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Effects of phosphorus availability on macroalgae: A review

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Abstract

Phosphorous is considered as an essential nutrient for life. Its availability in the water dictates the primary productivity, including macroalgae. In this paper, peer-reviewed articles reporting the effects of phosphorous on macroalgae for the past decades and up to the present were reviewed and recapitulated. The literature revealed that while phosphorous is one of the limiting nutrients in an open ocean, eutrophication in some coastal areas, which is fueled by anthropogenic activities, contributes to the excess phosphorous resulting in the occurrence of green tides. The general influences of phosphorous availability to many macroalgae were enhanced growth and biomass, especially with the interaction effect with nitrogen. However, some studies reported that the high concentration of phosphorous has deleterious effects on macroalgae. Hence, future studies are needed to fully understand the role of phosphorous availability in macroalgae.

Keywords: Green tides, Macroalgae, Phosphorous, Phosphate, Seaweeds

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1. Introduction

In modern oceans, phosphorus, alongside nitrogen, is among the inorganic nutrients which considered as the main regulators of photosynthetic marine organisms. Phosphorous plays crucial roles in various biological systems, where it acts as a structural molecule in biological membranes, nucleic acids, and cellular energy carrier ATP (Westheimer, 1987). In most global surface oceans, phosphorous is now labeled as depleted, which can result in the limitation of marine productivity, thereby impacting ecosystem structure (Duhamel et al., 2021). In important oceans, such as the Mediterranean Sea and oceanic gyres, the availability of phosphorous at low levels generally limits the production of phytoplankton and other photosynthetic living organisms; this is due to the high affinity of these organisms for the uptake of phosphorous (Wu et al., 2000; Thingstad et al., 2005; Elser et al., 2007). The primary sources of phosphorous in the marine environment are rivers, ground waters, atmospheric aerosols, and dust deposition (Reinhard et al., 2017). However, in modern society, phosphorous is dominantly dumped into the oceans from agriculture and domestic sources (Hansen et al., 2002; Torrent et al., 2007; Comber et al., 2013).

Enrichment of the main important macronutrients, phosphorous and nitrogen, is one of the devastating anthropogenic activities that develop eutrophication, which impairs the aquatic environment (Smith, 2003; Diaz & Rosenberg, 2008). The importance of terrestrial runoff is great in this event, especially after heavy rains (Den Haan et al., 2016). Globally, coastal eutrophication is now a rising issue and is considered a major threat to the oceans (Andersen et al., 2006; Andersen et al., 2009). The elevation of excess nutrients from human activities to the aquatic environment fuels great primary productivity and improved organic matter supply to the system and may alter and disturb the natural element cycle processes, which have numerous negative consequences (Carpenter, 2005). Macroalgae, in particular, serve as crucial indicators of the impacts caused by excessive nutrient levels.

Macroalgae, being photosynthetic organisms, require great arrays of nutrients, mainly nitrogen and phosphorous (Harrison & Hurd, 2001; Roleda & Hurd, 2019). As a matter of fact, macroalgae are used as biofilters to reduce the content of dissolved nutrients from the fish farm effluents (Hernández et al., 2005). Phosphorus is considered an essential nutrient, which every macroalga requires in relatively huge amounts to unceasingly supply their growth and survival (Lobban et al., 1985). Macroalgae have the ability to accumulate and store nutrients, including phosphorous (Lundberg et al., 1989). The phosphate concentrations available to macroalgae may vary according to depth, with higher levels found in the sediment compared with the water column (Larned, 1998). Hence, alterations in the availability of phosphorous in the aquatic environment would significantly impact the physiology and growth of macroalgae (Xu et al., 2010). This work reviewed and recapitulated the current peer-reviewed literature on the effects of phosphorous availability on macroalgae.

2. Phosphorous Availability Caused Green Tides

Green tides are fast-growing blooms of macroalgae, which have been reported in various coastal waters in recent times (Zheng et al., 2022; Tahiluddin et al., 2022). Green tides are caused primarily by the excess nutrient inputs to the coastal waters (Gladyshev & Gubelit, 2019), and their occurrences are indicators of too much nutrients (Fletcher, 1996; Kwon et al., 2017). Green tides affect many of the world's oceans, such as those reported to occur in the Yellow Sea, China (Zhou et al., 2015; Wang et al., 2015; Liu et al., 2016), Britanny, France (Diaz et al., 2013), Florida, USA (Charlier et al., 2008), and Mediterranean Sea (Menéndez & Comin, 2000). Additionally, green tides have been reported to occur in freshwater ecosystems (Rybak & Gąbka, 2018). The dominant green-tide-forming seaweed, *Ulva prolifera*, in the southern Yellow Sea, China, was investigated by Li et al. (2016) in the laboratory to determine its growth responses against organic and inorganic nutrients, including phosphorous. Their findings revealed that the growth rate of this green tide seaweed was found to be highly increased in organic phosphorous and nitrogen, compared to inorganic nutrients. However, the result of the affinity was the opposite.

The influences of dissolved nutrients, such as phosphorous and nitrogen, were investigated by Menéndez et al. (2002) on the nutrient content, growth, and uptake rates of green macroalga *Chaetomorpha linum* collected from Tancada lagoon, Mediterranean coast, and experimented under laboratory conditions. Phosphorous, or combination with nitrogen, showed a significant increase in biomass, rate of nutrient uptakes, and tissue content of nutrients. However, enrichment of this macroalga with phosphorous demonstrated an insignificant impact on chlorophyll content. The authors suggested that in the Tancada lagoon, the limiting nutrient was phosphorous rather than nitrogen.

3. Phosphorous Impacts on Various Macroalgae

Phosphorous is required by macroalgae for growth since it is the main constituent of RNA and, consequently, is involved in protein synthesis. Besides, phosphorous is also a component of sugar phosphates, phospholipids, and nucleotides, such as ATP (Douglas et al., 2014). The effects of phosphorous on red macroalgae have been demonstrated in different studies, with both render positive and negative results. Phosphorus limitation has adverse impacts on the red macroalga *Chondrus crispus*, causing its fronds to weaken and elevate its fragmentation (Neish et al., 1977). Ammonium phosphate (16-20-0: NPK), which is composed of 20% phosphate, is among the commercial inorganic fertilizer applied in the cultivation of macroalga *Kappaphycus striatus* as nutrient enrichment (Tahiluddin et al., 2022). This study reported that ammonium phosphate at a concentration of 8.82 g L^{-1} increased the growth and biomass of *K. striatus* from day 14-49 planted in an open sea using a modified fixed-off bottom method in addition to its reduced ice-ice disease prevalence (Tahiluddin et al., 2022). However, when pure phosphorous was used at the same concentration (i.e., 8.82 g L^{-1}) to the same macroalga species, the growth decreased significantly, notably on day 15, while no effect was observed on days 30 to 45 (Sarri et al., 2022). This can be related to the study of Abou-Aisha et al. (1995) that excess phosphate (localized phosphate pollution) at Wuseir and Safaga, Egypt, had a significant reduction in the biomass of macroalgae (*Jania* sp., *Caulerpa* sp., and *Turbinaria* sp.) when compared to the unpolluted site (Ghardaqa, Egypt).

Brown seaweed *Sargassum macrocarpum* responded to the levels of phosphorous according to season and its need for physiological processes. For instance, while there was a change in the levels of external phosphate, the phosphate uptake was relatively high during the growth period and low during the maturation period. The phosphorous demand was greatest during March (Ohtake et al., 2020). Similar species, *S. baccularia*, positively responded to the availability of both nutrients, phosphate and ammonium, by doubling the growth rate. However, it was unexpected to note that higher concentrations of these nutrients led to decreased growth rates (Schaffelke & Klumpp, 1998).

Green macroalga *Cladophora glomerata* demonstrated a high capacity to absorb excess nutrients (phosphorous and nitrogen) from the wastewater. Additionally, the biomass of *C. glomerata* was found to be correlated with phosphate concentration (Farahdiba et al., 2020). Kumari et al. (2015) explored the changes in the lipid and biochemical composition of *U. lactuca* when exposed to varying concentrations of phosphate and nitrogen. The researchers' findings demonstrated that seaweed thalli cultured in artificial seawater supplemented with phosphate exhibited a down-regulation of phosphatases, an increase in phospholipids attributable to the increased availability of phosphate. Additionally, they observed a reduction in nitrate reductase, pigments, monogalactosyldiacylglycerols, and polyunsaturated fatty acids as a result of nitrate limitation.

4. Phosphorus Uptake in Macroalgae

During active photosynthesis of macroalgae, such as in *Ulva lactuca*, the phosphate is taken up, accumulated, and stored as polyphosphate forms intracellularly (Lundberg et al., 1989). Generally, macroalgae uptake nutrients by employing several mechanisms ranging from passive transport (diffusion) for nutrients in gas form to active transport for inorganic nutrients like phosphorous and nitrogen (Harrison & Hurd, 2001). Nutrient uptake can be dependent on both abiotic and biotic factors (Harrison & Hurd, 2001; Roleda & Hurd, 2019). When compared with *U. lactuca*, estuarine red algal epiphyte, *Catenella nipae* was found to more consistently uptake phosphate from water; hence, this red alga is an excellent bioindicator for the status of phosphorus in the marine and estuarine environments (Runcie et al., 2004). The role of nitrogen in the phosphorus uptake efficiency of seaweed (*Fucus vesiculosus*) has been illustrated by Perini and Bracken (2014). Their findings highlighted that under various concentrations of nitrogen and phosphorous, seaweed *F. vesiculosus* when exposed to nitrogen availability, its uptake rate for phosphorus was higher than for those nitrogen-limited ones. This study indicates that interactions of these two important nutrients affect the seaweed's access to limiting nutrients. The phosphorus content of tropical seaweeds, i.e., *Hypnea valentiae*, *Gracilariopsis tenuifrons*, and *Ulva lactuca*, vary according to season, with the highest peak during summer (Lourenco et al., 2005), indicating that season influences the uptake of phosphorous in macroalgae.

5. Conclusion and Future Prospects

Phosphorus plays a critical role in the marine environment. Its availability in marine environments dictates the abundance of photosynthetic organisms, notably macroalgae, as they assimilate phosphorus (dissolved phosphate) for the photosynthesis process. Phosphorus is often a limiting nutrient in the aquatic environment. However, with the increasing human population in many coastal areas, discharging of anthropogenic phosphorus into the coastal waters may result in eutrophication which may be harmful to the environment. Different studies on the effects of phosphorus on macroalgae suggest that phosphorus availability in the water has a positive effect. Increasing phosphorus concentration can cause an increase in the rate of photosynthesis and increase the biomass of photosynthetic organisms. However, some studies indicated that using a high concentration (e.g., 8.82 g L^{-1}) of phosphorus may have adverse effects on the growth and physiology of the macroalgae. It is also important to note that nitrogen has a vital role to play in the uptake of phosphorous by macroalgae. Future research needs to explore the important effects of phosphorous on other macroalgae.

Conflict of interest

The author declares that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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