important part of biota of the littoral zones of lakes and reservoirs and are considered one of the most productive communities on Earth (Ondiviela *et al*., 2014). Many ecological functions have been assigned to them (Jeppesen *et al*., 1998; Kotta *et al*., 2014). These mainly include:

- Their role as primary producers in trophic food chains
- Source of habitats and refuges for algae, periphyton, zooplankton, invertebrate and vertebrates species
- Role in nutrient cycling in aquatic systems
- Influence on microclimate and hydrochemical processes in littoral zones
- Influence on sediment dynamics of freshwater ecosystems

Besides these, seagrass meadows have been regarded as sites of carbon sequestration and they potentially support CO_2 mitigation (Marba *et al*., 2015).

Climate has shown profound alterations over the years. These majorly include significant increases in emission of greenhouse gases. Increase in carbon dioxide (CO_2) from 280-650 ppm has been noted in the last few decades. Greenhouse gases have contributed to increase in global temperatures (IPCC., 2007) as the Earth surface temperatures have recorded an increase of 0.6°C. The rise in the global surface temperature by 1.4-5.8°C is predicted in the next 100 years (IPCC., 2007). Sea surface temperatures have also seen a rise of 0.4-0.8°C in the past century (IPCC., 2001). Besides this, alterations in seasonality (decreasing winter, early spring), precipitation (higher in winter and spring) and periodicity of storms have also been noted. Increase in Earth surface temperature has resulted in melting of glaciers leading to expansion of oceans and seas. Sea level has seen a rise at 2 mm $year^{-1}$ over the years and this has been caused due to thermal expansion of the oceans (IPCC., 2001; Eissa and Zaki, 2011). Increasing atmospheric CO_2 is substantially decreasing the oceanic pH (range from 0.3-0.5 units) (Feely *et al.*, 2004; Caldeira and Wickett, 2005; Tokoro *et al.*, 2014).

Rise in temperature, CO_2 concentration and alterations in precipitation directly and indirectly affect growth, productivity and distribution of terrestrial and aquatic vegetation (Kankaala *et al.*, 2000; Cramer *et al.*, 2001; Pearson and Dawson, 2003; Lucht *et al.*, 2006; Wrona *et al.*, 2006; Heikkinen *et al.*, 2009; Heino *et al.*, 2009; Peeters *et al.*, 2013; Tokoro *et al.*, 2014). Alterations in water chemistry and hydrological regimes affect the structure and function of aquatic ecosystems (freshwater and marine) especially in the boreal regions (Poff *et al.*, 2002; Nielsen, 2003; Rahel and Olden, 2008; Heino *et al.*, 2009; Knutti and Sedlacek, 2013; Alahuhta, 2015).

Changes in climate alter the characteristics of water. These include (a) high nutrient loading from the catchment to the lakes (Jeppesen *et al.*, 2009a, 2010, 2011, 2012), (b) high salinity causing shift to oligosaline or mesosaline conditions (Wrona *et al.*, 2006; Beklioglu and Tan, 2008; Jeppesen *et al.*, 2009b; Beklioglu *et al.*, 2011; Trenberth *et al.*, 2014) and (c) acidification of water leading to increase in Dissolved Organic Carbon (DOC) (Eissa and Zaki, 2011; Ejankowski and Lenard, 2015).

Climate-induced changes in air temperature, precipitation and other stressors affect the physical, chemical and biological characteristics of freshwater ecosystems (Wrona *et al.*, 2006; Alahuhta, 2015; Ejankowski and Lenard, 2015). The changes in the physico-chemical characteristics of water affect the growth, productivity and survival of aquatic plant species. The species composition gets altered because of impacts such as habitat loss/transition, shifting ranges and phenological alterations. Aquatic vegetation especially macrophytes are vulnerable to changes in climate. Since, macrophytes represent the keystone species of aquatic ecosystems, hence it becomes essential to study and discuss the effects of climate change on their growth patterns with its possible implications.

Alterations in different factors and growth of macrophytes

Temperature: Temperature is one of the major factors that regulate plant growth. The direct effects of increased temperature depend on the individual species and their thermal tolerances. Changes in temperature affect, (a) Phenology such as leaf bud burst, flowering (Meis *et al.*, 2009; Thackeray *et al.*, 2010), (b) Nutrient uptake (eutrophication) and competition between species (Weltzin *et al.*, 2003; Mooij *et al.*, 2005; Wrona *et al.*, 2006), (c) Metabolic events such as photosynthesis and respiration and (d) Enzyme mediated processes. Metabolic processes such as primary productivity and respiration increase with rise in temperature, known as the Q_{10} effect (the rate of change in processes over 10°C) but vary considerably among species.

Bioclimatic models predict that the primary effect of increased global temperature will be on seagrasses. Submerged vegetation is also likely to be affected because of alteration in growth rates. The aquatic plant species that have the highest temperature threshold value will be favoured and these mainly include thermo tolerant free-floating and submerged macrophytes such as *Hydrilla verticillata* and *Myriophyllum spicatum* (Short and Neckles, 1999; Hughes, 2000; Rooney and Kalff, 2000; Kotta *et al.*, 2014). Emergent aquatic macrophytes will become more abundant (increase by 25%) as the reproductive capacity including spore production, germination and sporophyte growth will be enhanced (Buschmann *et al*., 2004; Heikkinen *et al*., 2009; Rothausler *et al*., 2009, 2011; Riis *et al*., 2012). Enhancement in growth measured as increase in shoot length, plant height, leaf surface area and biomass production has been reported in *Phalaris arundinacea, Potamogeton natans, Lemna major, Equisetum fluviatile, Typha* on exposure to high temperature (3-7°C above ambient) (Riis *et al*., 2012). The enhanced growth could be attributed to increase in elemental contents especially N and P and increased physiological activities such as photosynthesis and respiration (Riis *et al*., 2012). Enhancement in productivity of seaweeds due to increase in temperature is primarily because of increase in photosynthesis. Increased seed germination in response to rise in temperature has been reported in *Ruppia* sp., *Zostera marina* and *Zostera noltii*. Biochemical and physiological adaptations such as heat shock proteins have been noted in aquatic species to encounter high temperatures (Sorte and Hofmann, 2005; Kim *et al*., 2011; Eggert, 2012). The studies project that phytoplankton might experience temperature-induced increase in photosynthetic rate and hence growth which will support the growth of other plants such as algae (Tokoro *et al*., 2014).

In general net photosynthesis of macrophytes increases with temperature up to an optimum value and then decreases dramatically. Very high temperatures have an overall negative impact on the Net Primary Productivity (NPP) of plants as rate of respiration increases at a greater pace than photosynthesis. Therefore, the plant primary productivity compromise. The changes are evident in microalgae and seagrasses (Rosset *et al*., 2010; Riis *et al*., 2012; Tait and Schiel, 2013; Kotta *et al*., 2014). In seagrasses, the rate of leaf respiration increases more rapidly with rising temperature than does that of photosynthesis, leading to both a steady decrease in the photosynthesis-to-respiration ratio with increasing temperature. A sharp decline of gross photosynthesis, is recorded beyond 30°C (Kotta *et al*., 2014). In eelgrass, *Zostera marina* L., the rate of leaf respiration increases more rapidly with rising temperature than photosynthesis, leading to a steady decrease in the photosynthesis-to respiration ratio (P:R). In nutshell, warming will favor growth of growth of few species, hence the diversity and species richness of macrophytes will decrease (Feuchtmayr *et al*., 2010).

Warmer temperatures increase dissolved organic carbon (humic) concentrations, resulting in browner water in aquatic ecosystems (brownification) which affect the growth and productivity of native and non-native aquatic plant species in mesocosms. *Elodea canadensis*, an aquatic invasive plant, showed higher relative growth rate in terms of length and weight, as well as higher weight to length ratio when grown in brown water. Studies suggest that with global warming, invasive free-floating plants might become more successful at the expense of submerged plants (Netten *et al*., 2010).

Nutrient enrichment: Nutrients are crucial for the growth of macrophytes. Alterations in the nutrient content affect the composition of aquatic plant communities particularly free-floating and rooted macrophytes (Madsen and Cedergreen, 2002). Warm climate support eutrophication (typically oligotrophic-mesotrophic boreal lakes) and hence, increase availability of nutrients such as nitrogen and phosphorus to plants. Increase in phosphorus concentration increase competition between macrophytes and phytoplankton (Jylha *et al*., 2004; Lacoul and Freedman, 2006). This results in phytoplankton dominance and disappearance of macrophytes (Scheffer *et al*., 1993; Declerck *et al*., 2005). Warming lead to a shift from a clear, macrophyte-dominated state to a turbid, phytoplankton-dominated state (Mooij *et al*., 2007). Under eutrophic conditions, seagrasses are often outcompeted by the various algal forms (Short *et al*., 1995). Eutrophication promote algal (benthic and planktonic) growth ultimately decreasing the light reaching the other plants hence decreasing growth, productivity and distribution of macrophytes (Partanen and Luoto, 2006). Macrophyte populations might decrease from nutrient enrichment (Harley, 2011). Studies also indicate that high nitrate concentrations support growth of free-floating species and hence instigate low species richness.

Studies suggest that in few cases free-floating such as *Salvinia natans* have been benefitted from increased temperature and increased nutrient loading but in other reports the growth of the submerged species such as *Elodea nuttallii* have been limited (Netten *et al.,* 2010).

CO_2 concentration: Aquatic plant species use CO_2 or both HCO_3 and CO_2. Free-floating plants use CO_2 (inorganic carbon source) from the air, while submerged species use both CO_2 (sediments, air and water) and HCO_3. Increase in CO_2 concentration will increase photosynthesis leading to enhancement in productivity favoring growth of aquatic plants particularly those using $CO_{2,}$ while survival of other species will be adversely affected. Algae and macrophytes using CO_2 and HCO_{3-} may double their growth rate with higher atmospheric CO_2 (Smolders *et al*., 2002; Tokoro *et al*., 2014). Emergent and floating macrophytes use CO_2 as a carbon source, hence their growth will be promoted from CO_2 increase. Enhancement in growth (2-8 times) has been observed in plants such as *Vallisneria americana*, *Ceratophyllum demersum* and *Hydrilla verticillata* exposed to elevated CO_2 (approx. $700\ \mu mol^{-1}$) concentrations (Alahuhta *et al*., 2011). The increased photosynthetic rate supported height development and production of root, rhizome and leaf biomass. An increased concentration of DOC in the water can stimulate the invasive non-native species such as *Elodea canadensis* by reducing the growth of other competitors, primarily algae and native submerged macrophytes.

The response of seagrasses to long-term increases in CO_2 depends on the physiological and morphological acclimation. The acidification of water due to increasing CO_2 affects the growth and distribution of aquatic macrophytes (Short and Neckles, 1999). Seaweeds will benefit from the increase in inorganic carbon concentration as more CO_2 is available for their accessibility while growth of macroalgae will be reduced (Beardall *et al*., 1998; Kroeker *et al*., 2010; Ejankowski and Lenard, 2015). In nutshell, high CO_2 concentration promotes eutrophication which supports algal growth ultimately decreasing the light reaching the other plants hence decreasing their productivity.

Light conditions: Light is an essential factor that limits the growth of aquatic plants. Eutrophication results in turbidity of the majority of the shallow lakes with transparencies ranging from 0.25-0.5 m, hence suppressing growth of macrophytes by limiting light (Riis *et al*., 2012). Increase in sea level also increases the depth of water thereby reducing the light availability. In turbid situations, only floating plant communities dominate. Growth of *Elodea canadensis, Egeria densa, Lagarosiphon major* showed three-fold decrease in branching and belowground biomass under reduced light (25-50%) conditions (Ejankowski and Lenard, 2015). The productivity of seagrasses showed reduction as photosynthesis will be limited (Short *et al*., 1995). It is predicted that increase in water depth by 50 cm due to sea level rise will reduce available light by 50%, causing 30-40% reduction in seagrass growth. The decrease in growth was evident viz. decline in shoot density, leaf number as observed in species such as *Z. marina* (Ondiviela *et al*., 2014). In contrast only few species such as *T. testudinum* and *C. nodosa* have shown an increase in leaf biomass, width and canopy height because of increased photosynthetic rate (Harley *et al.,* 2012).

Salinity: Increases in sea level alter the salinity level in water bodies. Increases in salinities to 0.5-5.0 ppt are supposed to cause replacement of oligohaline and mesohaline submerged macrophyte populations by seagrasses. Submerged aquatic vegetation is likely to be affected by changing salinity and nutrient imbalance caused due to differences in osmotic potentials between internal and external environments. Salt stress may limit growth directly through insufficient turgor for cell expansion or inhibition in photosynthesis in plants (Riddin and Adams, 2010). Though low salinity levels support growth of seagrasses, very high salinity (at 50 ppt and above) reduce biomass, limit reproduction and vegetative propagation of seagrass species thus affecting their distribution (Short and Neckles, 1999; Kotta *et al*., 2014). Studies suggest stimulation in germination of *Zostera nana*, *Z. marina*, *Z. noltii* and *Z. capricorni* seeds at low salinity levels (1±10 ppt) and improvement in growth of salt tolerant submerged and emergent species such as *Vallisneria americana*, *Ruppia maritima* and *Potamogeton pectinatus* at salinity levels of ~5-18 ppt (mesohaline) (Pearson and Dawson, 2003; Luoto *et al*., 2007; Luoto and Heikkinen, 2008; Heino and Toivonen, 2008; Lampinen and Lahti, 2009; Tingley and Herman, 2009; Kotta *et al*., 2014). Earlier studies have also developed morphological and biochemical adaptations such as salt exclusion mechanisms, thickened cell walls and increased numbers of chloroplasts and mitochondria in leaf epidermal cells to curtail high salinity conditions (Short and Neckles, 1999). Organic acids, nitrogen compounds such as proline, alanine, glutamate and carbohydrates have been reported to function in seagrasses as a strategy to counter increased osmotic potential (Bornette and Puijalon, 2011). Such adaptations allow successful physiological functioning of many seagrass species to saline environments (salinity in oceanic and estuarine environments).

Effect on wetlands: Alteration in factors such as temperature, rainfall, sea-level rise affect the vegetation of coastal and wetland ecosystems to a significant extent (Erwin, 2009). Increase in temperature enhance evaporation which further leads to water loss from the wetland patches and reduce the plant productivity (Scavia *et al.,* 2002; Wrona *et al*., 2006). On the other hand, melting of ice caps cause flooding to create new wetlands (Woo and Young, 2006). Increase in nutrient concentrations, temperature and sediment accumulation (siltation) are supposed to support growth of emergent macrophytes such as *Phragmites australis*, *Equisetum fluviatile*, *Typha latifolia* and *Schoenoplectus lacustris* leading to their increased vegetation cover, hence altering the community structure (Partanen and Luoto, 2006; Park and Blossey, 2008).

CONCLUSION

Alterations in different components of climate affect aquatic vegetation. The responses of climate change will vary among different plant groups in response to changing temperature, light and availability of nutrients. The impact will be evident as alterations in physiology, growth, reproduction of macrophytes and other plant forms. Significant alteration in production of macroalgae, phytoplanktons and macrophytes will have a great impact on the other ecosystems.

Bioclimatic envelope models suggest increase in emergent aquatic plant species followed by an expansion in their distribution. An overall increase in the cover of submerged aquatic vegetation under the projected influences of climate change is supposed to be triggered by seawater warming and an interactive effect of other environmental variables. The overgrowth of emergent aquatic macrophytes might pose a risk for sensitive macrophyte species in boreal freshwater ecosystems.

Although it is impossible to escape the effects of climate especially global warming, a modelling of the vegetation cover might help manage and thereby minimize risk of population collapses.

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