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A review on effect of global climate change on seaweed and seagrass

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Abstract
This study describes how global climate change influences the growth, production and reproduction of seaweed, seagrass and their associated ecosystems. All the data used in this study have been collected from numerous secondary sources. Seaweed survival, growth, and reproduction are varied with numerous environmental variables, including temperature, desiccation, wave heights, nutrient supply via upwelling and run-off, pH and carbon dioxide concentration itself. With the rising of sea levels, seagrass and seaweed habitats at any given location will experience reduced distribution and abundance. Either increases or decreases in salinity will impact seagrass and seaweed. The potential effects of increasing CO_2 and the impacts of greater UV-B radiation will alter seagrass and seaweed photosynthesis and productivity. This review underscores the critical need of research on the direct effects of the various aspects of global climate change on seaweeds and seagrass.

Keywords: Climate change, seaweed, seagrass, survival, growth, reproduction

Introduction

Changes in global climate and its variability have an influence on ecological, biological and socioeconomic systems [1, 2, 3]. The impacts of increased atmospheric carbon dioxide, elevated land and sea temperatures, increasing sea level, and increasing UV radiation could alter the growth of terrestrial and aquatic plants. These factors are causing the reorganization of local communities due to addition and deletion of species [4]. The possible effects of global climate change on natural and agricultural terrestrial plant communities have already received considerable attention [5, 6, 7, 8]. In contrast, relatively little emphasis has been given to the possible effects of global climate change on aquatic plant communities, including seagrasses [9]. Biological systems like coral reefs and terrestrial forest also have received more attention [7, 10] but considerably less attention has been devoted to seaweed-dominated ecosystems. Although seaweed and seagrass are known to be affected by the physical and chemical changes of marine environment but current and future impact of climate change on these communities remain poorly understood [11].

Seaweeds are important primary producers and ecosystem engineers that play a significant role in coastal habitats ranging from kelp forests to coral reefs. Seaweeds have economic importance not only for as a base of productive food web [12,13] but also as a key habitat structuring agents like corals and trees that harbor incredible biodiversity which are also economically valuable [14, 12, 13, 15]. Seaweeds have significant link to human cultural and economic systems through the provision of ecosystem goods and services [16] by serving as a source of food, medicine and natural protection [17]. Seaweed beds and coral reefs provide trillions of dollars of ecosystem goods and services every year along with other coastal ecosystems. There is a significant linkage between aquatic species and seagrass bed also [18]. Fishes and some other aquatic animals used seagrass bed as their permanent and temporary resident [18]. Changes in sea level, salinity, temperature, atmospheric CO2, and UV radiation also can alter distribution, productivity, and community composition of seaweed and seagrass. Although few studies has been focused in recent years but still there are significant knowledge gaps that hamper our prediction capacity to the adverse impact of climate change on seaweed and seagrass dominated systems. Developing accurate prediction for ecological effect of global climate change should have high priority due to its importance in effective conservation and management. Some of the areas where we lack basic understanding include importance of rate, duration and magnitude of environmental change.

This study describes how global climate change influences the growth, production and reproduction of seaweed, seagrass and their associated ecosystems.

Materials and Methods

All the data used in this study have been collected from numerous secondary sources. Data have been accumulated by reviewing articles, reports on the effect of climate change on seaweed and seagrass. Websites on seaweed and seagrass is also an important source of information where ‘seaweed’, ‘seagrass’, ‘climate change’, ‘abiotic change in coastal marine environments’, ‘temperature effect’, ‘effect of sea level rise’, ‘salinity effect’, ‘effect of increasing carbon dioxide’, ‘effects of UV-B radiation’, etc. were the keywords of web browsing in Britannia encyclopedia. All of these gathered data were comprehensively reviewed; synthesized and relevant information was used in this study.

Results and Discussion

Abiotic change in coastal and marine environments

Rising carbon dioxide concentrations in the atmosphere and in the oceans are inducing important physical and chemical changes. These include ocean acidification, warming, and sea-level rise, along with regionally specific fluctuation in wave heights, upwelling, terrigenous nutrient runoff, and coastal salinity [19]. The rise in CO_2 concentrations and global temperature since the industrial revolution are 100 to 1000 times faster than at any point in the past 420,000 years and are still increasing [7]. Rate of geochemical change in the oceans currently exceeds anything recorded in the last 300 million years. Both the magnitude and the rate of environmental change have serious adverse impact to marine species either to tolerate or adapt to a new ocean.

Effect of climate change on seaweed and sea grass

Seaweed survival, growth, and reproduction are known to vary with numerous climatically sensitive environmental variables including temperature, desiccation, [20, 10] salinity, wave heights [21] (Graham *et al.*, 1997) nutrient supply, p^H [22] and carbon dioxide concentration itself. To date, understanding the relationship between environmental change and the performance of individual seaweeds depends on a loose combination of mechanistic, physiological research, and phenomenological studies [12, 13]. Increased temperature may also alter seagrass distribution and abundance through direct effects on flowering [23] and seed germination [24]. Tidal height and tidal range effects on light availability, current velocities, depth, and salinity distribution are all factors that regulate the distribution and abundance of seagrasses. Primary effect of increased water depth will alter the location of the maximum depth, limit plant growth and directly affect seagrass distribution. Increased tidal range will restrict the depth to which plants can grow by increasing the stress of light limitation [25]. Aspects of water motion, including current velocity, circulation flow, and flow duration, all have effects on seagrass plants and habitat structure [26]. Increased salinity intrusion will cause replacement of oligohaline and mesohaline submerged macrophyte populations. Rising levels of atmospheric CO_2 are predicted to have significant direct effects on global vegetation [27], including aquatic plant communities (Table 1) [28, 29, 8].

Table 1: Effect of climate change on seaweed and seagrass

Drivers	Consequences
Temperature	Alter distribution and abundance Affect growth and seed germination
Tidal height	Affect light availability Limit photosynthesis
Salinity	Regulate distribution and abundance Fluctuation causes morality due to extreme intake and nutrient imbalance
Sea level rise	Increase water depth and reduce sunlight penetration Reduce photosynthesis Reduce distribution and decrease productivity
Increasing CO_2	Increase photosynthesis and growth Change species composition, nutrient cycling and decomposition
UV-B radiation	Inhibit photosynthetic activity Increase metabolic activity Increase resistance to herbivores and pathogens Decrease decomposition Carbon sequestration

Temperature effect

Global mean temperatures are expected to raise 1±3.5°C by the end of the next century [4]. Increasing water temperature will directly affect metabolism of seagrass and seaweed and the maintenance of a positive carbon balance [30] which could result in changes in seasonal and geographic patterns of species abundance and distribution [31]. Increased temperature may also alter seagrass distribution and abundance [24, 31, 19]. Temperature determines the performance of seaweeds at the fundamental levels of enzymatic processes and metabolic function [32]. Although seaweeds are generally well adapted to their thermal environment, but nevertheless experience during periods of environmental change and could cause cellular and sub cellular damage [7]. Such damage could slow growth, delay development and lead to mortality [20].

The effects of sea level rise

The direct impact of increasing in sea level is to increase the depth of water. Sea level rise will reduce the light to seagrass beds and seaweeds throughout their depth range and may limit plant photosynthesis [33, 19]. At any given location will experience reduced distribution, decreased productivity, altered bed structure and reduced functional values [34, 18]. The greater tidal flows due to sea level rise will increase water movement in coastal and estuarine areas [26]. Leaf biomass, width and canopy height increase with increasing current velocity [33]. Increases in tidal current velocity will change tidal circulation, flow patterns and tidal channels. In seagrasses, changing tidal channels may erode beds in some areas or create new depositional areas [35].

Salinity effect

Either increases or decreases in salinity will impact sea grass and seaweed. Sea grasses are subject to the same stresses as other vascular plants growing in saline environments [18]. Internal water deficits due to high external osmotic potentials, specific ion toxicity due to excessive salt intake, and nutrient imbalance resulting from inadequate carrier selectivity during ion uptake put adverse impact [36, 19]. Mortality rates of seaweed following short exposures to extreme temperatures or salinities can be similar to those found after longer exposures to less extreme conditions [35].

Effects of increasing carbon dioxide

Rising in the atmospheric CO_2 level has a significant direct effect on global vegetation including aquatic plant communities [27, 29, 19]. Typical plant responses to short-term CO_2 enrichment include increases in photosynthesis, growth, total biomass and tissue carbon or nitrogen ratio. Whether these responses will be maintained depending on the degree of photosynthetic acclimation to increased CO_2 studies to date have found both up-regulation [5, 17] and down-regulation [37] of photosynthesis and associated responses following long exposure to elevated CO_2 concentrations [38]. Evidence also suggests potential community and ecosystem consequences, such as changes in plant species composition, carbon sequestering nutrient cycling and decomposition [39, 3]. Increases in growth and biomass with increased CO_2 have been observed for the sea grass *Z. marina.* Growth responses to CO_2 depend on interactions with other environmental factors and will be reduced when factors such as nutrients, temperature, or light are limiting. The response of seagrasses to long-term increases in CO_2 also depends on the extent of physiological and morphological acclimation that occurs [40, 18]. Carbon dioxide concentrations in seaweed habitats are increasing with anthropogenic emissions and intensified upwelling of CO_2-enriched water. As with terrestrial plants it is predicted that seaweeds could be benefited from the increase in inorganic carbon concentration [41]. However, the situation in the sea is not so simple. CO_2-driven effects on photosynthesis and growth depends on the degree to which carbon is limiting, which in turn varies among habitat to habitat and among taxa. CO_2 diffusion rates are much higher in air than in water, thus seaweeds that remain exposed at low tide and those with floating canopies at the sea-air interface have greater access to CO_2 [41, 32]. However, aerial exposure does not necessarily reduce the probability of carbon limitation, as exposure at low tide could dramatically reduce rates of carbon acquisition and even emerged seaweeds can benefit from increasing atmospheric CO2 concentrations [42].

Effects of UV-B radiation

The effect of UV-B radiation on marine plants is expected to be greatest in shallow intertidal environments because the plants could remain at or above the water during low tide. The reaction of these plants to UV-B radiation could range from inhibition of photosynthetic activity to the increased metabolic cost of producing UV-B blocking compounds within plant tissue [32, 1]. Increases in UV-B radiation causes an increase in plant content of phenolic and other secondary compounds which in turn, may increase the plant's resistance to herbivores and pathogens and decrease rate of decomposition [32, 43, 17]. The indirect impact of increased UV-B radiation could be the sequestration of carbon. In turn, under increased global CO_2 levels, plants will have a greater supply of carbon for secondary metabolism which may increase the ability of higher plants to block UV-B radiation [43].

Conclusion

The increasing rate of global climate change seen in this century will significantly impact the earth's oceans, with large potential impacts to seaweeds and sea grasses. Both direct and indirect effects of global climate change will alter plant productivity, distribution and function. Increases in seawater temperature resulting from the greenhouse effect could have secondary impacts of changing water depth and tidal range, altered current circulation patterns, modified current velocities and increased salinity intrusion. The potential effects of increasing CO2 and the impacts of greater UV-B radiation will also alter seagrass and seaweed photosynthesis and productivity. At this point it is difficult to predict the consequences of global climate change on the seaweeds and seagrasses of any given bay or estuary; this literature review underscores the critical need for research on the direct effects of the various aspects of global climate change on seaweed and seagrass.

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