Theor Appl Climatol (2017) 129:1123–1132
DOI 10.1007/s00704-016-1837-3

ORIGINAL PAPER

Vulnerabilities of macrophytes distribution due to climate change

Kaizar Hossain[1] · **Sarita Yadav**[2] · **Shlrene Quaik**[1] · **Gaurav Pant**[3] · **A. Y. Maruthi**[4] · **Norli Ismail**[1]

Received: 6 August 2015 / Accepted: 15 May 2016 / Published online: 1 June 2016

Abstract The rise in the earth's surface and water temperature is part of the effect of climatic change that has been observed for the last decade. The rates of climate change are unprecedented, and biological responses to these changes have also been prominent in all levels of species, communities and ecosystems. Aquatic-terrestrial ecotones are vulnerable to climate change, and degradation of the emergent aquatic macrophyte zone would have contributed severe ecological consequences for freshwater, wetland and terrestrial ecosystems. Most researches on climate change effects on biodiversity are contemplating on the terrestrial realm, and considerable changes in terrestrial biodiversity and species' distributions have been detected in response to climate change. This is unfortunate, given the importance of aquatic systems for providing ecosystem goods and services. Thus, if researchers were able to identify early-warning indicators of anthropogenic environmental changes on aquatic species, communities and ecosystems, it would certainly help to manage and conserve these systems in a sustainable way. One of such early-warning indicators concerns the expansion of emergent macrophytes in aquatic-terrestrial ecotones. Hence, this review highlights the impact of climatic changes towards aquatic macrophytes and their possible environmental implications.

1 Introduction

Global change has been revealed and forecast to have major effects on biodiversity at local, regional and global scales. The global change constitutes a number of different forms of anthropogenic impacts, including land use alterations, nitrogen deposition and invasions of exotic species, much recent interest has been directed at climate change (Sala et al., 2000; Parmesan, 2006; Hossain and Rama Rao, 2014). Although the earth has experienced considerable climate changes in the past, the rate and magnitude of the recent and projected future changes are unprecedented (IPCC, 2001; Hossain et al., 2016). Furthermore, the effect of future climate change on biodiversity has been predicted to be unparalleled, with 15–37 % of terrestrial species possibly facing extinction due to climate change alone in the next 50 years (Thomas et al., 2004), and a similarly dark future has been suggested for freshwater species in the next few decades (Xenopoulos et al., 2005). Biodiversity, integrity and functioning of different ecosystems are facing serious problems on the global scale and freshwaters are one of the most highly threatened ecosystems. Thus, research on the effects of climate change on freshwater organisms and ecosystems has increased hastily in the last decade.

Evaluation of anthropogenic impacts on freshwaters relies on the integrity of community structure of biological groups and on the presence of indicator species that provides information about ecological quality in a water body (Rickert and Hines 1978; Carpenter et al. 2006). Aquatic macrophytes belong to one traditionally studied biological group in ecological assessments. Macrophytes indicate well on long-term changes

---

✉ Norli Ismail
norlii@usm.my; drni2015@gmail.com

[1] Environmental Technology Division, School of Industrial Technology, Universiti Sains Malaysia, 11800 Gelugor, Pulau Pinang, Malaysia

[2] Indian Institute of Tropical Meteorology, Ganeshkhind Road, Pune, Maharashtra, India

[3] Institute of Applied Sciences & Humanities, G.L.A. University, Mathura, UP, India

[4] Department of Environmental Studies, GITAM University, Visakhapatnam, Andhra Pradesh, India

of the littoral zone, but reflect poorer on rapid changes in water quality (Palmer et al. 1992, Melzer 1999).

Vascular plants (emergent, floating or submerged), byrophytes and macro algae in the aquatic environment are all considered as aquatic macrophytes. They play a vital role in preserving the fresh water diversity as they provide living places for other aquatic organism (Thackeray et al. 2010; Akasaka et al. 2010; Akasaka and Takamura 2011).

Seagrasses are plant communities which represent diverse plant forms growing intermingled with algae, and phytoplankton. Aquatic macrophytes are also able to change the abundance of stream fauna and possess the potential to compete for resources such as nutrients, light and space. They also provide physical structure, an increase in habitat complexity and heterogeneity that affect different types of organisms such as invertebrates, fish and water birds.

In rivers and streams, aquatic macrophytes and benthic algae act as the major primary producers (Hari et al., 2006; Schneider et al., 2012). They provide food and habitat, influence sediment composition as well as physical stream characteristics (Maltchik et al., 2007; Istvánovics et al., 2008; Kleeberg et al., 2010). In the aquatic environment, plant tissues play different roles depending on their positions. Table 1 shows the roles of different plant tissues in the aquatic environment, categorized by their tissues' position in the aquatic environment.

Table 1 Roles of macrophytes tissues in aquatic environment

Position of macrophytes tissues	Roles in aquatic environment
In air	-Reduce wind speed -Act as light attenuation -As the storage of nutrients, metals and organic matters -Improve the appearance
In water	-Reduce the velocity of flow -Provide filtering effect by absorption of various debris -Provide physical living or nursery habitats for organisms -Release of photosynthesis oxygen which help in increasing the aerobic degradation in aquatic environment -Uptake and act as storage for nutrients, metals and organic matters
In sediment	-Provide stabilization to the sediment surface (reduce erosion and restrain resuspension) -Provide physical living or nursery habitats for organisms -Release oxygen that facilitate aerobic degradation -Release of antibiotics and phytochelatins -Uptake and act as storage for nutrients, metals and organic matters

Source: Vymazal (2011) and Wang et al. (2015)

Factors such as physico-chemical state of water in terms of pH and transparency of water, sedimentation types, water depth and surface area are believed to affect the distribution and the richness of macrophytes (Geurts et al. 2008). However, James et al. (2005) reported that water chemistry (nutrients and components present) is predominantly vital in determining the richness of macrophytes although Akasaka et al. (2010) indicated that the importance vary with the growth forms of macrophytes. Free-floating macrophytes often have a large impact on freshwater ecosystems. The limitations of carbon hydroxide and sunlight for photosynthesis rarely happened. When nutrient loading is high, free-floating macrophytes will form dense mats that cover the entire surface of the water body. Hence, submerged macrophytes are strongly affected by the decrease in the amount of light penetrated, as well as dissolved inorganic carbon (DIC).

According to the EU Water Frame-work Directive (WFD; European Parliament, 2000; Lekka et al., 2004)), aquatic macrophytes have been listed as bio-indicators as the survival of aquatic macrophytes is highly dependent on environmental factors (Akasaka et al., 2010). One of the early-warning indicators is the expansion of emergent macrophytes in the aquatic-terrestrial ecotones (Alahuhta et al., 2011). Hence, the dispersion and abundance of macrophytes diversity can act as indicators of many environmental conditions and in this review, the focus lies on the immediate effect of climate change towards the growth of macrophytes.

2 Climate change

Climate warming is undeniable. Changes that have been observed since the 1950s are unprecedented. Warming is occurring in the atmosphere, as well as the ocean. Snow and ice are diminishing and the level of sea water has risen. However, ocean warming is more evident on the surface. According to IPCC (2014), the upper 75 m of the ocean is warmed by 0.11 (0.09 to 0.13) °C per decade over the period 1971 to 2010. The shrinking of glaciers is happening worldwide. The loss of the mass of glaciers has contributed to the rise of the sea level throughout the twentieth century.

The concentration of greenhouse gases (GHGs) in the atmosphere is highest in at least 800,000 years (IPCC, 2014). Concentrations of GHGs such as methane, nitrous oxide and carbon dioxide are showing increment since 1750, and concentration of carbon dioxide is increasing at the fastest rate for the year 2002–2011 (2.0 ± 0.1 ppm/year). The concentration of methane has shown increment after being stable for many years since the late 1990s. Nitrous oxide has shown steady increment at the rate of 0.73 ± 0.03 ppb/year over the last three decades (IPCC, 2014).

The climate has shown profound alterations over the years. Increases in carbon dioxide (CO_2) (an increase from 280 to

650 ppm) and other greenhouse gases have contributed to the increase in global temperatures (IPCC, 2007). Earth surface temperatures have increased by 0.6 °C and the mean global surface temperatures elevated for 1.4 to 5.8 °C in the next century is predicted (IPCC, 2007). An increment of 2–4 °C in temperature is expected by the end of the twenty-first century by; a 2–4 °C temperature increase is expected in the Mediterranean region in spring (Stocker et al., 2013). In the climatic region, freshwater ecosystems are often shallow water bodies or small lakes. Hence, they are predominantly prone to climate change (Álvarez-Cobelas et al., 2005; Morecroft and Keith, 2009; Parcerisas et al., 2012).

Climate change has imposed new selection pressure towards the distribution and abundance of the widespread macrophytes species (Rothausler et al., 2011; Lovejoy and Hannah, 2005). Higher tolerance level towards temperature change caused by climate change is expected specifically for species existing in an environment with numerous variables. Phenotypic features and phenotypic plasticity of the species may be changed to adapt in response to climate change (Walters, 2005).

Rise in temperature, CO_2 concentration and alterations in precipitation affect growth, productivity and distribution of terrestrial and aquatic vegetation directly and indirectly (Lucht et al., 2006; Wrona et al., 2006; Heikkinen et al., 2009; Heino et al., 2009; Peeters et al., 2013). Alterations in water chemistry and hydrological regimes affect the structure and function of aquatic ecosystems (freshwater and marine) especially in the boreal regions (Rahel and Olden, 2008; Heino et al., 2009; Knutti and Sedlacek, 2013). Changes in climate alter the characteristics of the water. These include high nutrient loading from the catchment areas to the lakes (Jeppesen et al., 2009a, b; 2010, 2011, 2012, 2014) and high salinity causing a shift to oligosaline or mesosaline conditions (Wrona et al., 2006; Beklioglu and Tan, 2008; Jeppesen et al., 2009a, Jeppesen et al., 2009b; Beklioglu et al., 2011; Trenberth et al., 2014).

Aquatic macrophytes are keystone species in the aquatic ecosystems. Hence, it becomes mandatory to study and discuss the effects of climate change on aquatic vegetation.

3 Growth and distribution of macrophytes influenced by abiotic factors for climate change

Temperatures of river and lake water are expected to be affected imminently by climate change (Hammond and Pryce, 2007). As river water temperatures are in close equilibrium with the air temperature, when the air temperature increases, the river temperature will be affected as well. The European Environment Agency (EEA) (EEA 2007) reported, in the past 100 years, a temperature rise of 1–3 °C has been observed in major European rivers. In addition, Hari et al. (2006) reported significant increment in temperature for water courses in Switzerland at all altitudes.

Temperature influences plant growth extensively. However, the effects of increased temperature somehow depend on individual species and their thermal tolerances. Temperature may alter plant phenology, for instance, busting of leaf bud, flowering period, nutrient uptake, competition between species and lastly the metabolic events including photosynthesis, respiration and enzyme-mediated processes (Meis et al., 2009; Thackeray et al., 2010; Mooij et al., 2005).

Emergent aquatic macrophytes will become more abundant (increase by 25 %) as the reproductive capacity including spore production, germination and sporophyte growth will be enhanced (Heikkinen et al., 2009; Anja et al., 2009).

Enhancement in growth measured as an increase in shoot length, plant height, leaf surface area and biomass production has been reported in *Phalaris arundinacea*, *Potamogeton natans*, *Lemna major*, *Equisetum fluviatile*, and *Typha* on exposure to high temperature (3–7 °C above ambient). The enhanced growth could be attributed to the increase in elemental contents especially N and P and increased physiological activities such as photosynthesis and respiration. Enhancement in productivity of seaweeds due to the increase in temperature is due to the increase in photosynthesis. Increased seed germination in response to the increase 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).

In contrast, very high temperatures will have an overall negative impact on the net primary productivity (NPP) of plants as an increase in the rate of respiration is more rapid compared to photosynthesis. At higher temperatures, the rate of respiration increases at a faster speed, and primary productivity compromised. The changes are evident in microalgae and seagrasses (Rosset et al., 2010; Tait and Schiel, 2013). In eelgrass, *Z. 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) (Short and Neckles, 1999; Demars and Trémolières 2009).

Higher temperature plays a vital role in accelerating most of the chemical reactions and bacteriological processes. Therefore, the increase in temperature due to climate change will affect the growth of macrophytes. Elevation in temperature had a small effect on macrophytes relative to nutrient effect (Feuchtmayr et al., 2007). In a nutshell, warming will favour the growth of a few species; hence, the diversity and species richness of macrophytes will decrease (Feuchtmayr et al., 2010).

4 Nutrient

According to Brown et al. (2007), climate change is expected to have effects on river regimes, river flow velocity, hydraulic characteristics, water levels, inundation patterns, residence times, changes in the wetted areas as well as habitat availability and connectivity across habitats. Most probably, under the influence of climate change, rivers will be under low flow conditions during summer. Biochemical oxygen demand (BOD) and phosphorus level would increase. However, ammonia levels would reduce as higher nitrification rates that may occur. Hence, nitrate concentration will increase as ammonia decays (Kleeberg et al., 2010; Whitehead et al., 2009). Suspended solids and nutrients from land are transported by runoff to water bodies; thus, they stimulate the growth of emergent aquatic macrophytes. Alteration in the nutrient composition will particularly affect the free-floating and rooted macrophytes (Feuchtmayr et al. 2007; Human et al. 2015).

Warm climate support eutrophication (typically oligotropic-mesotrophic boreal lakes) and hence increases the availability of phosphorus to plants. High phosphorus concentrations negatively influence the growth of submerged macrophytes. Increase in phosphorous concentration increase competition between macrophytes and phytoplankton (Lacoul and Freedman, 2006). This results in phytoplankton dominance and the disappearance of macrophytes (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).

Thus, a long-term effect of global change may cause more rapid eutrophication and accelerate the loss of seagrass habitats. Eutrophication promotes algal (benthic and planktonic) growth, ultimately decreasing the light reaching the other plants, hence decreasing growth, productivity and distribution of macrophytes. In a nutshell, increased nutrient loading increases the abundance of algae but decreases the diversity of other macrophytes (Partanen and Luoto, 2006).

Studies also indicate that high nitrate concentrations support the growth of free-floating species and hence instigate low species richness. Macrophyte populations might decrease from nutrient enrichment (Harley, 2011). Nutrient enrichment stimulates the production of planktonic microalgae and opportunistic macroalgae at the cost of seagrasses and perennial macroalgae (Human et al. 2015).

Nevertheless, severe eutrophication (nitrogen or phosphorus overloading) has caused a decrease in species diversity and disappearance of submerged macrophytes (Ansari et al., 2011; Xing et al., 2013). However, in eutrophic condition, high macrophytes diversities can still be observed (Le Bagousse-Pinguet et al., 2012). Sand-Jensen et al. (2008) indicated that the declining of diversities is only at the very end of the eutrophication gradient.

5 CO_2 concentration

Aquatic plant species survive on either CO_2 or both HCO_3 and $CO_{2.}$ The CO_2 (inorganic carbon source) in the air is mainly being utilized by free-floating plants whereas submerged species survived on both CO_2 from sediments, air and water and $HCO_{3.}$ The rise of CO_2 level in the atmosphere will directly promote the photosynthesis process leading to intensification of productivity which favours the growth of aquatic plants specifically those mainly utilizing $CO_{2.}$ Nevertheless, the survival of other species may be negatively affected (BhupinderDhir, 2015).

Limiting factors for the growth and the productivity of submerged macrophytes are the limited availability of free CO_2 in natural water bodies and limited uptake of inorganic carbon due to high diffusion resistance. Emergent and floating macrophytes use CO_2 as a carbon source; hence, their growth will be promoted as a direct result of the CO_2 increase. Enhancement of 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 μmol^{-1}) concentrations (Alahuhta et al., 2011). The increased photosynthetic rate supported height development and production of more root, rhizome and leaf biomass. However, the response of seagrasses to long-term increases in CO_2 depends on the physiological and morphological acclimation. Seaweeds will benefit from the increase in inorganic carbon concentration as more CO_2 is more accessible while the growth of macroalgae will be reduced (Kroeker et al., 2010).

The growth rate of algae and macrophytes utilizing CO_2 and HCO_3 may be doubled due to atmosphere CO_2 elevation under the eutrophic condition. On the other hand, threefolds of growth of macrophytes that are restricted to CO_2 assimilation may be observed (Schippers et al., 2004).

The increase in CO_2 concentration in the atmosphere is very likely to affect plant traits including photosynthesis and plant growth. Acclimation towards the climate changes will be essential for the plant to compete and expand. Phenotypic plasticity has been known as a vital feature of submerged aquatic plants for capturing resources (Hyldgaard and Brix, 2012; Malheiro et al., 2013). Malheiro et al. (2013) found a strong phenotypic response with submerged species *Myriophyllum aquaticum* (Vell.) Verdc. The leaf surface was reported to be maximized in order to increase CO_2 uptake.

Increased concentrations of free CO_2 may bring disadvantages for some species that survive under low light intensity. Hence, the high concentrations of free CO_2 may not have significant impact towards submerged species as their invasiveness is partly due to their capability to use bicarbonate. The study also suggested that the invasive bicarbonate users responded little to changes in free CO_2 availability. Hence, in the future, the increase of free CO_2 concentration in water bodies may be more likely to favour species that are currently limited by the ambient free CO_2 concentration (Caldeira and Wickett 2005; Eller et al., 2015).

Carbon and light availability are the two major factors that are interrelated with each other on the effects on growth and photosynthetic traits of macrophytes especially the submerged species. The rate of supply of dissolved inorganic carbon (DIC) is one of the major constraints associated with underwater photosynthesis. However, aquatic macrophytes often have adaptive features which will assuage this constraint. Sediment and atmospheric CO2 pools will be utilized in conjunction with a physiological and biochemical mechanism to enhance the efficiency of carbon uptake.

6 Light conditions

Light intensity is a crucial limiting factor when it comes to the growth of aquatic plants. Eutrophication indirectly resulted from climate change has affected water turbidity of major shallow lakes with transparencies ranging from 0.25 to 0.5 m. This has resulted in growth suppression of macrophytes as only very limited light is available. On the other hand, the rising of sea level has further increased the water depth which thereby reduced the availability of light. Under high water turbidity, only floating plant communities will strive (BhupinderDhir, 2015). According to Hussner et al. (2010, 2011), the growth of *Elodea canadensis*, *Egeria densa*, and *Lagarosiphon major* decreased by threefold in branching, as well as the below-ground mass under reduced light conditions (25–50 %). Variations in light and temperature have led to acclimation within the submerged aquatic plants.

In a study conducted by Eller et al. (2015) with four invasive aquatic plants, the results indicated that under high free CO_2 concentration, *Hydrilla verticillata* showed 12 times higher root/shoot ratio in low light intensity condition compared to those in high light intensity condition. As for *E. Canadensis*, higher main and total shoot lengths were reported in high light intensity. However, the number of internodes was greater in low light intensity condition. Few species such as *Thalassia testudinum* and *Cymodocea nodosa* have shown an increase in leaf biomass, width and canopy height because of the increased photosynthetic rate (Harley et al., 2012).

Morphological adaptation due to light intensity was observed in *Charahispida* and *Cattleya intermedia*. Branches were reported to be pointing steeply upward towards the high light intensity condition (Schneider et al., 2015). The stems of *Chara* that were branching out towards the light under high light intensity can be interpreted as a protective mechanism in order to protect the plant from excessive light (Schneider et al., 2015). Enhanced elongation under low light intensities is construed as a method to increase light harvest by growing into an area with higher available light (Blindow and Schütte, 2007).

7 Salinity

Coastal flooding and changes in sea level caused by climate change will affect the salinity of estuaries. A slight increase in salinity to 0.5–5.0 parts per thousand will lead to the replacement of species such as *oligohaline* and *mesohaline* submerged macrophyte populations by seagrasses (BhupinderDhir, 2015). Low salinities (1 ± 10 ppt) stimulate germination of *Zostera nana*, *Z. marina*, *Z. noltii* and *Zostera capricorni* seeds, and while in high salinities, the seedlings survival is affected. Germination of many upper estuarine submerged macrophyte species has been shown to decrease with the increase in salinity. The salinity of ~5–18 parts per thousand (mesohaline) supports the growth of salt-tolerant submerged and emergent species such as *Vallisneria americana*, *Ruppia maritima* and *Potamogeton pectinatus* (Luoto et al., 2007; Luoto and Heikkinen, 2008; Heino and Toivonen, 2008; Lampinen and Lahti, 2009; Tingley and Herman, 2009).

Localized elimination of non-halophytic macrophytes species was caused by a drastic rise in salinity. Though these may not change the community's composition, evidence suggested that such salinity elevation could modify the habitat ranges of non-halophytic macrophyte species in wetlands by reducing their inundation stress tolerance (Salter et al., 2008). The rise in salinity will probably restrict the ability of macrophytes to alleviate the effect of rising water levels. Keddy (2010) reported macrophytes species strongly displayed zonation as a result of their inundation tolerance limit as inundation reduces the availability of light and atmospheric gases to plants and species. As a result, the reduction in tolerance towards inundation due to the increase in salinity will control the potential of elevation ranges of susceptible species within salt-affected wetlands (Johns et al. 2014).

Plants develop morphological and biochemical adaptations such as salt exclusion mechanisms, thickened cell walls and increased numbers of chloroplasts and mitochondria in leaf epidermal cells. Various organic acids, nitrogen compounds such as proline, alanine, glutamate and carbohydrates also function internally in seagrasses to counter increased osmotic potential. Increases in salinity caused changes in seagrass leaf ultrastructural morphology and increased the complexity of the plasmalemma mitochondrial system (Bornette and Puijalon, 2011). Such adaptations to saline environments allow successful physiological functioning of many seagrass species within the upper ranges of the salinity in oceanic and estuarine environments. Nevertheless, very limited studies were carried out on macrophytes' growth in response to various conditions in the last decade (Table 2).

Table 2 Macrophytes growth in response to various conditions and stress in the last decade'

Studies	Macrophytes	Elements	Reference
Stream condition (riparian disturbance)	Emergent and submerged species -*Hygrophila angustifolia* R.Br. -*Sagittaria* sp. -*Colocasia esculenta* (L.) Schott -*Ageratum conyzoides* L. subsp. Conyzoides -*Sphagneticola* (*Wedelia*) *trilobata* (L.) Pruski- -Unidentified Asteraceae -*Hydrocotyle* sp. 1 -*Hydrocotyle* sp. 2 -*Drymaria cordata* (L.) Willd. ex Roem & Schult. -*Commelina* spp. -*Cyperus aquatilis* R.Br. -*Cyperus aromaticus* (Ridl.) Mattf. & Kuek.* -*Cyperus odoratus* L. -*Cyperus involucratus* Rottb. -*Cyperus polystachyos* Rottb. -*Cyperus sphacelatus* Rottb. -*Cyperus trinervis* R.Br. -*Schoenoplectus mucronatus* (L.) Palla ex J.Kearn. -Unidentified Cyperaceae -*Elatine gratioloides* A.Cunn. -*Myriophyllum* sp. -*Blyxa* sp. -*Hydrilla verticillata* (L.f.) Royle -*Vallisneria nana* R.Br. -Unidentified -Hydrocharitaceae *Lomandra* sp. -Unidentified Malvaceae -*Arundodonax* L. var. donax* -*Axonopus fissifolius* (Raddi) Kuhlm. -*Chrysopogon filipes* (Benth.) Reeder -*Cyrtococcum oxyphyllum* (Hochst. ex Steud.) Stapf -*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs -*Pennisetum purpureum* Schumach. -*Sacciolepisindica* (L.) Chase-*Sorghum halepense* (L.) Pers. -*Urochloa mutica* (Forssk.) T.O. Nguyen -Unidentified *Poaceae* -*Philydrum lanuginosum* Banks & Sol. Ex Gaertn. -*Cladopus queenslandicus* (Domin) C.D.K. Cook -*Persicaria barbata* (L.) H. Hara -*Persicaria lapathifolia* (L.) Grey -*Persicaria strigosa* (R.Br.) H. Gross -*Potamogeton javanicus* Hassk. -*Potamogeton* sp.	–	Mackay et al. 2010
Metal accumulation	-*Phragmites australis* -*Typhacapensis* -*Spartina maritima*	Cd Cu Pb, Zn	Phillips et al. 2015
Trace elements accumulation	-*Najas marina* -*Potamogeton lucens* -*Nuphar lutea* -*Potamogeton nodosus*	As Cr Zn Ni Pb Cu	Mazej and Germ 2009
Toxicity of herbicide fungicides and wood preservative/biocide	-*Elodea canadensis* -*Elodea nuttallii* -*Myriophyllum spicatum* -*Potamogeton crispus* -*Ranunculus circinatus*	Asulam Chlorothalonil Fluazinam Pentachlorophenol	Arts et al. 2008
Sampling and temporal variation, phosphorus concentration and climate stress (annual growing degree days)	-*Chara* spp.	–	Beck et al. 2014
Ground water-fed river towards macrophytes distribution	-*Azolla filiculoides* Lam -*Berula erecta* (*Huds*) Coville -*Butomus umbellatus* L. -*Callitriche obtusangula* Le Gall -*Ceratophyllum demersum* L.	CO_2 pCO_2 NH_4 PO_4	Demars and Trémolières 2009; Takamura et al. 2009

Table 2 (continued)

Studies	Macrophytes	Elements	Reference
	-*Chara vulgaris* L. -*Elodea canadensis* Michx. -*Elodea callitrichoides* (Rich.) Casp. -*Elodea nuttallii* (Planch.) H. St. John. -*Enteromorpha intestinalis* (L.) Link -*Fontinalis antipyretica* Hedw. -*Groenlandia densa* (L.) Fourr. -*Hydrodictyon reticulatum* (L.) Bory -*Lamprocystis roseopersicina* (Kützing) Schroeter -*Lemna minor* L./*minuta* Kunth -*Lemna trisulca* L. -*Mentha aquatica* L. -*Myosotis scorpioides* L. -*Myriophyllum spicatum* L. -*Myriophyllum verticillatum* L. -*Nuphar lutea* (L.) Sm. -*Potamogeton coloratus* Hornem. -*Potamogeton crispus* L. -*Potamogeton friesii* Rupr. -*Potamogeton pectinatus* L. -*Potamogeton perfoliatus* L. -*Potamogeton pusillus* L. -*Potamogeton* × *fluitans* Roth. -*Ranunculus fluitans* Lam. *Rorippa nasturtium-aquaticum* (L.) Hayek -*Sparganium emersum* Rehmann -*Spirodela polyrhiza* (L.) Schleid. -*Spirogyra* link -*Veronica anagallis*-aquatica L. -*Veronica beccabunga* L. -*Zannichellia palustris* L.		
Trace elements transfer	-*Ranunculus acris* L. -*Phragmites australis* (Cav.) Trin. Ex Steud. -*Carex riparia* Ehrh., -*Lythrum salicaria* L. -*Iris pseudacorus* L., -*Juncus effusus* L., -*Phalaris arundinacea* L.	Cu Zn, Cd Cr Pb Ni Mo	Marchand et al. 2014
Environmental gradient (light deficiency and wave disturbance)	Submerged macrophytes	–	Istvánovics et al. 2008
Plastic responses to free CO2 and light	-*Elodea canadensis* -*Egeria densa* -*Hydrilla verticillata* -*Ceratophyllum demersum*	–	Eller et al. 2015
UVB radiation exposure	-*Chara baltica* -*Chara hispida* -*Chara vulgaris* -*Nitella hyalina* -*Myriophyllum spicatum*	–	Rubio et al. 2015

8 Conclusions and future prospective

Climate represents an important part of vegetation distribution globally. Each species has its own distribution patterns and the limitations of which are mostly defined by climate at a worldwide scale. Vegetation distribution patterns show the influence of climatic change towards plant survival, physiology and growth, as well as the climatic effects on ecological interactions (competitions, pollination and herbivory). Different types of plants are adapted to the different climatic conditions. Hence, it is reasonable to expect that climatic change would gradually lead to a change in species distributions and community composition (Morecroft and Keith, 2009).

Studies demonstrated that alterations in different components of climate will affect aquatic vegetation to a broader extent. The responses of assemblages will vary among different plant groups in response to changing temperature, light and the availability of nutrients. Impact of climate changes is evident in terms of effects on their physiology, growth, reproduction and survival in macrophytes. Bioclimatic envelope models suggested an increase in emergent aquatic plant species followed by an expansion in their distribution.

Impact on macrophytes growth and distribution brought by climatic change is inevitable. Anthropogenic activities have caused endless possibilities of pollution towards the natural environment and macrophytes habitat. Diversity and distribution of macrophytes may be altered due to climate change just as indicated in studies. Increase in nutrient concentrations, temperature and sediment accumulation (siltation) will support the growth of emergent macrophytes such as *Phragmites australis*, *E. fluviatile*, *Typhalatifolia* and *Schoenoplectus lacustris* leading to their increased vegetation cover, hence altering the community structure (Partanen and Luoto, 2006; Park and Blossey, 2008). Significant alteration in the production of macroalgae, phytoplanktons and macrophytes will have a great impact on the other ecosystems. Hence, macrophytes can be taken as a reliable bio-indicator to study the relationships between environmental disturbance and vegetation growth. Responses to vegetation growth in relation to temperature have been the most imminent. However, there is no doubt that in a long run, a local change in precipitation or other climatic change may become more significant due to the global rise of temperature.

Acknowledgment The authors acknowledge The World Academic of Science (TWAS), Italy, and Universiti Sains Malaysia, Malaysia, for providing world class infrastructure to continue the research work.

References

Akasaka M, Takamura N (2011) The relative importance of dispersal and the local environment for species richness in two aquatic plant growth forms. Oikos 120(1):38–46

Akasaka M, Takamura N, Mitsuhashi H, Kadono Y (2010) Effects of land use on aquatic macrophyte diversity and water quality of ponds. Freshw Biol 55:909–922

Alahuhta J, Heino J, Luoto M (2011) Climate change and the future distributions of aquatic macrophytes across boreal catchments. J Biogeogr 38:383–393

Álvarez-Cobelas M, Catalán J, García de Jalón D (2005) Impactossobre los ecosistemasacuáticoscontinentales. In: Moreno JM (ed) Evaluación Preliminar de los Impactosen Espanapor Efectodel Cambio Climático. Ministerio de Medio Ambiente y Universidad de Castilla-La Mancha, Madrid, pp. 113–146

Anja RE, Esteban HTIA, Ulf K, Beatriz TGF, Martin T (2009) Effect of temperature and grazing on growth and reproduction of floating Macrocystisspp. (Phaeophyceae) along a latitudinal gradient. J Phycol 45:547–559

Ansari A, Khan F, Gill S, Varshney J (2011) Aquatic plant diversity in eutrophic ecosystems. In: Ansari AA, Singh Gill S, Lanza GR, Rast W (eds) Eutrophi- cation: causes, consequences and control. Springer, Netherlands

Arts GHP, Belgers JDM, Hoekzema CH, Thissen JTNM (2008) Sensitivity of submersed freshwater macrophytes and endpoints in laboratory toxicity tests. Environmental Pollution 153(1):199–206

Beck MW, Tomcko CM, Valley RD, Staples DF (2014) Analysis of macrophyte indicator variation as a function of sampling, temporal, and stressor effects. Ecol Indic 46:323–335

Beklioglu M, Tan CO (2008) Restoration of a shallow Mediterranean lake by biomanipulation complicated by drought. Fundam Appl Limnol 171:105–118

Beklioglu M, Meerfhoff M, Sondergaard M, Jeppesen E (2011) Eutrophication and restoration of shallow lakes from a cold temperate to a warm Mediterranean and a (sub) tropical climate. In: Ansari AA, Singh Gill G, Lanza GR, Rast W (eds) Eutrophication: causes, consequences and control, 1st edn. Springer, New York, pp. 91–108

BhupinderDhir (2015) Status of aquatic macrophytes in changing climate: a perspective. J Environ Sci Technol 8(4):139–148

Blindow I, Schütte M (2007) Elongation and mat formation of Chara aspera under different light and salinity conditions. Hydrobiologia 584:69–76

Bornette G, Puijalon S (2011) Response of aquatic plants to abiotic factors: a review. Aquat Sci 73:1–14

Brown LE, Hannah DM, Milner AM (2007) Vulnerability of alpine stream biodiversity to shrinking glaciers and snowpacks. Glob Chang Biol 13(5):958–966

Caldeira K, Wickett ME (2005) Ocean model predictions of chemistry changes from carbon dioxide emissions to the atmosphere and ocean. J Geophys Res 110. doi:10.1029/2004JC002671

Carpenter SR, DeFries R, Dietz T, Mooney HA, Polasky S, Reid WV, Scholes RJ (2006) Millennium ecosystem assessment: research needs. Science 13:257–258

Declerck S, Vandekerkhove J, Johansso LS, Muylaert K, Conde-Porcuna JM (2005) Multi-group biodiversity in shallow lakes along gradients of phosphorus and water plant cover. Ecology 86:1905–1915

Demars BOL, Trémolières M (2009) Aquatic macrophytes as bioindicators of carbon dioxide in groundwater fed rivers. Sci Total Environ 407(16):4752–4763

EEA (European Environment Agency) (2007) Climate change and water adaptation issues. EEA Tech. Report no. 2/2007, Copenhagen, Denmark

Eggert A (2012) Seaweed responses to temperature. Seaweed Biol Ecol Stud 219:47–66

Eller F, Alnoee AB, Boderskov T, Guo WY, Kamp AT, Sorrell BK, Brix H (2015) Invasive submerged freshwater macrophytes are more plastic in their response to light intensity than to the availability of free CO_2 in air-equilibrated water. Freshw Biol 60(5):929–943

European Parliament (2000) Directive 2000/60/EC of the European Parliament and of the council establishing a framework for community action in the field of water policy. OJEC 43:1–72

Feuchtmayr H, McKee D, Harvey IF, Atkinson D, Moss B (2007) Response of macroinvertebrates to warming, nutrient addition and predation in large-scale mesocosm tanks. Hydrobiologia 584(1): 425–432

Feuchtmayr H, Moss B, Harvey I, Moran R, Hatton K, Connor L, Atkinson D (2010) Differential effects of warming and nutrient loading on the timing and size of the spring zooplankton peak: an experimental approach with hypertrophic freshwater mesocosms. J Plankton Res 32:1715–1725

Geurts JJM, Smolders AJP, Verhoeven JT, Roelofs JGM, Lamers LPM (2008) Sediment Fe: PO_4 ratio as a diagnostic and prognostic tool for the restoration of macrophyte biodiversity in fen waters. Freshw Biol 53(10):2101–2116

Hammond D, Pryce A R (2007) Climate change impacts and water temperature. Environment Agency Science Report SC060017/SR, Bristol, UK

Hari R, Livingstone D, Siber R, Burkhardt-Holm P, Güttinger H (2006) Consequences of climatic change for water temperature and brown trout populations in alpine rivers and streams. Glob Chang Biol 12(1):10–26

Harley CDG (2011) Climate change, keystone predation and biodiversity loss. Science 334:1124–1127

Harley CDG, Anderson KM, Demes KW, Jorve JP, Kordas RL, Coyle TA, Graham MH (2012) Effects of climate change on global seaweed communities. J Phycol 48:1064–1078

Heikkinen RK, Leikola N, Fronzek S, Lampinen R, Toivonen H (2009) Predicting distribution patterns and recent northward range shift of an invasive aquatic plant: Elodea canadensis in Europe. BioRisk 2: 1–32

Heino J, Toivonen H (2008) Aquatic plant biodiversity at high latitudes: patterns of richness and rarity in Finnish freshwater macrophytes. Boreal Environ Res 13:1–14

Heino J, Virkkala R, Toivonen H (2009) Climate change and freshwater biodiversity: detected patterns, future trends and adaptations in northern regions. Biol Rev 84:39–54

Human LRD, Snow GC, Adams JB, Bate GC, Yang SC (2015) The role of submerged macrophytes and macroalgae in nutrient cycling: a budget approach. Estuar Coast Shelf Sci 154:169–178

Hussner A, Hoelken HP, Jahns P (2010) Low light acclimated submerged freshwater plants show a pronounced sensitivity to increasing irradiances. Aquat Bot 93:17–24

Hussner A, Hofstra D, Jahns P (2011) Diurnal courses of net photosynthesis and photosystem II quantum efficiency of submerged Lagarosiphon major under natural light conditions. Flora 206:904–909

Hyldgaard B, Brix H (2012) Intraspecies differences in phenotypic plasticity: invasive versus non-invasive populations of Ceratophyllumdemersum. Aquat Bot 97:49–56

IPCC (2001) Climate change 2001: The Scientific Basis. Intergovernmental Panel on Climate Change: Workinh Group I. http://www.grida.no/climate/ipcc_tar/wg1/index.htm

IPCC (2007) Climate change 2007: Synthesis report: contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. IPCC, Geneva, Switzerland, p 1–104

IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Pachauri RK, Meyer LA (eds.). IPCC, Geneva, Switzerland, p 151

Istvánovics V, Honti M, Kovács Á, Osztoics A (2008) Distribution of submerged macrophytes along environmental gradients in large, shallow Lake Balaton (Hungary). Aquat Bot 88(4):317–330

James C, Fisher J, Russell V, Collings S, Moss B (2005) Nitrate availability and hydrophyte species richness in shallow lakes. Freshw Biol 50:1049–1063

Jeppesen E, Kronvang B, Meerhoff M, Sondergaard M, Hansen KM (2009b) Climate change effects on runoff, catchment phosphorus loading and lake ecological state and potential adaptations. J Environ Qual 38:1930–1941

Jeppesen E, Kronvang B, Olesen JE, Sondergaard M, Hoffmann CC (2011) Climate change effects on nitrogen loading from cultivated catchments in Europe: implications for nitrogen retention, ecological state of lakes and adaptations. Hydrobiologia 663:1–21

Jeppesen E, Meerhoff M, Davidson TA, Trolle D, Sondergaard M (2014) Climate change impacts on lakes: an integrated ecological perspective based on a multi-faceted approach, with special focus on shallow lakes. J Limnol 73:84–107

Jeppesen E, Moss B, Bennion H, Carvalho L, DeMeester L (2010) Interaction of climate change and eutrophication. In: Battarbee KR, Moss B (eds) Climate change impacts on freshwater ecosystems. Blackwell Publishing Ltd., Berlin, Germany, pp. 119–151

Jeppesen E, Moss B, Bennion H, Friberg N, Gessner MO (2009a) Interaction of climate and eutrophication. In: Kernan M, Battarbee R, Moss B (eds) Changing climate and changing freshwaters: a European perspective. Blackwell, Berlin, Germany

Jeppesen, E, Sondergaard M, Lauridsen, TL, Liboriussen L, Bjerring R (2012) Recent climate induced changes in freshwaters in Denmark. In: Goldman CR, Kumagari M, Robarts RD (Eds.) Climatic change and global warming of inland waters: impacts and mitigation for ecosystems and societies. New York, USA, ISBN-13: 9781118470619, p 156–171

Johns C, Ramsey M, Bell D, Vaughton G (2014) Does increased salinity reduce functional depth tolerance of four non-halophytic wetland macrophyte species? Aquat Bot 116:13–18

Hossain K, Rama Rao A (2014) Environmental change and it's affect. Eur J Sustain Dev 3(2):89–96

Hossain K, Quaik S, Ismail N, Rafatullah M, Ali I, Hatta ZA, Avasn M, Pant G, Rameeja S (2016) Climate change- perceived impacts on agriculture, vulnerability, and response strategies for improving adaptation practice in developing countries (South Asian Region). Int J Agric Res 11(1):1–12

Keddy P (2010) Wetland ecology: principles and conservation, second edn. Cambridge University Press, Cambridge

Kim E, Park HS, Jung Y, Choi DW, Jeong WJ (2011) Identification of the high-temperature response genes from Porphyraseriata (Rhodophyta) expression sequence tags and enhancement of heat tolerance of *Chlamydomonas* (Chlorophyta) by expression of the > Porphyra HTR2 gene. J Phycol 47:821–828

Kleeberg A, Kohler J, Sukhodolova T, Sukhodolov A (2010) Effects of aquatic macrophytes on organic matter deposition, resuspension and phosphorus entrainment in a lowland river. Freshw Biol 55(2):326–345

Knutti R, Sedlacek J (2013) Robustness and uncertainties in the new CMIP5 climate model projections. Nat Clim Chang 3:369–373

Kroeker KJ, Kordas RL, Crim RN, Singh GG (2010) Meta-analysis reveals negative yet variable effects of ocean acidification on marine organisms. Ecol Lett 13:1419–1434

Lacoul P, Freedman B (2006) Environmental influences on aquatic plants in freshwater ecosystems. Environ Rev 14:89–136

Lampinen R, Lahti T (2009) Plant atlas of Finland 2008. University of Helsinki, The Finnish Museum of Natural History, Botanical Museum, Helsinki

Le Bagousse-Pinguet Y, Liancourt P, Gross N, Straile D (2012) Indirect facilitation promotes macrophyte survival and growth in freshwater ecosystems threatened by eutrophication. J Ecol 100:530–538

Lekka E, Kagalou I, Lazaridou-Dimitriadou M, Albanis T, Dakos V, Lambropoulou D, Sakkas V (2004) Assessment of the water and habitat quality of a Mediterranean River (Kalamas, Epirus, Hellas), in accordance with the EU Water Framework Directive. Acta Hydrochim Hydrobiol 32:175–188

Lovejoy TE, Hannah L (2005) Climate change and biodiversity. Yale University Press, New Haven

Lucht W, Schaphof S, Erbrecht T, Heyder U, Cramer W (2006) Terrestrial vegetation redistribution and carbon balance under climate change. Carbon Balance Manage 1:6

Luoto M, Virkkala R, Heikkinen RK (2007) The role of land cover in bioclimatic models depends on spatial resolution. Glob Ecol Biogeogr 16:34–42

Luoto M, Heikkinen RK (2008) Disregarding topographical heterogeneity biases species turnover assessments based on bioclimatic models. Glob Chang Biol 14:483–494

Mackay SJ, James CS, Arthington AH (2010) Macrophytes as indicators of stream condition in the wet tropics region, Northern Queensland, Australia. Ecol Indic 10(2):330–340

Malheiro ACE, Jahns P, Hussner A (2013) CO_2 avail- ability rather than light and temperature determines growth and phenotypical responses in submerged Myriophyllum aquaticum. Aquat Bot 110: 31–37

Maltchik L, Rolon AS, Schott P (2007) Effects of hydrological variation on the aquatic plant community in a floodplain palustrine wetland of Southern Brasil. Limnology 8:23–28

Marchand L, Nsanganwimana F, Cook BJ, Vystavna Y, Huneau F, Le Coustumer P, Mench M (2014) Trace element transfer from soil to leaves of macrophytes along the Jalled'Eysines River, France and their potential use as contamination biomonitors. Ecol Indic 46:425–437

Mazej Z, Germ M (2009) Trace element accumulation and distribution in four aquatic macrophytes. Chemosphere 74(5):642–647

Meis S, ThackreyS J, JonesI D (2009) Effects of recent climate change on phytoplankton phenology in a temperate lake. Freshw Biol 54: 1888–1898

Melzer A (1999) Aquatic macrophytes as tools for lake management. Hydrobiologia 395/396:181–190

Mooij WM, Hulsmann S, Domis LNS, Nolet BA, Bodelier PLE (2005) The impact of climate change on lakes in the Netherlands: a review. Aquat Ecol 39:381–400

Mooij WM, Janse JH, Domis LNS, Hulsmann S, Ibelings BW (2007) Predicting the effect of climate change on temperate shallow lakes with the ecosystem model PCLake. Hydrobiologia 584:443–454

Morecroft M D, Keith S A (2009) Plant ecology as an indicator of climate and global change. In: climate change: observed impacts on Planet Earth, 1st edn. Elsevier B.V., p 297–305

Palmer MA, Bel SL, Butterfield I (1992) A botanical classification of standing waters in Britain: applications for conservation and monitoring. Aquat Conserv Mar Freshwat Ecosyst 12:125–143

Parcerisas L, Marull J, Pino J, Tello E, Coll F, Basnou C (2012) Land use changes, landscape ecology and their socioeconomic driving forces in the Spanish Mediterranean coast (El Maresme County, 1850–2005). Environ Sci Pol 23:120–132

Park MG, Blossey B (2008) Importance of plant traits and herbivory for invasiveness of Phragmites australis (Poaceae). Am J Bot 95:1557–1568

Parmesan C (2006) Ecological and evolutionary responses to recent climate change. Annu Rev Ecol Evol Syst 37:637–669

Partanen S, Luoto M (2006) Environmental determinants of littoral paludification in boreal lakes. Limnologica Ecol Manag Inland Waters 36:98–109

Peeters ETHM, Zuidam JP, Zuidam BG, Nes EH, Kosten S (2013) Changing weather conditions and floating plants in temperate drainage ditches. J Appl Ecol 50:585–593

Phillips DP, Human LRD, Adams JB (2015) Wetland plants as indicators of heavy metal contamination. Mar Pollut Bull 92(1–2):227–232

Rahel FJ, Olden JD (2008) Assessing the effects of climate change on aquatic invasive species. Conserv Biol 22:521–533

Rickert DA, Hines WG (1978) River-quality assessment: implications of a prototype project. Science 200(4346):1113–1118

Rosset V, Lehmann A, Oertli B (2010) Warmer and richer? Predicting the impact of climate warming on species richness in small temperate waterbodies. Glob Chang Biol 16:2376–2387

Rothausler E, Gomez I, Karsten U, Tala F, Thiel M (2011) Physiological acclimation of floating *Macrocystispyrifera* to temperature and irradiance ensures long-term persistence at the sea surface at mid-latitudes. J Exp Mar Biol Ecol 405:33–41

Rubio F, Rojo C, Núñez-Olivera E, Rodrigo M (2015) Effects of UVB radiation exposure from the molecular to the organism level in macrophytes from shallow Mediterranean habitats. Aquat Bot 120:112–120

Sala OE, Chapin FS III, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M, Wall DH (2000) Global biodiversity scenarios for the year 2100. Science 287:1770–1774

Salter J, Morris K, Boon PI (2008) Does salinity reduce the tolerance of two con- trasting wetland plants, the submerged monocot Vallisneria australis and the woody shrub Melaleuca ericifolia, to wetting and drying? Mar Freshw Res 59:291–303

Sand-Jensen K, Pedersen NL, Thorsgaard I, Moeslund B, Borum J, Brodersen KP (2008) 100 years of vegetation decline and recovery in Lake Fure, Denmark. J Ecol 96:260–271

Schippers P, Lurling M, Scheffer M (2004) Increase of atmospheric CO2 promotes phytoplankton productivity. Ecol Lett 7:446–451

Schneider SC, Lawniczak AE, Picínska-Faltynowicz J, Szoszkiewicz K (2012) Do macrophytes, diatoms and non-diatom benthic algae give redundant information? Results from a case study in Poland. Limnologica 42:204–211

Schneider SC, Pichler DE, Andersen T, Melzer A (2015) Light acclimation in submerged macrophytes: the roles of plant elongation, pigmentation and branch orientation differ among Chara species. Aquat Bot 120:121–128

Short FT, Neckles HA (1999) The effects of global climate change on seagrasses. Aquat Bot 63:169–196

Sorte CJB, Hofmann GE (2005) Thermotolerance and heat-shock protein expression in Northeastern Pacific Nucella species with different biogeographical ranges. Mar Biol 146:985–993

Stocker T F, Qin D, Plattner G K, Tignor M, Allen S K, Boschung J, Nauels A, Xia Y, Bex V, Midgley P M (2013) Climate Change 2013: The physical science basis. Intergovernmental Panel on Climate Change, Working Group I Contribution to the IPCC Fifth Assessment Report (AR5). Cambridge University Press, New York

Tait LW, Schiel DR (2013) Impacts of temperature on primary productivity and respiration in naturally structured macroalgal assemblages. PLoS ONE 8:26

Takamura N, Ito T, Ueno R, Ohtaka A, Wakana I, Nakagawa M, Ueno Y, Nakajima H (2009) Environmental gradients determining the distribution of benthic macroinvertebrates in Lake Takkobu, Kushiro wetland, northern Japan. Ecol Res 24:371–381

Thackeray SJ, Sparks TH, Rederiksen M, Burthe S, Bacon PJ (2010) Trophic level asynchrony in rates of phenological change for marine, freshwater and terrestrial environments. Glob Chang Biol 6: 3304–3313

Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BFN, De-Siqueira MF, Grainger A, Hannah L, Hughes L, Huntley B, Van Jaarsveld AS, Midgley GF, Miles L, Ortega-Huerta MA, Peterson AT, Philips OL, Williams SE (2004) Extinction risk from climate change. Nature 427:145–148

Tingley R, Herman TB (2009) Land-cover data improve bioclimatic models for anurans and turtles at a regional scale. J Biogeogr 36: 1656–1672

Trenberth KE, Dai A, van der Schrier G, Jones PD, Barichivich J, Briff KR, Sheffield J (2014) Global warming and changes in drought. Nat Clim Chang 4:17–22

Vymazal J (2011) Plants used in constructed wetlands with horizontal subsurface flow: a review. Hydrobiologia 674(1):133–156

Walters R (2005) Towards an understanding of photosynthetic acclimation. J Exp Bot 56:435–447

Wang C, Zheng S, Wang P, Hou J (2015) Interactions between vegetation, water flow and sediment transport: a review. J Hydrodyn Ser B 27(1):24–37

Whitehead PG, Wilby RL, Battarbee RW, Kernan M, Wade J (2009) A review of the potential impacts of climate change on surface water quality. Hydrol Sci J 54(1):101–123

Wrona FJ, Prowse TD, ReistJ D, Hobbie JE, Levesque LMJ, VincentW F (2006) Climate change effects on aquatic biota, ecosystem structure and function. AMBIO: J Hum Environ 35:359–369

Xenopoulos MA, Lodge DM, Alcamo J, Marker M, Schulze K, Van-Vuuren DP (2005) Scenarios of freshwater fish extinctions from climate change and water withdrawal. Glob Chang Biol 11:1557–1564

Xing W, Wu HP, Hao BB, Liu GH (2013) Stoichiometric characteristics and responses of submerged macrophytes to eutrophication in lakes along the mid- dle and lower reaches of the Yangtze River. Ecol Eng 54:16–21