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Seaweed and its Role in Bioremediation - A Review

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Abstract

Increase in global population has resulted in considerable accumulation of wastes in the environment which eventually reach the surrounding waterbodies. Anthropogenic waste leads to deterioration of water quality, making it unsuitable for further use. The water coming after anthropogenic interference are mostly left out untreated, and may contain contaminants like hydrocarbons, phosphorous, heavy metals, nitrogenous compounds, pesticide residues, dyes etc. The polluted waterbodies are mainly a resultant of various anthropogenic activities which is getting discharged with different treatment levels into the aquatic system. These pollutants are finally getting accumulated in the coastal waterbodies leading to pollution and imbalance to the coastal ecosystem. Bioremediation aims at viable treatment technique which lowers the consequences of this contamination on the environment by employing biological agents, such as bioconcentration and removal using seaweeds. Several research works had reported the efficiency of seaweed in removing these pollutants, nutrients and heavy metals from aquaculture systems, agricultures and urban outflow and industrial effluents. In this chapter, we discuss about the application of seaweed in different ecosystem for removing the effluents and contaminants present in the water bodies and improving the water quality. The technique employed by seaweed for quenching these pollutant compounds from water bodies are also included.

Keywords: Seaweed, bioremediation, aquatic system, biofiltration

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Introduction

Seaweeds are a group of nonflowering primitive marine plants with no distinctive roots, stem, and leaves. They are precious resource for renewable marine living and are spread in intertidal, shallow and deep seawater up to 150m deep. They also occur in estuaries and back water. Seaweeds are growing epiphytes on rocks, dead coral shells, pebble, solid substrates and other plants. Seaweed biomass contains a lot of metal ions like K^{+}, Na^{+}, Ca^{2+}, Mg^{2+}, etc. Seaweeds are rich in polysaccharide kinds of structure and storage. Their structural polysaccharides are primarily celluloses, hemicelluloses and xylans, storage polysaccharides such as laminarian, alginic acid, carrageenans, fucoidan, agar, and alginates.

Macro algae species are reported to be the source of hydrocolloids, such as agar, carrageen, and alginate (Jimenez-Escrig & Sanch-Muniz, 2000). Red algae Eucheuma is used in the manufacturing of carrageenan which is widely used in cosmetics, food technology and industrial applications.

These are also having importance in human consumption. Roughly 20 edible algae varieties are commercially utilized in Europe for human consumption. (Lähteenmäki-Uutela et al., 2021)After harvesting, the plants are immediately dried and cut into strips or powdered. Kombu is used in Japan for fish preparation, meat dishes and soups and also as rich vegetables. It is delicious to add this powdered kombu in sauces, soups, or as curry with rice. Some varieties are used to make a tea like infusion.

Bioremediation is a technology for pollution control that uses biological systems to catalyse the degradation or transformation into less harmful forms of various toxic chemicals. Bioremediation is effective and efficient decontamination method that has become increasingly popular nowadays to reduce pollution from the environment. Sewage disposal has become an ecological issue in urban and semiurban colonies (Moore, 1998). Bioremediation is a new approach to decontamination treatment. Bioremediation focuses primarily on the strategies that can be used to biologically clean up contaminants. Removal and recovery of wastewater is important for the safety of the environment and human health. The process of bioaccumulation is known as the active mode of metal accumulation by living cells depending on the cell's metabolic activity (Volesky, 1990; Wase & Foster, 1997).

Microalgae are not unique in their bio removal capabilities, while in some conceptual bio removal processes they offer advantages over other biological materials. Microalgae strains are purposely grown and employed for specific bio removal applications and have the potential to provide substantial improvements in addressing global metal pollution problems (Wilde & Benemann, 1993). Biosorption of heavy metals is reported to be a highly costeffective and a novel alternative for decontaminating metal containing effluents by certain types of nonliving biomass (Kratochvil & Volesky, 1998).

The waste water produced by anthropogenic activities is discharged in to the aquatic environment with varying levels of treatment. Pollutants in these contaminated water body, particularly nitrogen, phosphorus, metal, and hydrocarbons, gets accumulated in coastal waters, leading to pollution and marine ecosystem imbalance. Bioremediation is a sustainable method for the treatment of these water bodies, thereby reducing the impact of this pollution by using biological organisms to remove these contaminants, with an increasing focus on seaweed.

Seaweeds in domestic sewage treatment

Seaweeds are able to remove efficiently most of the nutrients from the waste water. It can remove nutrients such as nitrogen and phosphorous from domestic sewage under standard treatment process. *Gracilaria verrucosa* have the higher efficiency inremoving BOD & COD levels, while *Ulva faciata* has more efficiency in removing ammonia (Sasikumar & Rangasamy, 1994). In relation to contributing its use in various sectors, seaweed has been extensively studied and used as an absorbent in wastewater treatment to substitute functionally activated carbon. Waste water can be a byproductfrom manufacturing sectors, plants, landfills, homes, textile sectors, petrochemical sectors, aquaculture, farming, etc. Organic and inorganic pollution is a prevalent situation in these waste water. The sources of these organic compounds are derived from domestic wastewater, urban runoff, effluents from agriculture and aquaculture treatment plants, industrial effluents such as paper pulp production, food processing sector etc. Some of the prevalent organic pollutants are pesticides, fertilizer, hydrocarbons, phenolic compounds, plasticisers, biphenyls, oils, fats, detergents and pharmaceuticals (Ali et al., 2012).Examples of organic pollutants include benzene, toluene, ethyl benzene, p-xylene (BTEX), dyes & chemicals (Garcia et al., 2017; Wojtyla et al., 2018). Heavy metal ions, arsenides, and fluorides are some of the normal inorganic poisonous pollutants present in the domestic sewage bodies (Cao et al., 2014). Several trials to treat distinct kinds of sewage with distinct methods of macro algae adsorption are not new. It focuses on many ways, including removing dye, and chemical oxygen demand (COD), biological demand for oxygen (BOD), phenols, heavy metals, etc. In fact, very restricted trials are concentrated on reduction of COD & BOD, carbon fixation, lipid manufacturing, total organic carbon (TOC) and turbidity (Zhao et al., 2014; Resiset al., 2016) from wastewater using macro algae since the majority of them were concentrated on removing colors, phenols and heavy metals.

Application of seaweed bioremediation in aquaculture systems

The inclusion of marine algae in integrated multitrophic aquaculture (IMTA) has been suggested as a suitable substitute for environmentally viable production of aquaculture, as a preliminary origin of food and also for aquatic bioremediation due to its high capacity to remove inorganic nutrients from waste water (Neori et al., 2008; Neori et al., 2004; Fleurence et al., 2012). The advantage of integrated shrimp and green seaweed (*Ulva clathrate*) aquaculture had showed high efficiency in removing inorganic nutrients from water effluents (Copertino et al., 2009). In addition, a better feed uptake was observed for *Litopenaeus vannamei* (Cruz Suárez et al., 2009) and in *Farfantepaneus californiensis* (Rodriquez et al., 2014).

The coastal seaweed community composed of *Chaeotomorpha spp, Polysiphora spp, Ulva spp, Cytoseria spp,* was employed to eliminate copper ion from synthetic aqueous medium. This experiment was conducted in batch mode to study the effect of pH, biosorbent amount, metal ion concentration and contact time on the biosorption process. It was observed that the biosorption capacity of copper ions was influenced by the operating parameters. The highest biosorption ability for copper ions obtained was 180.36 mg g^{-1}. Hence it was proved that coastal seaweed varieties has better bioremediation capacity for copper from polluted aquatic environment (Deniz *et al.,* 2018).

Recent research developments and commercial application of marine algal farming shows the capability of marine algae to eliminate nutrients and metals from terrestrial and coastal aquaculture, urban agriculture runoff and industrial effluents. It demonstratesthat, despite the technical difficultiesto execute this technology on large scale, bioremediation offers an opportunity to thoroughly eliminate the pollutants ecologically friendly polluted seawater.

Tremblay et al. (2017), studied, the bioremediation capability of *Palmaria palmate* and *Ulva lactuca* for eliminating the dissolved elements in a completely recirculated cold seawater ecosystem representing of an estuarine aquatic environment. In this study, the laboratory grown seaweed was employed in depicting the marine environment of the Gulf of Saint Lawrence (Quebec, Canada), i.e., salinity of 24 psu, 5 and 10ºC, and under three groups of high nitrate (NO^{3-}) & phosphate (PO_4^{3-}) concentrations (2865:195, 3570:242, & 4284:291 μM). It was noted that there was no significant change either in nutrient or temperature levels. *P. palmata*'s growth rate was independent of concentrations of temperature and nutrients with average of 0.64 ± 0.18 % FW day^{-1}. At 10ºC and intermediate concentration of nutrients, *U. lactuca* exhibited excessive growth rate (2.81 ± 0.72% FW day $^{-1}$) by absorbing these nutrients from the water body and thereby reducing the nutrient content in water body.

Sudharshan *et al. (2013) of* University of South Australia found that sodium enhance bacteria's ability to degrade DDT in anaerobic environment. DDT (1, 1, 1-trichloro-2, 2 bis (p-cholorophenyl) ethane) a legacy pesticide could be a major contaminant in the sediment ecosystem and thus economic methods are required to eliminate DDT from the environment. In this study, DDT contaminated soil was treated with powdered green and red algae (*Ulva spp* & *Gelidium spp*) and it was observed that as much as 80% of the compound wasremoved after six weeks. It was noticed that in the initial days, the rates of DDT biodegradation increased in the following order relating to the percentage by weight of added seaweed to soil 0.5>1>0>3>5>13 (w/w). It was also noticed that the lower level of seaweed added, stimulated the DDT transformation rates, whereas higher level of seaweed addition inhibited DDT transformation. The prominent metabolite found was DDE (1,1,1- trichloro 2,2-bis (p-chlorophenyl) ethane) during soil incubation. The maximum quantity of 4,4- dichlorobenzophenone (DBP) (2.5%) was noticed in soil modified with 0.5% (W/W) seaweed, indicating further DDD breakdown. High levels of Dissolved Organic Carbon (DOC) in soil modified with larger amounts of seaweed may have significantly retarded DDT degradation, probably due to DDT binding to DOC and subsequently decreasing DDT's bioavailability to soil microorganisms.

We have a growing need in modern society to rethink about the waste disposal in order to manage natural resource sustainably (Clark, 2014). In farm fertilizers, both phosphorous (P) and nitrogen (N) are important elements of concern once they reach the aquatic bodies. P is a limited resource and efforts are being made to retain and recycle this element as well as limit aquatic eutrophication (Carpenter & Bennett, 2011). Sode et al. (2013) studied the efficiency of the green macro algae *U. lactuca* for bioremediation of rejected water from a sludge fed biogas plant. There were two separate experiments, the first experiment (N score experiment) aimed to evaluate the quality of waste water as a source of nutrients for algal growth, compared to inorganic sources of nitrogen Simultaneously another second experiment was conducted to study the nutrient intake rates and *Ulva*'s bioremediation capacity over a range of concentrations of nutrients. Based on the observations, growth and nutrients removal were considered as parameters for optimizing. Similar elimination rates of 22.7 mg N g DW^{-1} d^{-1} and 22.7 mg P g DW^{-1} d^{-1} were obtained at water rejection concentrations of 80 and 89 μM NH^{4+} respectively. The feasibility of implementing Ulva can be achieved by a combined and integrated use of the produced biomass in a biorefinery for bioremediation of eliminated water (Sode et al., 2013).

Red algae *Porphyra leucostica* is aeffective, low-cost and biodegradable sorbent biomaterial to reduce environmental and wastewater heavy metal pollution. *Porphyra leucosticta* was examined for the biological enrichment and biological precipitation to eliminate Cd (II) and Pb (II) ions from waste water.

The experimental characters that interfere with the process of bioremediation have been studied, such as pH, contact time, dosage of biomass. Maximum bioremediation capacity was observed for 31.45mg/g for Cd(II) and 36.63 mg/g for Pb(II) at 15g/L biomass, pH 0.8 & 120 minute contact timer, containing initial 10.0 mg/L of Cd(II) and 10.0 mg/L of Pb(II) solution. *Porphyra leucosticta* biomass was efficient in removing 10.0 mg/L of Cd(II) and 10.0 mg/L of Pb(II) solution with 70% bioremediation capacity for Cd(II) and 90% for Pb(II) (Ye et al., 2015).

Seaweeds can play an significant part in controlling eutrophication, improving the quality of water and improving viable low cost aquaculture (Neori, 2008; Copertino et al., 2009). Seaweeds are capable of removing upto 90% of nutrients released from intensive fish culture system (Shpigel et al., 2019). *Ulva* species are efficient in growing well in increased levels of nitrogen and proliferate well to create larger biomass there by removing larger amounts of nutrients (Bolton et al., 2009).

Aquaculture's fast development is followed by enhanced release of nutrient rich water into aquatic system and coastal water bodies, resulting in water quality eutrophication and deterioration. Seaweeds are appropriate candidates for reducing the concentration of dissolved inorganic nutrients released by aquaculture effluents and there by enhance the quality of water and enable sustainable aquaculture. The de eutrophication capability of *Ulva reticulate* was studied in a shrimp hatchery at Malaysia, for observing its capacity to eliminate nutrients from shrimp brood effluents in batch (SBE) crop scheme. Rabiei et al. (2014) had studied on *Ulva reticulate* biofiltration capacity over a 12 days period. Ammonic-nitrogen (NH_3-N) concentrations were decreased by 100% (after 12 h), nitrite (NO_3-N) by 100% (after 18 h), orthophosphate (PO_4-P) by 89% and nitrate (NO_3-N) by 33% (after 12 days). There was also an 18.5% improvement in seaweed biomass over the experimental period. The *Ulva reticulata* grew better in SBE system, producing protein (6.1 ± 1.1%) and carbohydrate (39.9 ± 4.5%). Carbohydrate and protein content in seaweed grown in SBE system were observed to be higher than seawater *Ulva reticulate*. Hence it can be directly implemented as an effective biofilter for the removal of nutrients from shrimp hatchery effluent water.

Increasing human activity in coastal regions, particularly in agriculture, aquaculture and wastewater treatment, causes eutrophication by releasing nitrogen and phosphorus in seashore waters (Correll, 1998). Sometimes tertiary treatment is implicated to prevent the unwanted impacts of nutrients from secondary treated sewage. Usually this includes the use of costly or harmful chemicals (deBashan & Bashan, 2004). The cultivation of algal biomass in effluent system is an exciting option.

Macro algaehave long been used in sewage treatment, especially in tropical developing nations (Dunstan & Menzel, 1997; Dunstan & Tenore, 1972; Oswald, 1988; deBashan et al., 2002, deBashan & Bashan, 2004). The primary issue with their use in such application is that it is hard to distinguish the algal mass from the treated effluent due to their tiny size. Macroalgae, on the other hand, demonstrated comparable nutrient effectiveness and exhibit easy harvest. The introduction of seaweeds as biofilters for tertiary sewage treatment system depends on species capacity to use nutrients from secondarily treated sewage and species usage frequency of the significant nutrients and species salinity tolerance.

Several studies have investigated about the viability of using various species of seaweed as biofilters in tertiary sewage treatment system employing either in sewage sludge or effluent water body. (Prince, 1974; Goldman et al., 1974a, b; Ryther et al., 1979; Wong & Lau 1979). Recently, the utilization of marine algae as biofilter has developed tremendously and has concentrated on removing inorganic nutrients from the effluent coming out from fish ponds in integrated aquaculture systems (Krom et al., 1995; Neori et al., 2004) or take off heavy metals from industrial discharge (Davis et al., 2003).

Tsagkamilis et al. (2010) studied the application of seaweed for the absorption of phosphate from the sewage treatment in order to enhance the quality of water by reducing eutrophication. Data obtained from laboratory and field were collected for the study on the sewage treatment system. Three distinct macroalgae were screened for this. Based on the observations obtained, they intended a continuous flow system with water turnover of ¼ volumes per hour, in combination of 60% wastewater effluent, 40% seawater and 30gL-1initial biomass of *U. lactuca* replaced for every 10 days. The study observed that *U. lactuca* is a promising candidate as a biofilter agent for eliminating phosphate from the effluent presently released from waste water treatment plants.

Caulerpa recemosa, and *Ulva lactuca*, it play an important role in the bioremediation of heavy metals such as boron, lead, cadmium cupper, solid and liquid chromium (Bursali et al., 2009; Hammud et al., 2014; Ghoneim et al., 2014; Ibrahim et al., 2016). They also play a significant role in removing and absorbing ammonia, phosphate, nitrate and nitrite from nutrient rich aquaculture, wastewater and industrial waste water for its development and cultivation (Chung et al., 2002; Schramm, 1991).

Krishna et al. (2017) studied the bioremediation capability of *Caulerpa racemosa* and *Ulva lactuca* from industrial dye effluents. In this study the decolorization property was measured at different concentration and pH. The ability of these macroalgae *Caulerpa racemosa* and *Ulvalactuca* to remove pollutants was assessed through physiochemical effluent assessment indicating potential reduction in total dissolved solids and phosphate, but enhanced ammonia nitrogen is dissolved in both treatments. Biochemical analysis of accumulated macroalgae demonstrates decreasing protein content, complete sugar, chlorophyll a and chlorophyll b, complete chlorophyll and carotenoid content with growing days of therapy and concentration of effluent. The Fourier Transform Infrared analysis confirmed the accumulation of dye particulars into the algal cell functional groups which hold them inside. The *Ulva lactuca* shows significant decolorization in the present study. Thus the study observed the bioremediation capacity of green macroalgae which can be applicable in the industrial waste water treatment.

Pollution from heavy metals, especially Pb, can harm the estuary and aquatic coastal ecosystems. It might decrease the quality of the water. The capability of seaweed *G. verrucosa* to reduce heavy metal Pb with different concentrations in the seawater is influenced by concentration and expose period. The higher the concentration and longer exposure period of Pb, themore is the heavy metals that can be reduced in seawater and thus improving the water quality (Handhani et al., 2017).

Textile sectors are one of the largest contributor in discharging effluent water and complicated chemicals. Textile discharges include coloured wastewater, biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH, turbidity, and toxic chemicals (Davis, 2003). Direct discharge of this effluent water into water bodies such as lakes and rivers contaminate the water and influences the fauna and flora. Textile industry effluents comprise distinct kinds of colorants, which show very low biodegradability due to elevated molecular weight and complicated constructions (Donghee et al., 2005). Latinwo et al. (2015) studied the potential for the removal of heavy metals such as iron (Fe), calcium (Ca), magnesium (Mg), potassium (K), silver (Ag), and chromium (Cr) from textile waste water by green seaweed biomass. This study concluded that, green seaweed biomass has high bio absorptive choices for certain metal such as Fe, Ca, Ag, & Cr with corresponding values of 87.5%, 99.9%, 100%, & 86.8% respectively. A steady decrease in their concentration with a contact time of 60 minutes was observed. Thus, green seaweed can be used as an excellent agent to treat textile industry wastewater that includes the presence of heavy metals as a low costbio sorbent.

Conclusion

Bioremediation which technically implies the incorporation of living organisms, primarily microorganisms, to degrade the environmental contaminants into less toxic forms. It generally employs naturally occurring bacteria fungi or plants to disintegrate or detoxify substances hazardous to human health or environment. Several studies had reported that, seaweeds have the potential to eliminate pollutants from contaminated water bodies including seawater, through land-based and coastal bioremediation processes, and recycling of these impurities into beneficial by-products which can be attained through the harvest and processing of seaweed biomass. Hence seaweed may represent a good source to control or reduce the environmental contaminants.

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