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Phytoplankton And Its Key Role in Mitigating Climate Change: A Mini Review

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Abstract

In the process of carbon sequestration, CO_2 present in the earth's atmosphere is captured and stored as part of the biological carbon cycle via photosynthesis to mitigate warming of earth and avert climate change. Now, it is crucial for the various community around the world to acknowledge alternative sinks for carbon beyond the traditional focus on forests. The present review will provide a comprehensive scenario of the potential role of phytoplankton in carbon sequestration within freshwater wetlands and its contribution in mitigating climate change.

Keywords: Phytoplankton, Carbon sequestration, Wetland, Biological carbon mitigation, Climate change

Introduction

According to IPCC Climate Change 2023 Synthesis Report, Global warming is projected to persistently increase from 2021 to 2040 due to escalating cumulative CO_2 emissions. Even under the lowest greenhouse gas emissions scenario, there is a greater chance of reaching the temperature all over the world to 1.5°C which is the level before the industrialization period. In higher emissions scenarios, it is either likely or very likely that temperatures will exceed this threshold. Increasing industrial activities and urbanization have resulted in higher emissions of CO_2, which is considered as the main greenhouse gas causing changes in the climate and temperature of the world [1]. Carbon sequestration is the process of capturing atmospheric CO_2 and storing it in long-term carbon reservoirs to prevent its release into the atmosphere [2] to mitigate global warming and avert climate change [3]. Carbon dioxide is sequestered from the atmosphere by producers as part of the biological carbon cycle via photosynthesis [4].

Wetlands are significant carbon sinks, encompassing only 5-8% of the surface of the earth but storing approximately 35% of the carbon stock of the world [5-7]. Carbon sequestration in wetlands involves the photosynthetic removal of CO_2 by wetland macrophytes or producers, which is then converted into carbon compounds and subsequently into soil organic matter. A study conducted in Ohio indicated that sequestration rates of the carbon in the inland wetlands lies in the temperate zone is found between 56 to 504 gC m^2 yr^{-1}. Depressional wetland communities demonstrated a carbon sequestration rate of 317 ± 93 gC m^2 yr^{-1}, which is recorded significantly high ($P < 0.01$) than the 140 ± 16 gC m^2 yr^{-1} observed in riverine communities. It has been reported that in the forested wetland community of the *Quercus palustris,* a high sequestration rate of carbon at 473 gC m^2 yr^{-1}, while the riverine habitat with a high number of the water lotus showed the highest sequestration rate among riverine types, at 160 gC m^2 yr^{-1} [8]. In addition to this, the carbon sequestration rates at the montane wetland within Odaesan National Park, Republic of Korea are recorded between 58.3 to 125.3 gC m^2 yr^{-1} [9]. The present review will provide a comprehensive scenario of the role of phytoplankton in carbon sequestration within freshwater wetlands and its contribution to mitigating climate change. A pilot experiment was also conducted in August 2024 in Loktak Lake of Manipur, India, which is also recognized as Ramsar Wetland to quantify the chlorophyll a content in phytoplankton and estimate the carbon stock.

Biological carbon mitigation (BCM) refers to the process by which autotrophic organisms convert CO_2 into organic carbon through photosynthesis, resulting in the production of substantial amounts of biomass [10]. Phytoplankton are among the fastest-growing photosynthetic organisms, utilizing CO_2 as their primary building block [11]. Microalgae are rapidly growing photoautotrophic organisms utilizing CO_2 as their primary building block [12] and exhibit higher photosynthetic efficiencies compared to terrestrial plants [13], with an efficiency rate 10 times more than that of plant communities found in terrestrial habitats as a result of their peculiar structure for conservation of energy [14]. In this regard, in order to mitigate the low CO_2 affinity of the key carbon-fixing enzyme ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO), CO_2 concentrating mechanism (CCM) was employed by them [15] and they have high potential to uptake and assimilate CO_2 and HCO^{3-} which are dissolved organic form of carbon [16,17]. It is also reported that microalgal photosynthesis can facilitate the formation of calcium carbonate, offering a potential mechanism for long-term carbon storage [18,19] and the phytoplankton utilize carbon dioxide to generate biomass and energy through enzymatic fixation by RuBisCO in the Calvin-Benson cycle [20].

In an interesting study conducted by Ramaraj *et. al* in the year 2014, it was demonstrated that microalgae grown in the natural freshwater system which is unsupplemeneted and less carbon stock can assimilate 100% of carbon present in the atmosphere for biomass sequestration thus signifying that atmospheric CO_2 provided all the carbon necessary for the growth of microalgal in the system [21]. It is presumed that approximately 1 kilogram of microalgae can fix 1.84 kilograms of atmospheric carbon dioxide [22] and recently this kind of bio fixation of carbon emission using microalgae has emerged as a promising method for carbon sequestration, offering additional advantages through the downstream utilization and applications of the resultant microalgal biomass [23]. A promising alternative to CO_2 captures strategies can be presented by integrating CO_2 fixation from flue gas, nutrient removal from wastewater, and biomass production, potentially enhancing economic competitiveness with established carbon capture and storage (CCS) methodologies [24]. It was estimated that a minimum of 1.83 tons of CO_2 are required to produce 1 ton of algal biomass.

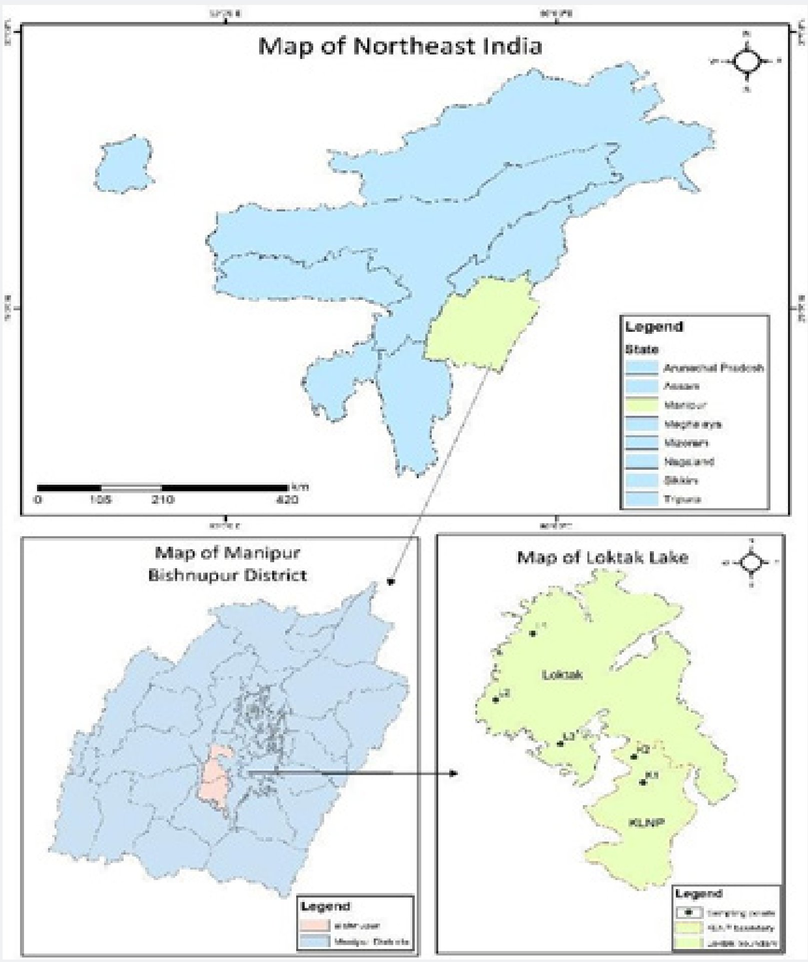

Figure 1: Map of Northeastern State of India showing an outline map of Loktak Lake and KLNP indicating the sampling points.

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Further, there is published literature that reported that the concentration of chlorophyll "a" in microalgae is influenced by a variety of factors, including the amount of available sunlight, nutrients, hydrology, light intensity, catchment area, and other variables [25]. Estimating the concentration of chlorophyll-"a" content in microalgae is crucial for determining the overall algal biomass and is a key variable in the photosynthetic process. [4,25]. While, we carried out a pilot study by collecting the water samples for the determination of chlorophyll-"a" content in August 2024 at Loktak Lake (the largest freshwater lake in northeastern India) and Keibul Lamjao National Park (the south-eastern fringes of Loktak Lake) of Manipur, a North Eastern State of India which lie in the Indo-Myanmar hots spots of biodiversity of the world (Figure 1), the estimated phytoplankton biomass was approximately 0.99 mg/m^3 in Loktak Lake and 0.768 mg/m^3 in Keibul Lamjao National Park for the month of August 2024 [26-30]. It has also been reported that, in a study conducted on shrimp ponds, the carbon adsorption during shrimp farming was found to be 0.7139 tons C ha^{-1} in extensive/traditional ponds, 7.8069 tons C ha^{-1} in semi-intensive ponds, and 9.0752 tons C ha^{-1} in intensive ponds [31]. Chlorophyll "a" concentrations were estimated to be notably elevated, with an average increase from 7.7 µg L^{-1} in the river to 34.8 µg L^{-1} in the lakes in the northern Pantanal, along the Cuiaba River in state of Mato Grosso [32].

Now, it is crucial for the global community to acknowledge alternative carbon sinks beyond the traditional focus on forests. Although forests play a significant role as both sources and sinks of carbon, precise estimation of forest carbon stocks is essential for assessing carbon loss due to deforestation and evaluating the potential carbon storage of regenerated forests [33]. Similarly, to accurately determine the carbon storage and sequestration potential of wetlands, further research and evaluation are necessary across various wetland types, including their components and ecological processes. A more comprehensive understanding of these processes, particularly concerning phytoplankton, is highly anticipated and essential for advancing our knowledge.

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