Feature article

Seaweeds: an ideal component for wastewater treatment for use in aquaculture

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Introduction

Protection of the envi_onment is a major concern all over the world. Although the sea covers more than 70% of the surface of our planet, as far as human activities are concerned, the continental shelf is the most important portion since it is the main source of living marine resources used as food for humans. The shallow part of this zone, along the coast, is the most sensitive due to its smaller volume of water and the proximity to point and diffuse sources of wastewater discharge. (At present, nearly 40% of the world's population is living within 60 km of the sea, and are directly or indirectly affecting this zone). These occur because the output of domestic, industrial and agricultural activities is discharged, often with no treatment at all directly or via rivers, into estuaries and marine environments. These outputs, or so called wastewaters, are composed of various nutrients, microbes, antibiotics and heavy metals. Moreover, at present there is an increase in global demand for seafood and this has been met by increased aquaculture. As a result of this rapid production, the aquaculture activities are affecting the environment in a variety of ways, especially fish and shrimp aquaculture, which needs to be supplemented with an exogenous source of energy (food). It was demonstrated that organic and inorganic inputs of food to fish culture have a substantial impact on organic matter and nutrient loading in coastal areas (Chopin et al. 1999), affecting the sediments beneath the culture installations and producing variations in the nutrient composition of the water column. This leads, for example, to enhanced sediment metabolism, anoxia, sulfate reduction, and sulfide accumulation, high nitrogen (N) and phosphorus (P) flux, acidification, turbidity, and all other processes associated with eutrophication (Troell and Berg 1997). These environmental modifications can also affect the benthic fauna, fish abundance, bird populations, macroalgal growth and diversity, epiphytic load and chemical composition, shifts in phytoplanktonic and zooplanktonic communities, and the composition and abundance of bacteria.

Heavy metals in wastewater effluents are known to cause severe damage to aquatic life due to its toxic effects and accumulation throughout the food chain. They are toxic in both their chemically combined forms as well as the elemental form. Presence of antibiotics in water body is dangerous because they tend to bioaccumulate in the tissue of aquatic organisms, lead to the development of resistant bacterial strains and thus may have serious implication on human health. The effects of untreated wastewater on the environment are manifold and depend on types and concentrations of pollutants. Important contaminants in terms of their potential effects on receiving waters are outlined in Table 1.

This type of aquatic pollution is mostly prevalent in developing countries where only a small proportion of the wastewaters produced by sewered communities are treated. In Latin America, for instance, less than 15% of the wastewater collected in sewered cities and towns are treated prior to discharge. Often the reason for the lack of wastewater treatment is financial, but it is also due to the ignorance of low-cost wastewaters treatment processes. Currently, the global burden of excreta-related disease is extremely high. Over half the world's rivers, lakes and coastal waters are seriously polluted by untreated domestic, industrial and agricultural wastewaters, and they contain high numbers of faecal bacteria. Thus effective wastewater treatment needs to be recognized as an environmental and human health imperative.

The ecological engineers had developed numerous techniques - physical, chemical and biological methods for treating wastewaters effluents. Besides, there are also natural systems for wastewater treatment, which are designed to take advantage of the physical, chemical, and biological processes that occur in the natural environment when water, soil, plants, microorganisms and the atmosphere interact. Natural treatment systems include land treatment, constructed wetlands and seaweeds cultivation. These systems can often be the most cost-effective option in terms of operation and are frequently well suited for developing countries. There are two main ar-

Table 1. Important contaminants in wastewater

Contaminants	Reason for importance
Suspended solids (SS)	Lead to development of sludge deposits and anaerobic conditions when untreated wastewater is discharged to the aquatic environment.
Biodegradable organics	Principally made up of proteins, carbohydrates and fats. They are commonly measured in terms of BOD and COD. If discharged into inland rivers, streams or lakes, their biological stabilization can deplete natural oxygen resources and cause septic conditions that are detrimental to aquatic species.
Pathogenic organisms	Found in wastewater can cause infectious diseases.
Priority pollutants, including organic and inorganic compounds	May be highly toxic, carcinogenic, mutagenic or teratogenic.
Refractory organics	Resist conventional wastewater treatment include surfactants, phenols and agricultural pesticides.
Heavy metals	Usually added by commercial and industrial activities, must be removed for reuse of the wastewater because of its toxicity.
Antibiotics	Develop antibiotic resistant bacterial strain, residual effect.

Source: Adapted from Metcalf and Eddy, Inc., Wastewater Engineering, 3rd edition.

eas where seaweeds have the potential for use in wastewater treatment. The first is the treatment of sewage and some agricultural wastes to reduce the total N and P containing compounds before release of these treated waters into rivers or oceans. The second is for the removal of toxic metals from industrial wastewater.

Effects of seaweeds on nutrients

Continuous discharge of wastewater effluents into the aquatic environment may results in chronic bioaccumulation and eutrophication with consequent negative ecological impacts. This eutrophication is due to the enrichment of waters with nutrients such as N and P containing compounds. This frequently leads to unwanted and excessive growth of nuisance algae. Eutrophication can occur naturally, but it can be accelerated by the introduction of sewage effluent into rivers and coastal waters. Seaweeds can be used to reduce the N and P content of sewage effluents. They can concentrate nutrients by a factor of up to 10^5 over seawater levels (Lobban and Harrison 1997) and also respond to increased nutrient availability by augmenting internal stores. Many types of seaweed have a preference to take up ammonium (NH_4^+) in the form of N for their growth and NH_4^+ is the prevalent form of N in most wastewater. When NH_4^+ and nitrate (NO_3^+) are present simultaneously, they remove NH_4^+ faster than NO_3^+. NH_4^+ is the preferred form for plant growth because the incorporation of NO_3^+ requires additional metabolic energy and enzymatic activity. The root zones are superb micro-sites for bacterial communities. These bacteria carry out nitrification and thus make N available for absorption. Another important feature of many types of seaweed is their ability to take up more P than they require for maximum growth. However, some seaweeds cannot directly assimilate and utilize some organic matters, especially large molecular compounds.

The well-developed root system of the seaweeds offers expanded adhesive base for microorganisms (microzoon, bacteria and algae) and results in the formation of a mutual beneficial sub-system based on the coordinated and additive effects between them. The metabolite secreted by their roots during its growing process offered nutrition and protection for all kinds of heterotrophs. The macrophyte cultivating area and open area formed a purification system, just like wastewater treatment engineering.

Their purification mechanisms are described as follows:

(1) Nitrogen removal process

a) Nitrification (aerobic condition)

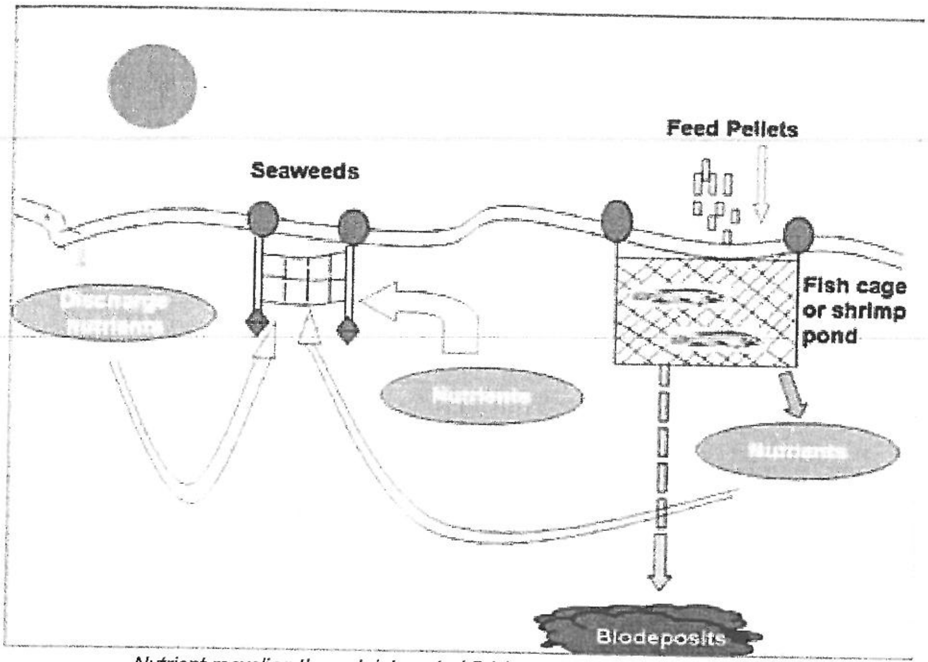
$$NH^+_4 \rightarrow NO_2^- \rightarrow NO_3^-$$

b) Denitrification (anaerobic condition)

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

(2) Phosphorus removal process

Under the anaerobic conditions, P removal bacteria used the energy which is released from the dehydrolytic reaction of orthophosphate and polyphosphate, to absorb the organic matters into bacteria cells as well as to release absorbed P. Under the aerobic condition, the bacteria used the energy released from the oxidation decomposition reaction of the organic matter in the cell to absorb the P existing outside the cell. The difference between the absorbing and releasing speed caused the excessive absorption of P. Neori et al. (2000) obtained significant removal of NH_3-N from fishpond effluents by using macroalgal biofilters. Msuya and Neori (2002) observed an increase in protein content of *Gracillaria* and *Ulva* when cultured in fishpond effluents indicating that the macroalgae removed more N than they needed and therefore stored it in their thalli. Moreover, the use of macroalgae biofilters for the removal of nutrients from the effluents has been found to be cost-effective.



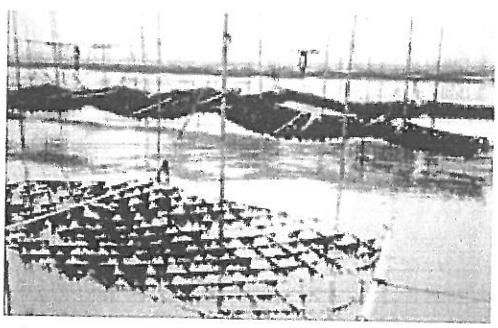
Nutrient recycling through integrated fish/seaweeds aquaculture system.

Effects of seaweeds on heavy metals/ antibiotics/ anthropogenic materials

Most of the heavy metal salts are soluble in water and form aqueous solutions and consequently cannot be separated by ordinary physical means of separation. Physico-chemical methods, such as chemical precipitation, chemical oxidation or reduction, electrochemical treatment, evaporative recovery, filtration, ion exchange, and membrane technologies have been widely used to remove heavy metal ions from industrial wastewater. These processes may be ineffective or expensive, especially when the heavy metal ions are in solutions containing in the order of 1-100 mg dissolved heavy metal ions/L. Biological methods such as biosorption/ bioaccumulation for the removal of heavy metal ions may provide an attractive alternative to physico-chemical methods (Kapoor and Viraraghavan 1995). Seaweeds have the property to sequester many heavy metals and can be used for the development of highly effective biosorbent materials. Many types of biomass in non-living form (bacteria, fungi, yeast and others) are available for making biosorbent materials but the capacities of some species of marine algae were found to be much higher than those of other types of biomass. They were also much higher than those of activated carbon and natural zeolite and were comparable to those of synthetic ion exchange resins (Matheickal et al.1997). Biosorption of metals is not based on only one mechanism. It consists of several ones that quantitatively and qualitatively differ according to the type of biomass, its origin and its processing. Metal sequestration may involve complex mechanisms, mainly ion exchange, chelation, adsorption by physical forces and ion entrapment in inter and intra fibrilar capillaries and spaces of the structural polysaccharide cell wall network. The main component in seaweeds responsible for metal sorption is the alginate which is present in a gel form in their cell walls. Brown algae cell walls are very porous and easily permeable to small ionic species. Furthermore, seaweeds possess rigid physical shapes and structures which make their application in biosorption processes particularly suitable. Morphologically, the seaweed thallus particles approximate flat chips rather than having a spherical shape which thereby facilitates rapid metal ion mass transfer and effective metal binding. Compared with conventional methods for removing toxic metals from industrial effluents such as precipitation with lime, ion exchange and precipitation with biosulphide (H_2S produced by sulfate-reducing bacteria), the biosorption process by seaweeds offers the advantages of low operating cost, minimization of the volume of chemical and/or biological sludge to be disposed of, high efficiency in detoxifying very dilute effluents, and no nutrient requirements. These advantages have served as the primary incentives for developing full-scale biosorption processes to clean up heavy-metal pollution.

Effect on water quality

Macrophytes can improve the water quality by reducing algal density and increasing transparency. Some submerged plants can secrete allelopathic substances such as terpenoid, steroid, phenolic compounds etc. which restrict the growth of harmful algae. The water quality integrated index such as chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS) and transparency remains higher in a non macrophyte cultivating area than in a macrophyte area. Belmont et al. (2004) recorded removal of more than 80% of TSS, COD, NO_3 and about 50% of $NH_4^+$of domestic sewage water when treated in wetlands containing various ornamental plants. Redding et al. (1997) observed an increase in the amount of dissolved oxygen in the waters



Seaweed cultivation in coastal area to reduce aquaculture pollution. (Source: FAO 2003).

treated with aquatic macrophytes. However, in both these studies, freshwater macrophytes were used.

Economical aspects

The gains in vegetation biomass used in the treatment of wastewater effluents can provide economic returns to many communities when harvested. These can be realized, for example through biogas production, animal feed, fiber for paper making, and compost. Moreover, the water generated becomes suitable for irrigation or aquacultural purposes. At present, the common seaweeds used were red algae (*Porphyra, Gracilaria*), brown algae (*Laminaria, Undaria*) and green algae (*Ulva, Enteromorpha*) however, there is potential to use other types of seaweeds.

Characteristics of seaweeds

The seaweeds used for wastewater treatment should preferably have some commercial value. They should be able to tolerate a wide variation in salinity because of the dilution of salinity by the sewage or wastewater. For instance, intertidal and estuarine species such as *Enteromorpha* and *Monostroma* are the most tolerant. From temperature tolerance point of view, tropical or subtropical forms of red and brown seaweeds which are of commercial interest can be successfully used, while cold-temperate species are usually too sensitive to changing seasons and may fail to grow (and remove nutrients) in the winter months. Moreover, they should have more membrane surface for nutrient uptake as Porphyra, a red algae whose mono- and distromatic thallus is 20 - 60 µm thick. This gives them a very high surface area to volume ratio and placing cells very close to pools of inorganic nutrients.

Integration with fish culture

Integrating seaweeds with fish culture could minimize coastal eutrophication problems by turning the wastes of one species into a resource for another species. Such a balanced ecosystem approach will provide nutrient bioremediation capability, mutual benefit to the cocultured organisms, economic diversification by producing other value-added marine crops, and increased profitability per cultivation unit for the aquaculture unit. Moreover as guidelines and regulations on aquaculture effluents are forthcoming in several countries, using appropriately selected seaweeds as renewal biological nutrient scrubbers represents a cost-effective means for reaching compliance by reducing the internalization of the total environmental costs. By adopting integrated polytrophic practices, the aquaculture industry could find increasing environmental, economic, and social acceptability and become a full and sustainable partner within the development of integrated coastal management frameworks.

Seaweeds grown in fish cages. (Source: FAO 2003).

Conclusions

This clearly demonstrates the suitability of seaweeds for wastewater treatments. Such practices are less expensive and less labour intensive than implementing and respecting regulations or laws on conventional wastewater treatment enacted by state or governing agencies. Though some pilot scale studies have proven their practicality, the use of such an approach has not yet reached commercial reality. Therefore, more research is needed in this aspect so as to develop a model for effective and economical wastewater treatment.

References

Belmont, M.A., E. Cantellano, S. Thompson, M. Williamson, A. S´anchez, and C.D. Metcalfe. 2004. Treatment of domestic wastewater in a pilot-scale natural treatment system in central Mexico. Ecological Engineering 23:299–311.

Chopin, T., C. Yarish, R. Wilkes, E. Belyea, S. Lu, and A. Mathieson. 1999. Developing porphyra/salmon integrated aquaculture for bioremediation and diversification of the aquaculture industry. Journal of Applied Phycology 11:463-72.

Kapoor, A. and T. Viraraghavan. 1995. Fungal biosorption - an alternative treatment option for heavy metal bearing wastewater: a review. Bioresource Technolology 53:195-206.

Lobban, C.S. and P.J. Harrison. 1997. Seaweed Ecology and Physiology. Cambridge University Press, New York USA.

Matheickal, J.T., J. Feltham, and Q. Yu. 1997. Cu (II) binding by marine alga *Ecklonia radita* biomaterial. Environmental Technology 18:25-34.

McHugh, D. J. 2003. A guide to the seaweed industry. FAO Fisheries Technical Paper 441. Food and Agriculture Organization of the United Nations, Rome, Italy.

Metcalf and Eddy. 1991. Wastewater Engineering: Treatment Disposal and Reuse, 3rd edition, McGraw-Hill, New York, USA.

Msuya, F. E. and A. Neori. 2002. *Ulva reticulata* and *Gracilaria crassa*: macroalgae that can biofilter effluent from tidal fish ponds in Tanzania. Western Indian Ocean Journal of Marine Science 1:117-126.

Neori, A., M. Shpigel, and D. Ben-Ezra. 2000. A sustainable integrated system for culture of fish, seaweed and abalone. Aquaculture 186:279–291.

Redding, T., S. Todd, and A. Midlen. 1997. The treatment of aquaculture wastewaters - a botanical approach. Journal of Environmental Management 50:283–299.

Troell, M. and H. Berg. 1997. Cage fish farming in the tropical lake Kariba: impact and biogeochemical in sediment. Aquaculture Research 28:527- 544.