

The previously held notion that unlike terrestrial plants, submerged plants like algae will not show any response to an increase of atmospheric carbon dioxide. CO₂ fixation and ammonia removal rates were estimated as 260 g CO₂ m⁻³.h⁻¹ and 0.92 g NH₃ m⁻³.h⁻¹, respectively, when the alga was cultivated in wastewater supplemented with 460 g PO₄⁻³.m⁻³ without pH control at 15% (v/v) CO₂. Andersen et al. [38] grew specimens of *Littorella uniflora*, one of the isoetids (small slow-growing evergreen perennials that live submerged along the shores of numerous freshwater lakes and rely primarily on sediment-derived CO₂ for their photosynthesis) in sediment cores removed from Lake Hampen (Denmark) in 75-liter tanks. In a different study Anderson and Anderson [39] measured the CO₂-induced in situ growth response of a mixture of several species of filamentous freshwater algae (dominated by *Zygnema* species, but containing some *Mougeotia* and *Spirogyra*), as well as an isoetid community of macrophytes (dominated by *Littorella uniflora*, but containing some *Myriophyllum alterniflorum* and a few other species). In search of a simple method for removing CO₂ from high-CO₂-concentration stack gases, Yue and Chen [43] isolated and cultured a freshwater microalga of the genus *Chlorella* for periods of six days in vessels filled with growth media through which air of a variety of different CO₂ concentrations was continuously bubbled. Yun, et al., [42] cultivated *Chlorella vulgaris* in wastewater discharged from a steel-making plant with the aim of developing an economically feasible system to remove ammonia from wastewater and CO₂ from flue gas simultaneously (since no phosphorus compounds existed in wastewater, external phosphate (15.3 – 46.0 g.m⁻³) was added to the wastewater). Other microalgae species, *Chlorella minutissima*, grown under extreme carbon dioxide concentrations (0.036% – 100%), strongly increase the microalgal biomass through photochemical and non-photochemical changes in the photosynthetic apparatus [47]. These results indicate that the carbon uptake by fresh and saltwater systems may increase more than expected, and that nuisance algal blooms may be aggravated at elevated atmospheric carbon dioxide concentrations. Most of the studies that have established this fact have historically utilized CO₂ concentration increases on the order of 300 – 400 ppm, which represents an approximate doubling of the air's current CO₂ concentration; and they have been conducted on terrestrial plants [36,37]. Such significant enhancement of growth rate with enriched CO₂ was also confirmed at different levels of inorganic N and P. The maximal rates of net photosynthesis, photosynthetic efficiency and light-saturating point increased significantly in high-CO₂-grown cells. In conclusion, these extreme CO₂ concentrations—about 1,000 times higher than the ambient one—can be easily metabolized from the unicellular green alga to biomass and can be used, on a local scale at least, for the future development of microalgal photobioreactors for the mitigation of the point source-produced carbon dioxide. A red seaweed common to the Northeast Atlantic intertidal zone, *Lomentaria articulata*, was grown for three weeks in hydroponic cultures subjected to various atmospheric CO₂ and O₂ concentrations to determine the effects of these gases on growth [40]. Similar results were obtained by Watanabe et al. [44] for another *Chlorella* alga, by Hanagata et al. [15] for both *Chlorella* and *Scenedesmus* species, and by Kodama et al. [16] for the marine microalga *Chlorococcum littorale*. The effect of increased CO₂ concentration on the growth rate of three planktonic algae (*Chlamydomonas reinhardtii*, *Chlorella pyrenoidosa*, and *Scenedesmus obliquus*) enhanced significantly [46]. The authors concluded that increased CO₂ concentrations with

decreased pH could affect the growth rate and photosynthetic physiology of the three algae species. Moreover, plants grown in elevated atmospheric CO₂ environments typically exhibit increased rates of photosynthesis and biomass production [35]. JEP 650 Microalgae Tolerance to High Concentrations of Carbon Dioxide: A Review the elevated CO₂: by 220% in early July, by 90% in mid-August, and by a whopping 3,750% in mid-November. *Scenedesmus* was completely inhibited by 100% CO₂.