Method for biological bioremediation of eutrophication of marine coastal zone and inland water bodies

FIELD OF INVENTION

The invention relates to a method for the containment of pollutants present in the aquatic environment and to a device for implementing the biological bioremediation method for eutrophication in tropical and temperate coastal zone sea water and inland water bodies; relating to the cultivation of various kind of edible and inedible seaweed in tandem with or without other aquatic organism. Its steps:

An offshore structural enclosure island designed for extensive biofiltration, with dual function of microparticulate (organic and inorganic) removal from water column as well as wave energy deflection. The enclosure structure setup has the creation of clearer water zone within than without as the primary objective, through biofiltration and hydrodynamic change.

The design firstly incorporates curved wave deflectors above water surface to deflect and dampen wave energy from reaching within the enclosure, protecting structures within from wave impact damages.

By constant dampening of surface wave and ripples, the wave deflectors facilitate calm/ still-water effect at the water surface within the enclosure. And then underwater, 2 or more layers of dense green lip mussel growth (inner & outer layer), where a series of vertical rope substrates is arrayed into a curtain, having maximum surface in water column for mussel spat attachment.

The mussel curtains form a physical barrier whereby influx of organic and inorganic particles is reduced.

Within the enclosure, floating grid frames support a network of ropes arrayed likewise, for maximum utilization of water space for the cultivation of macroalgae and or seaweed. Large

scale seaweed cultivation offshore for the sequestration of dissolved nutrients in the water column of the water body, nitrogen and phosphorous, as well as carbon sequestration. The offshore biofilter curtain barrier complements well with seaweed cultivation from the water clarifying effects out of the above-mentioned functions, increasing light penetration in water depth in turbid waters leading to improved photosynthesis of seaweed.

This single offshore structural enclosure, where the initially-bred seaweed biomass density is metric ton/enclosure; described as a single floating grid frame from substantially 1m x 1m , 2m x 2m, 3m x 3m or any other dimensions, where substrates such as long lines are secured within for seaweed cultivation. This single platform frame is subsequently joined more to form an Island type structure which is provided with at least 2 to 14 of 5m wide by 10m long wooden frame grids, forming a single seaweed island formation which can take form in many sizes and shapes. This island is highly mobile and can be anchor via established anchoring and mooring methodology. The island design also provides for multi trophic farming which include farming of species at the lower trophic level (usually plants or invertebrates) which use waste products such as faeces and uneaten feed from the higher trophic species (typically finfish), as nutrients. The lower trophic species can then be harvested in addition to the fish. The frame body of seaweed island are provided with at least 1 suspended body and fixed by 4 to 24 anchoring and mooring system, depending on the size of the entire structure. It combines seaweed cultivation with other aquatic culture for mixed culture, used for bioremediation of eutrophication of marine and fresh water culture.

DESCRIPTION OF ENCLOSURES

This purpose of the design is an arrangement of minimum 2 different enclosures and 2 tropical or temperate species, in an integrative manner. The outer rim of the structure, biofilter curtain barrier removes water borne suspended solids by action of biofiltration and sedimentation by the slowing down of water currents, to enhance the inner zone in cultivation of rapid bloom forming chlorophyte macroalgae species, as a geoengineering solution for the rapid uptake of nutrients (N and P) within the eutrophicated zone. Such environment is usually characterized by turbid water due to heavy loading of suspended particles, composed mainly of silt from terrestrial run-offs and also phytoplankton cells. Yet the same type of

environment is usually eutrophicated with excess of nutrients stemming from close proximity to modern civilization's establishments, whether residential or industrial.

While nutrient rich water is an advantage to macroalgae growth, high turbidity shading sunlight from depth penetration isn't advantageous to macroalgae.

Many macroalgae species requires high intensity underwater light field afforded by natural sunlight, for optimum photosynthesis and growth. Underwater light fields are vulnerable to human activities. Anthropogenic disturbances such as eutrophication, dredging operations and accelerated soil erosion due to the de-afforestation of river catchments can modify underwater light climates in coastal regions. Increases in water turbidity produced by these activities can reduce growth factors for these photosynthetic macroalgae, tilting the favour and opportunity to other non-macroalgae species. Water borne ultra-fine particles such as inorganic silt as poses epi-fouling problems for macroalgae by coating thallus's and tissues, effectively smothering the entire algae, hampering their production.

The offshore seaweed bioremediation enclosure platform incorporates an outer protective circular wave breaker as a mechanical filter barrier to reduce suspended particles from entering macroalgae cultivation zone. The wave breaker is a floating drum-like structure made of HDPE material mixed with seaweed bioplastics , arrayed in a circular form with regular intervals of long nylon ropes anchored to the sea floor to maintain the circular shape.

Firstly, the wall of mussels grown on vertical ropes attached underneath the surface wave breaker will filter out phytoplankton and trap silt particles, improving water clarity which leads to improved sunlight penetration for the cultivated macroalgae within the circle. Secondly the wave breaker floating on water surface will dampen incoming wave energy from tides, winds, and vessel wakes. The result is reduction of ripple effect, further improving sunlight penetration down the water depth as light scattering at water surface is reduced. Macroalgae/seaweed can then be cultivated deeper within water column, vertically. Similarly, the floating platform comprising workstations and miscellaneous utility floors within the circular wave breaker are protected from wave breakages, reducing structural maintenance cost.

The macroalgae cultivation structure is a network of long lines attached to floating pen grid frames. Seed stock inoculums are usually produced in a central hatchery lab which supply seed cultivars to be planted with ropes within the grids.

DISCLOSURE

1. This application claims the benefit of priority of Singapore Patent Application No. xxxxx, filed xx April 2022, the content of it being hereby incorporated by reference in its entirety for all purposes.

2. The invention relates to a method for the containment of pollutants present in the aquatic environment and to a device for biological bioremediation method for eutrophication in tropical and temperate coastal zone sea water and inland water body (fresh water).

3. Eutrophication is a big word that describes a big problem in the nation's estuaries. Harmful algal blooms, dead zones, and fish kills are the results of a process called eutrophication — which occurs when the environment becomes enriched with nutrients, increasing the amount of plant and algae growth to estuaries and coastal waters.

4. Sixty-five percent of the estuaries and coastal waters in the contiguous U.S. that have been studied by researchers are moderately to severely degraded by excessive nutrient inputs. Excessive nutrients lead to algal blooms and low-oxygen (hypoxic) waters that can kill fish and seagrass and reduce essential fish habitats. Many of these estuaries also support bivalve mollusk populations (e.g., oysters, clams, scallops), which naturally reduce nutrients through their filter-feeding activities.

5. Eutrophication sets off a chain reaction in the ecosystem, starting with an overabundance of algae and plants. The excess algae and plant matter eventually decompose, producing large amounts of carbon dioxide. This lowers the pH of seawater, a process known as ocean acidification. Acidification slows the growth of fish and shellfish and can prevent shell formation in bivalve mollusks. This leads to a reduced catch for commercial and recreational fisheries, meaning smaller harvests and more expensive seafood.

6. The major nutrients that cause over-enrichment are nitrogen and phosphorus. The sources of nutrients vary among regions and are very often remote from the body of affected water. Agriculture, human sewage, urban run-off, industrial effluent, and fossil fuel combustions are the most common sources. The intensive use of commercial fertilizers over the last 50 years has increased crop yield but much of the nutrients not absorbed by crops find their way into local rivers and lakes, and are carried downstream to the estuaries, and eventually to the sea. Human activities have resulted in the near doubling of nitrogen and tripling of phosphorus flows to the environment when compared to natural causes. Trends in agricultural practices, energy use, and population growth indicate that eutrophication, especially in coastal areas, will be an ever-growing problem.

7. Nutrient over-enrichment often leads to algal bloom resulting in changes in biodiversity and loss of habitats (e.g., decline of coral reef), and appearance of "dead zones" where most animals are driven away or die of hypoxia. Change in abundance and diversity of living organisms have adverse impacts on the environmental quality of lakes and coastal waters.

8. Eutrophication is characterized by excessive plant and algal growth due to the increased availability of one or more limiting growth factors needed for photosynthesis (Schindler 2006), such as sunlight, carbon dioxide, and nutrient fertilizers. Eutrophication occurs naturally over centuries as lakes age and are filled in with sediments (Carpenter 1981). However, human activities which include aquaculture operations have accelerated the rate and extent of eutrophication through both point-source discharges and non-point loadings of limiting nutrients, such as nitrogen and phosphorus, into aquatic ecosystems (i.e., cultural eutrophication), with dramatic consequences for drinking water sources, fisheries, and recreational water bodies (Carpenter et al. 1998). For example, aquaculture scientists and pond managers often intentionally eutrophy water bodies by adding fertilizers to enhance primary productivity and increase the density and biomass of recreationally and economically important fishes via bottom-up effects on higher trophic levels (Boyd & Tucker 1998). However, during the 1960s and 1970s, scientists linked algal blooms to nutrient enrichment resulting from anthropogenic activities such as agriculture, industry, and sewage disposal (Schindler 1974). The known consequences of cultural eutrophication include blooms of blue-green algae (cyanobacteria), tainted drinking water

supplies, degradation of recreational opportunities, and hypoxia. The estimated cost of damage mediated by eutrophication in the U.S. alone is approximately $2.2 billion annually (Dodds et al. 2009)

9. A common symptom of nutrient over-enrichment is the excessive production of algal biomass. Where excess algal proliferation is dominated by certain species of toxic algae, mass mortalities of wild fish and shellfish, birds and even mammals occur; fish farms that use these waters are also impacted. Paralysis, diarrhea, and amnesia were associated with human consumption of contaminated seafood. In 1997, hundreds of dead fish were found in Chesapeake Bay and Pokomoke River near Maryland in the United States, resulting in waterway closures and public rejection of aquatic produce from the area. The economic loss suffered by the local seafood industry was estimated to be US$43 million (Lipton, D. W., 1998, Pfiesteria's economic impact on seafood industry sales and recreational fishing. Pfiesteria: where do we go from here? Economics of Policy Options for Nutrient Management and Dinoflagellates Conference. University of Maryland, Department of Agriculture and Natural Resources, College Park). In 1998, an algal bloom wiped out 90 percent of the entire stock of Hong Kong's fish farms and resulted in an estimated economic loss of US$40 million (Lu, S., and I. J. Hodgkiss, 2004, “Harmful algal bloom causative collected from Hong Kong waters.” Hydrobiologia 512(1-3): 231-238).

10. Corals and associated organisms in the reef ecosystem are adapted to oligotrophic conditions. Thus, nutrient enrichment resulted from various anthropogenic activities on the coast and land can dramatically influence the functioning of the reef ecosystem. Terrestrial runoff from rivers and streams carrying excess nutrients (inorganic nutrients such as ammonium, nitrate, and phosphate) due to the agricultural, industrial, and various urban activities are the major source of nutrient pollution in the coral environment (Kroon et al., 2012; Liñán-Cabello et al., 2016). Direct discharge of untreated sewage in coastal waters increases the concentration of inorganic nutrients such as ammonium, nitrate, nitrite, and phosphate (Wear & Thurber, 2015). A study showed a sharp increase in the nitrate (75-fold), phosphate (31-fold), and ammonium concentrations (threefold) in the reef environment as a result of terrestrial runoff after heavy rainfall (den Haan et al., 2016). Another major source of nutrient pollution is coastal fish farming, which increases the organic content of the reef ecosystem near the aquaculture farm through waste like

feed pellets, feces, and other organic matter (Garren, Smriga, & Azam, 2008). Similarly, agriculture activities near coastal areas contribute to the pesticide and dissolved inorganic nutrients in the reef ecosystem (Waterhouse, Brodie, Lewis, & Mitchell, 2012). The huge growth in tourism adds up to direct or indirect nutrient pollution in the reef ecosystem (Lachs et al., 2019). Submarine groundwater discharge is reported to increase nutrient pollution in the Santiago reef flat in Northwestern Philippines (Senal et al., 2011).

11. Nutrient enrichment in the coral environment influences the shift of the benthic community from corals towards more algae and sponges (Lapointe, 1997). A study showed that turf algae and opportunistic macroalgae will primarily get benefit from chronic nutrient exposure, which will ultimately outcompete the reef-building corals (den Haan et al., 2016). The prevalence of algae in a coral ecosystem has severe ecological implications, which include coral bleaching, reduced coral growth, and coral mortality. For instance, an increase in calcification rate was observed at elevated P, which in long term stresses the coral animals and damage their skeletal integrity (Dunn et al., 2012). Another study reported the decrease in coral resilience and new coral recruit settlement in the presence of macroalgae, algal turfs, and sediment (Birrell, McCook, & Willis, 2005). Increased nutrients promote zooxanthellae growth, which in turn increases oxidative stress in the symbiont and induces bleaching and susceptibility of corals to disease (Morris, Voolstra, Quigley, Bourne, & Bay, 2019). Nutrient-rich water promotes the growth of plankton-feeding larvae of Crown of Thorn Starfish (COTS)—the coral predator (De'ath, Fabricius, Sweatman, & Puotinen, 2012). Nutrient pollution changes the microbial balance around the coral animals and promotes the growth of opportunistic microbes that eventually make the coral animal susceptible to coral disease such as yellow blotch and black band disease (BBD; Bruno, Petes, Drew Harvell, & Hettinger, 2003; Redding et al., 2013). The scenario gets worse when combined with other stressors like sea surface temperature rise (SST) and ocean acidification (OA) (Johnson & Carpenter, 2018). Overall, the nutrient pollution in the reef environment introduces an imbalance in the reef ecosystem (D'Angelo & Wiedenmann, 2014; Silbiger et al., 2018).

12. Citation of any reference of this application is not to be construed as an admission that such reference is prior art to the present application.

SUMMARY OF THE INVENTION

1. The invention provides biological methods for the containment of pollutants present in the aquatic environment and to a device for implementing the biological bioremediation method for eutrophication in tropical and temperate coastal zone sea water and inland water bodies (fresh water).

2. The bioremediation process will reduce the nutrient in the water body via bio stimulation and bioaugmentation which can be used to prevent algal overgrowth, prevent the occurrence of an algal bloom including a harmful algal bloom or a hypoxic zone.

3. The invention can also be used to reduce the algal biomass in a pre-existing algal bloom, harmful algal bloom, or hypoxic zone.

4. The invention can also be used to prevent or reduce the loss of seagrasses and/or perennial benthic macroalgae in an aquatic area; leading to long term restoration of the pre-existing aquatic bio diversity.

5. The invention can be used in eutrophic water found inland or in coastal areas, including but not limited to lake, river estuary, continental shelf, lagoon, drowned river bed, embayment, gulf, and coastal plain. Typically, the source of the nutrients in eutrophic water is agricultural runoff, industrial effluent, sewage, upwelling, aquaculture waste, or a mixture thereof. The oversupply of nutrients in a body of eutrophic water support algal growth leading to an increase in algae biomass, an algal bloom, a harmful algal bloom, or hypoxia. In certain embodiments, the growth rate of the algae in eutrophic water is limited by the concentration of at least one of these elements: nitrogen, phosphorous, iron, or silicon.

6. Eutrophic water and algal bloom can be identified by one or more techniques, such as but not limited to analysis of water samples and remote sensing. Optionally, the data can be analyzed in combination with historical data for a region. For example, eutrophic water can be found in a location where an algal bloom has occurred previously or occurs on a regular, diurnal, seasonal, or annual basis.

7. A community of different algae comprising microalgae such as raphidophytes, dinoflagellates, diatoms, and/or cyanobacteria are commonly found in eutrophic water. In an algal bloom, bloom species belonging to the following taxonomic groups are found: *Anabaena, Phenomenon, Microcystis, Noctiluca, Alexandrium, Prorocentrum, Gymnodinium, Ceratium, Pfiesteria, Dinophysis, Gyrodinium, Heterosigma, Chattonella, Skeletonema, Synedropsis, Pseudonitzschia, Leptocylindrus, Chaetoceros; Phaeocystis, Nannochloris, Stichococcus, Aureococcus, Miraltia, Guinardia, Spermatozopsis, Urosolenia, Nitschia, Cyclotella, Cryptomonas*, and *Pedinophora*.

8. Depending on the bloom species and water conditions, such as turbidity, dissolved oxygen level and toxin level, the invention contemplates using seaweed and or a combination of multi-trophic farming aquatic staples to feed on the nutrient. Aquatic staples such as Planktivorous feeders that have developed specialized structures (e.g. gill lamellae in bivalves such as green mussels) to feed on plankton, phytoplankton in particular, are preferred. The planktivorous organisms in the enclosure can be chosen for their preference for plankton of a particular size range that matches the size of the bloom species. As the composition and size distribution of the plankton community in a bloom change over time, a different assemblage of planktivorous organisms with appropriately matching preferences of food size or type can be used.

9. In preferred embodiments, the planktivorous feeders are preferably bivalves, such as but not limited to oysters, mussels, scallops, clams and shellfish such as abalone. Depending on the local environment, marine, brackish, and/or freshwater species can be used. The seaweed, fishes, planktivorous feeders and shellfishes are cultured within the enclosure of the invention until the algal biomass is reduced; achieving a quantifiable bioremediation of the surrounding areas. The seaweed, planktivorous organisms and shellfish are then harvested or gathered and processed by methods known in the art for seafood processing and rendering of fish meal and fish oil, extract for the pharmaceutical and cosmetic industry for the production of specialty chemicals and nutraceuticals. The seaweed, planktivorous organisms and shellfish can also be harvested for human consumption.

Methods for making biofuel and construction aggregates from seaweed grown in enclosures and harvested from the eutrophic water, are aspects of the invention.

10. In various embodiments, the invention is used in a location where the water conditions are favorable for development of an algal bloom, or an algal bloom is developing. The invention can be practiced by towing a mobile enclosure to and mooring it at or near, a location with an algal bloom and/or hypoxic zone.

11. To deploy the invention in a body of eutrophic water, the seaweed, planktivorous organisms and shellfish are introduced into an enclosure situated in the body of water.

12. The invention can be deployed just before the start of a regular algal bloom, or after a bloom has developed.

13. By manipulating the selective genetic of the seaweed and the algorithm of species mix with Planktivorous feeders and shellfish, this invention can be produced for use in the said Seaweed Island concept at any time during the year.

14. In various embodiments, the seaweed, planktivorous organisms and shellfish of the invention are attached and or confined so that they can be harvested from the water easily. Also encompassed are systems for culturing, transporting, and processing of seaweed, planktivorous organisms and shellfish of the invention.

15. The enclosures of the invention are artificial structures that attached and or confine the seaweed, planktivorous organisms and shellfish in a eutrophic zone, such as but not limited to cages and nets as well as, solid substrates.

16. The enclosure is floating and can be installed as an island with various permutation in an area.

17. In certain embodiments of the invention, the enclosures are not permanently installed and can be relocated to another geographic location. In one embodiment, the enclosure is a

towage cage or net in which the seaweed, planktivorous organisms and shellfish are cultured. Non-limiting examples of an enclosure include a modified vessel or a modified oil/gas production platform.

BRIEF DESCRIPTION OF THE DRAWINGS

Overview diagram of Biofilter Curtain Barrier Enclosure, encircling a platform for seaweed cultivation

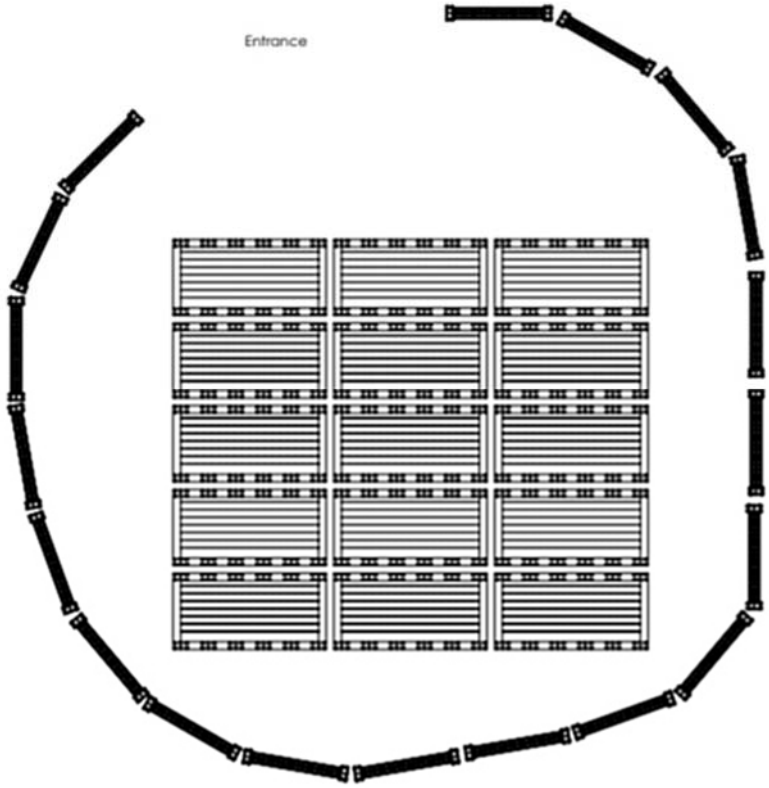


Figure 1. A plan view diagram of a floating Offshore Structural Enclosure Island for seaweed cultivation that comes with an outer Bioremediation filter Curtain Barrier which is Encircling the entire enclosure.

Figure 1 shows a framework a floating Offshore Structural Enclosure Island for the application of containment of pollutants present in the aquatic environment and to a device

for implementing the biological bioremediation method for eutrophication in tropical and temperate coastal zone sea water and inland water body; relating to the cultivation of various kind of edible & inedible seaweed in tandem with or without other aquatic organism. The encircling biofilter curtain barrier indicates an embodiment of the invention for containment of pollutants present via the reduction in the nutrient in the water which will in turn reduce the algal biomass in eutrophic coastal waters (marine and brackish ecosystems).

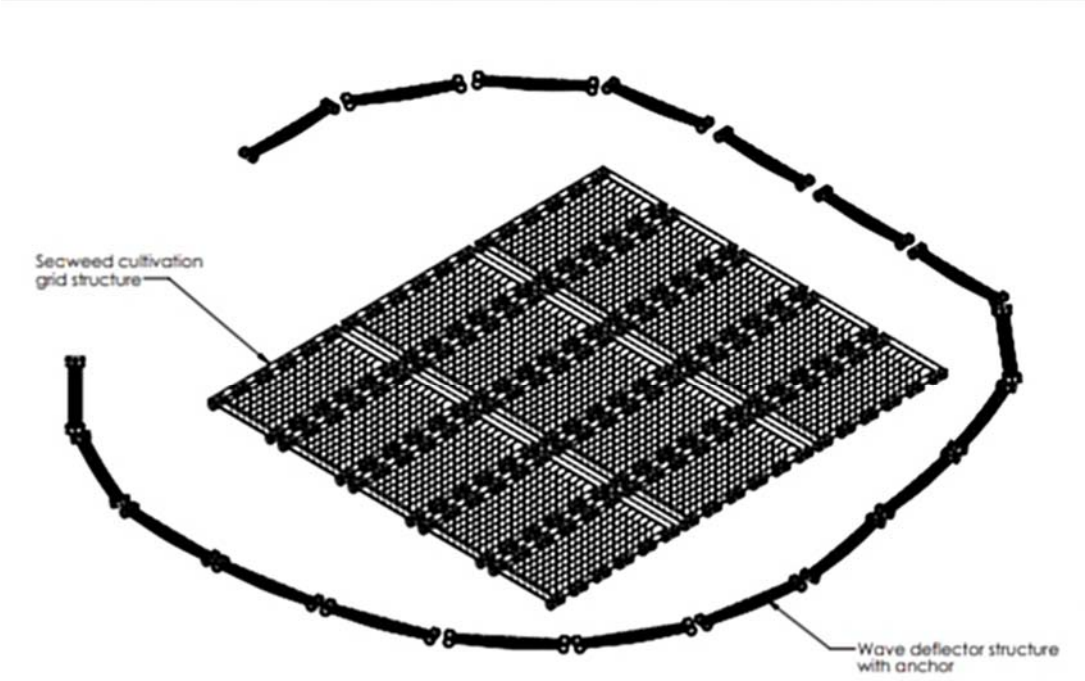


Figure 2 - An embodiment of the invention directed to a proprietary outer protective circular wave breaker

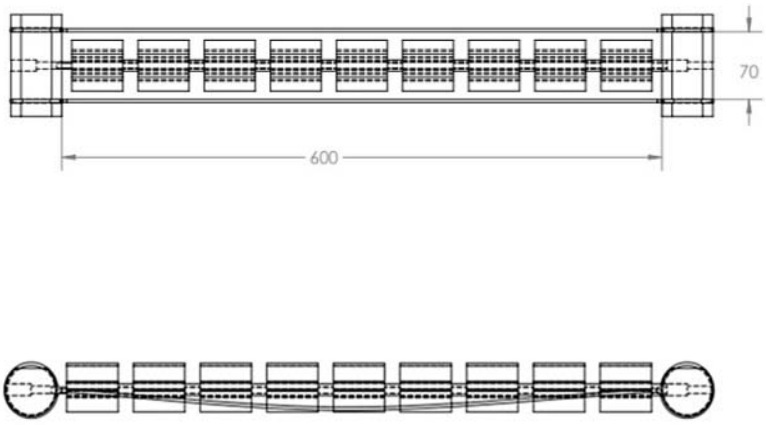


Figure 3 - Plan Elevation - Proprietary Wave deflation device – With curved surface wave breaker float

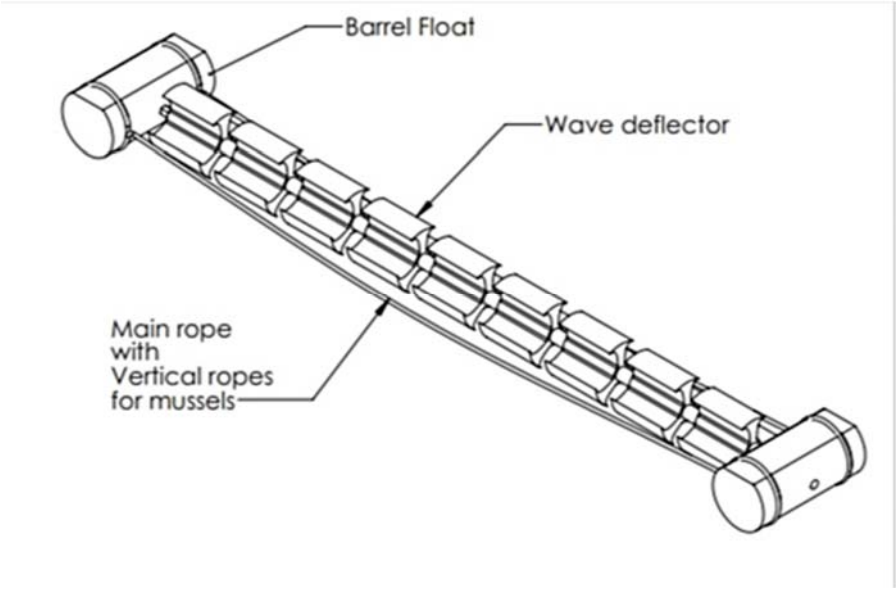


Figure 4 - Side elevation of proprietary outer protective circular wave breaker

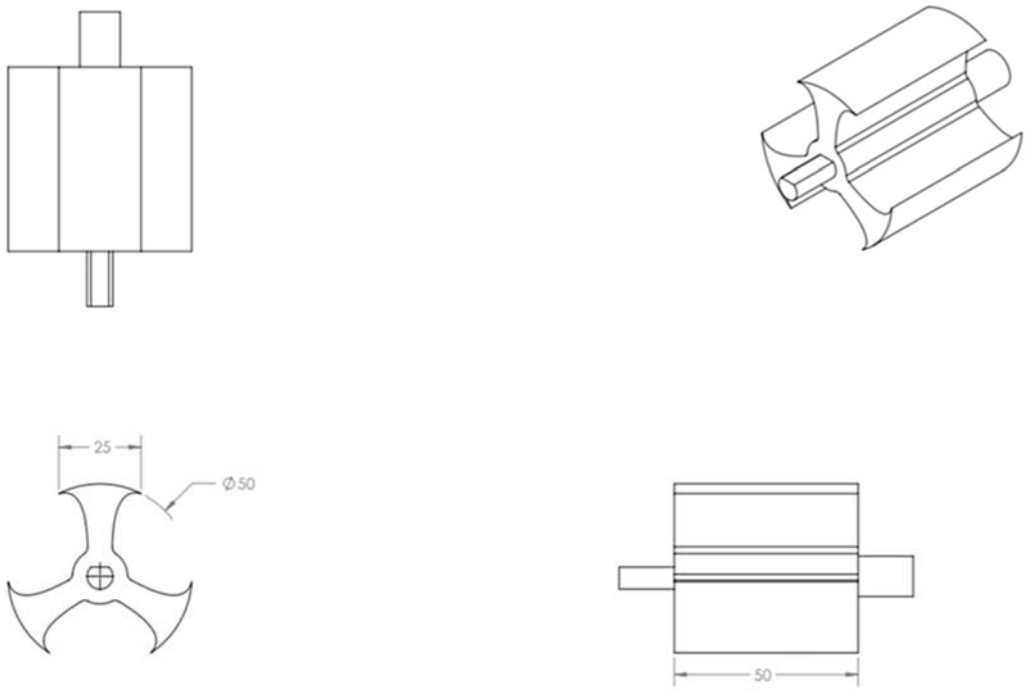


Figure 5 - Proprietary Wave deflation device – With curved surface wave breaker float.

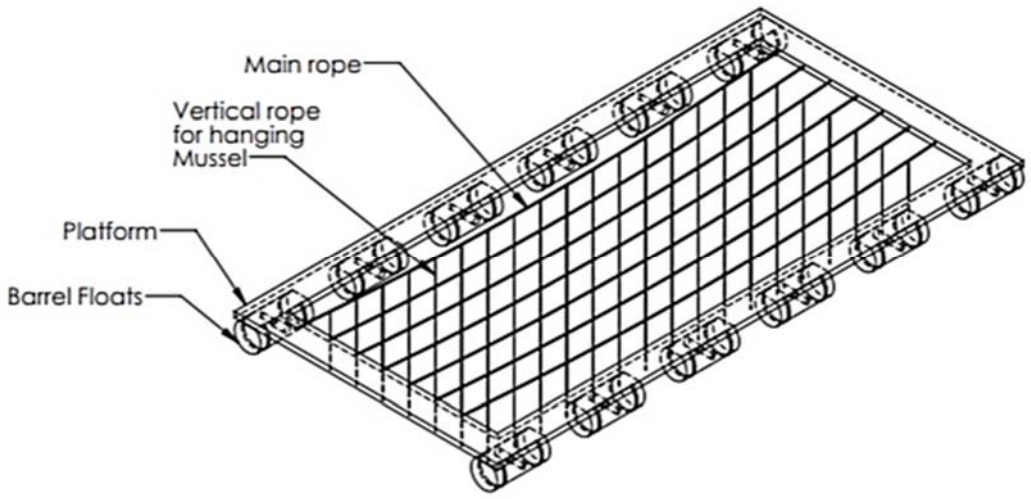


Figure 6 – Single Offshore structural enclosure - A Floating Grid frame with long lines secured. Lines of vertical rope substrate are then attached to these long lines for seaweed cultivation.

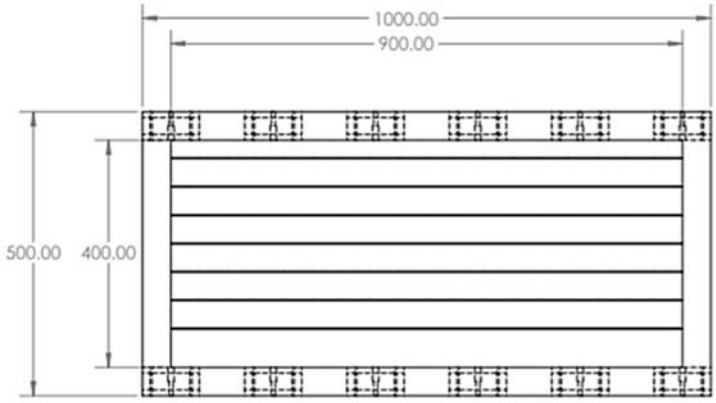


Figure 7 – Seaweed cultivation grids with lines of vertical rope substrate (top view)

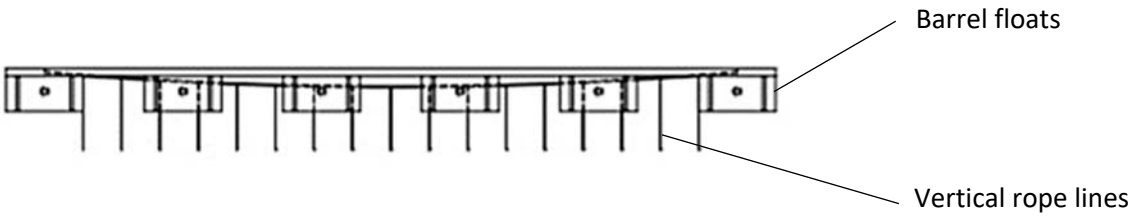


Figure 8 – Seaweed cultivation grids with lines of vertical rope substrate (front view)

DETAILED DESCRIPTION OF THE INVENTION

1. The over-enrichment of water by nutrients, referred to herein as “eutrophication” degrades many aquatic ecosystems worldwide. The current conceptual model of eutrophication recognizes an interacting set of direct and indirect responses of an aquatic ecosystem to nutrient enrichment. Nutrient input stimulates accumulation of phytoplankton biomass, followed by vertical flow of algal-derived organic matter to bottom waters and the sediments, decomposition of the organic matter by bacteria which use up the available dissolved oxygen. Indirectly, eutrophication affects water transparency, distribution of vascular plants and biomass of macroalgae, nutrient cycling, nutrient ratios, plankton community composition, frequency of toxic/harmful algal blooms, habitat quality for metazoans, and reproduction/growth/survival of pelagic and benthic invertebrates.

2. Our evolving conceptual model of the eutrophication problem identified that these activities can and will lead to loss of fishery resources and environmental amenities, starting from anthropogenic activities that produce nutrients, eutrophication, and the development of dead zones. The inventors believe that an understanding of the relationships of various elements in a eutrophic system offers the possibility of a biological intervention with a view towards abating the deleterious effects of eutrophication.

3. The invention relates to biological level bioremediation for reducing nutrient built-up and algal biomass in eutrophic water. The methods of the invention employ mainly seaweed and organisms of various trophic levels to consume nutrient and algae in waters rich in nutrients.

4. The invention takes care of nutrient loading in the water which causes algal productivity to proceed at rates that are many orders of magnitude higher than consumption by animal forms. Zooplankton blooms generally follow the peak in phytoplankton blooms which begin to diminish due to overgrazing or nutrient depletion. The invention takes into account these relationships in population dynamics of blooms and bloom induced trophic associations.

5. The invention is based in part on the recognition that the presence of nutrient in eutrophic water are the major cause for massive eutrophication. The inventor believe that algae can be removed efficiently by the removal of the nutrient which is the major feed source for these algae whereby resulting in reduce incidents of eutrophication, natural bioremediation of the coastal zones or affected areas, gradual return of the bio diversity that has been reduced or decimated and return of endemic marine species that will contribute, on the long term, the revival of the fishery industry and have a positive impact on food security.

6. This invention will also positively impact and possibly stall and reverse the effects of global warming action on the oceans and see a gradual decremental on the surrounding temperature of the water.

7. According to the invention, the seaweed, planktivorous organisms and shellfish that are cultured in the eutrophic water, are tasked to oxidize and consume the nutrient, thereby preventing the growth of the algal biomass. The floating enclosure (seaweed island) can be maintained until either the nutrient level is reduced to a desired level, or the organisms have grown to a desirable size and are ready to be harvested. The body of eutrophic water can be restocked with more enclosures or Seaweed islands for as long as the needed. The invention also provides that seaweed, planktivorous organisms and shellfish that are used for the biological bioremediation can be used for the production of alternative protein, fish meal replacement, food, biofuel, industrial feedstock, or aquaculture feed, extract for the pharmaceutical and cosmetic industry for the production of specialty chemicals and nutraceuticals.

8. The invention is also supported by the observation that benthic bivalve filter feeders play the role of a biological, locale-specific attribute which modulates the response of an estuarine-coastal ecosystem to nutrient enrichment, leading to large differences among such ecosystems in their sensitivity to nutrients. For example, one of the better predictors of chlorophyll a concentration in Danish estuaries, a measure of algal biomass concentration, is the biomass of mussels. Another example shows that the balance

between phytoplankton production and loss to benthic feeders can be disrupted by the colonization of an ecosystem by non-indigenous suspension feeders. This occurred in northern San Francisco Bay when the Asian clam *Potamocorbula amurensis* became widely established in 1987; and since then, chlorophyll biomass has been persistently low and primary production has been reduced 5-fold (Alpine & Cloern, 1992, Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary, Limnol. Oceanogr. 37:946-955). These phenomena occur where there is an interaction between the pelagic and benthic zones involving a large number of benthic bivalve suspension feeders removing phytoplankton from the water.

9. In various embodiments of the invention, the seaweed, planktivorous organisms and or shellfish introduced into a body of eutrophic water are confined to the infrastructure of the invention. Optionally, the seaweed island invention is held in enclosures that can be relocated from one geographic location to another. The culturing of the seaweed, planktivorous organisms and shellfish in the eutrophic water can entail replenishing the eutrophic water around the infrastructure with increased levels of dissolved oxygen above the current hypoxic level.

10. In one embodiment of the invention, the methods can be initiated by installing an infrastructure or seaweed island in a eutrophic zone, such as locations that are prone to formation of harmful algal bloom and/or hypoxic zone.

11. The invention is designed to be transportable, and is relocated to where there are reports of algal biomass is accumulating or detection of high nutrient level or hypoxic scenario. Different species of seaweed, planktivorous organisms and shellfish at various ages or developmental forms can be used in combination or in sequence to remove reduce algae bloom from eutrophic water. An advantage of the present invention is the flexibility of its deployment in almost any location where there is a body of eutrophic water and at any time of the year. Because the seaweed, planktivorous organisms and shellfish are confined to the systems of the invention in certain embodiments, they can be readily removed from the eutrophic water. Thus, the presence of the seaweed, planktivorous organisms and shellfish of the invention in a eutrophic zone is not necessarily persistent. Methods for maintaining stock in an artificial environment, adapted to producing

organisms of the appropriate age or developmental stage year-round for use in the invention, are also parts of the invention.

12. The invention also combines the use of remote sensing and water sampling technologies to identify eutrophic zones so that algal overgrowth in the eutrophic zones can be controlled before it develops into harmful algal bloom (HAB) or leads to hypoxia. The systems of the invention optionally include data systems that comprise remote sensing and water sampling subsystems, data integration and modeling subsystems; stationary or mobile enclosures for the culture of seaweed, planktivorous organisms and shellfish; guidance system for steering mobile enclosures; assemblages of seaweed, planktivorous organisms and shellfish that are active at multiple trophic levels.

13. The present invention is different from the current practice of biomanipulation, bio stimulation or bioaugmentation which calls for the specific removal of zoo planktivorous fishes, introduction of chemical, bacteria or probiotic etc. The population of planktivorous organisms of the present invention is distinguishable from the naturally occurring benthic bivalves because the feeders of the invention are initially cultured on an artificial substrate that can be moved horizontally along a river or a coastal region as well as vertically at various depths in a water column, depending on the amount of algal biomass and the conditions of the water (e.g., level of dissolved oxygen).

14. The primary nutrients responsible for eutrophication are nitrogen and phosphorous, although other nutrients, such as iron and silicates, are also implicated. Whether primary production by phytoplankton is nitrogen or phosphorous limited is a function of the relative availabilities of the two elements in water. Phytoplankton require approximately 16 moles of nitrogen for every mole of phosphorous they assimilate, i.e., the Redfield ratio of 16:1, (Refield, 1958, American Scientist, 46:205-222). If the Redfield ratio is less than 16:1, phytoplankton growth will tend to be limited by nitrogen. If the ratio is higher, phytoplankton growth will tend to be phosphorous limited. It has been observed that nitrogen limitation is more prevalent in coastal marine ecosystems than in lakes.

15. The methods of the invention are applicable to all bodies of water including both inland waters and coastal waters, as well as discharged waste water into the ocean that are pretreated and NEA approved for discharge into the oceans.

16. FIG. 2 shows where the systems and methods of the invention can be applied as an outer protective circular wave breaker which also function as a mechanical filter barrier to reduce suspended particles from entering macroalgae cultivation zone. The wave breaker is a floating drum-like structure made of HDPE material, arrayed in a circular form with regular intervals of long nylon ropes anchored to the sea floor to maintain the circular shape. Firstly, walls of mussels are grown on vertical ropes attached underneath the surface wave breaker will filter out phytoplankton and trap silt particles, improving water clarity which leads to improved sunlight penetration for the cultivated macroalgae within the circle. Secondly the wave breaker floating on water surface will dampen incoming wave energy from tides, winds, and vessel wakes. The result is reduction of ripple effect, further improving sunlight penetration down the water depth as light scattering at water surface is reduced. Macroalgae/seaweed can then be cultivated deeper within water column, vertically. Similarly, the floating platform comprising workstations and miscellaneous utility floor within the circular wave breaker are protected from wave breakages, reducing structural maintenance cost. To avoid duplicate descriptions, the invention will be described mostly in the context of coastal waters without limiting the invention to only uses in coastal waters. It should be understood that the systems and methods of the invention are similarly applicable to inland waters, such as rivers, ponds and lakes, and waste water, unless specified otherwise.

17. The term “coast” includes all areas between land and ocean, such as but not limited to, beaches, estuaries, marine habitats along the shore, as well as the shallow coastal ocean just offshore. A coast can be more specifically classified as open continental shelf, coastal embayment, river plume estuary, coastal plain or drowned river valley estuary, coastal plain salt marsh estuary, lagoon, fjord estuary, coral reef system, tectonically-caused estuary, large river with non-drowned river estuary, seagrass-dominated estuary, rocky-intertidal macroalgae dominated estuary etc.

18. It is contemplated that the systems and methods of the invention can be used in the named exemplary coastal systems or in any places with similar physiographic characteristics globally. Exemplary areas would include but not limited to areas where algal blooms and hypoxic zone appear regularly.

19. For clarity of disclosure, and not by way of limitation, the detailed description of the invention is divided into the subsections which follow.

ECOLOGICAL EFFECTS OF EUTROPHICATION

1. The terms “eutrophic” and “eutrophication” are used herein to describe the presence of an abundance of nutrients in a body of water, i.e., nutrient enrichment. For many aquatic ecosystems, primary productivity is limited by nutrient availability. Therefore, a direct response to nutrient input in these ecosystems is an increase in phytoplankton biomass, leading to the formation of an algal bloom. A body of water with productivity greater than about 300 g C m^{-2} $year^{-1}$ and exhibits at least one of the following characteristics is referred to as a body of eutrophic water, that forms a eutrophic zone in a body of water.

2. Some of the characteristics of eutrophic water, relative to non-eutrophic water (i.e., exhibiting productivity less than 300 g C m^{-2} $year^{-1}$) include but are not limited to, increased phytoplankton productivity, high chlorophyll a concentration, decreased light availability to benthic zone, high epiphytic growth rate, high non-perennial macroalgae growth rate, changes in dominance from benthic algae to pelagic algae, and a shift in dominance from diatoms to dinoflagellates.

3. The body of water that becomes eutrophic can range from about 10, 50, 100, 200, 500 and up to 1000 m^2, or from about 1, 2, 5, 10, 20, 50, 100, 200, and up to 500 km^2. The invention can be used to reverse at least some of the changes observed in the aquatic environment that results from eutrophication.

4. Many coastal waters and inland water body are shallow enough that benthic plant communities thrive where sufficient light penetrates the water column to the seafloor.

5. Benthic vascular plants (seagrasses) and perennial macroalgae are more adapted to low nutrient environments than phytoplankton and ephemeral macroalgae. An increase in nutrient input results in the progressive selection for fast-growing algae that are best adapted to high-nutrient conditions, at the expense of slower-growing seagrasses and perennial macroalgae.

6. Phytoplankton biomass can reduce light penetration and epiphytic microalgae becomes more abundant on seagrass leaves in eutrophic water contributing to light attenuation. Ephemeral macroalgae, such as *Ulva, Caldophora*, and *Chaetomorpha*, can form extensive thick mats over the seagrass leading to its disappearance from the seafloor. Loss of benthic seagrasses and macroalgae will result in changes in the associated fauna, and increases sediment resuspension that causes influx of nutrients from the sediment further promoting algal blooms.

7. The accumulation of ephemeral macroalgae is a nuisance to recreational users of beaches and waterways. The invention can be used to prevent or reduce the loss of seagrasses and perennial macroalgae by reducing the phytoplankton biomass.

8. Plankton species have a wide range of nutrient requirements and the plankton community composition of a coastal region can be directly changed by eutrophication. A limitation of silicates in the water restricts the growth of diatoms and/or the amount of silicon in their bodies.

9. It has been observed that as the size of the diatom population in a water column falls, an increase in the number of flagellates is detected. Among the many species of algae that thrives in a body of water, some can produce toxins that are harmful to other organisms that either ingest these species or share the same aquatic environment.

10. For example, the species *Chaetoceros* has been associated with the deaths of farmed salmon, they have long, barbed spines that lodge in fish gills, causing a buildup of mucus, degeneration of the respiratory system, and eventual death by suffocation. Some species interfere with fish reproduction. When one or more species of algae that can produce toxins or cause harm to other marine life and humans, proliferate and become numerically

dominant in a eutrophic zone, a harmful algal bloom (HAB) is formed. The invention can be used to prevent the formation of a harmful algal bloom or to reduce the algal biomass in a harmful algal bloom.

11. Eutrophication is also accompanied by an increased demand for oxygen, due in part to respiration of the increased biomass of plants and animals in the nutrient-loaded system, but mostly to respiration of bacteria in the water column and sediments that consume the organic matter produced by or resulting from death of, the plant and animal biomass. If the loss of oxygen is not offset by the introduction of additional oxygen by photosynthesis or mixing, then hypoxia or anoxia occurs.

12. Dissolved oxygen less than about 2.0 to 3.0 mg per liter is referred to herein as hypoxia. Anoxia is a form of hypoxia when biologically useable dissolved oxygen is completely absent.

13. Hypoxia and anoxia are more likely to occur in warmer months because of thermal stratification of the water body that prevents mixing of oxygen-rich surface water with bottom water. The occurrence of areas of hypoxia near the coasts can kill marine life, disrupt their migration and habitat, and change the benthic community structure. The invention can be used to prevent hypoxia in a eutrophic zone, which includes removing algal biomass in the body of water that lies above the hypoxic zone.

ALGAL BLOOM

1. As used herein the term “algae” refers to any organisms with chlorophyll and a thallus not differentiated into roots, stems and leaves, and encompasses prokaryotic and eukaryotic organisms that are photoautotrophic or photo auxotrophic.

2. The term “algae” includes macroalgae (commonly known as seaweed) and microalgae. For certain embodiments of the invention, algae that are not macroalgae are preferred. The terms “microalgae” and “phytoplankton,” used interchangeably herein, refer to any microscopic algae, photoautotrophic or photoautotrophic eukaryotes (such as, protozoa), photoautotrophic or photoautotrophic prokaryotes, and cyanobacteria (commonly referred

to as blue-green algae and formerly classified as Cyanophyceae). The use of the term "algal" also relates to microalgae and thus encompasses the meaning of "microalgal."

3. The term "algal composition" refers to any composition that comprises algae, such as an aquatic composition, and is not limited to a body of water within an area, or a sample of a body of water. The microalgae of the invention are also encompassed by the term "plankton" which includes phytoplankton, zooplankton and bacterioplankton. It is contemplated that many aspects of the invention can be practiced with a planktonic composition, without isolation of phytoplankton, or removal of the zooplankton or other non-algal planktonic organisms.

4. The composition and numbers of phytoplankton communities depend on a balance of local factors. Phytoplankton inhabit all types of aquatic environment, including but not limited to freshwater (less than about 0.5 parts per thousand (ppt) salts), brackish (about 0.5 to about 31 ppt salts), marine (about 31 to about 38 ppt salts), and briny (greater than about 38 ppt salts) environment. Field observations indicate the distribution of sizes of a phytoplankton community often varies with resource availability and hydrographic conditions. It has been observed generally that small phytoplankton are dominant under oligotrophic conditions, and large phytoplankton are more abundant in eutrophic water. The methods of the invention can be used to drastically reduce the population of phytoplankton and algal biomass.

5. Algal species can be identified by microscopy and enumerated by counting or flow cytometry, which are techniques well known in the art. Chlorophyll a is a commonly used indicator of algal biomass. However, it is subjected to variability of cellular chlorophyll content (0.1 to 9.7% of fresh algal weight) depending on algal species. The estimated biomass value can be calibrated based on the chlorophyll a content of the dominant species within a population. Published correlation of chlorophyll a concentration and biomass value can be used in the invention. Chlorophyll a concentration is to be measured within the euphotic zone. The euphotic zone is the depth at which the light intensity of the photosynthetically active spectrum (400-700 nm) equals 1% of the subsurface light intensity.

6. Nutrient over-enrichment destabilizes plankton populations by allowing certain species to compete successfully against all other species present. Apparently, initiation of an algal bloom (including a harmful algal bloom) is dependent on a series of events or a set of optimal conditions. Thus, a bloom can be circumvented by disrupting at least one event in the sequence, or altering the optimal conditions. A body of eutrophic water comprising more than about 1×10^5 algal cells per ml can develop a bloom under certain conditions. For example, the body of eutrophic water can comprise more than about 2×10^5, about 5×10^5, about 8×10^5 algal cells per ml. The term "algal bloom" as used herein refers to the presence of algae in a body of water comprising at least about 1×10^6 algal cells per ml or greater, such as but not limited to about 5×10^6 algal cells per ml, about 10^7 algal cells per ml, about 5×10^7 algal cells per ml, and about 10^8 algal cells per ml.

7. Powerful remote sensing technologies are available to facilitate detection of algal bloom and identification of eutrophic waters that may develop a bloom. For example, at least four satellites have been commonly used for chlorophyll and phytoplankton mapping: AVHRR, SEAWIFS, LANDSAT and MODIS. Imaging spectrometers (also known as hyperspectral sensors) used in remote sensing simultaneously collect spectral data as both images and as individual spectra. A range of techniques, including fourth-derivative analysis, have been put into operational practice for analysis of algal blooms. For an overview of this technology, see, for example, Remote sensing of algal bloom dynamics by Richardson, L in Bioscience Vol. 46, no. 7, pp. 492-501. July-August 1996; and US patent publication US 2005/0164333 A1.

8. The systems of the invention comprise of data systems which include but are not limited to a measurement device adapted to record the water parameters of the water; a data processing device having programming instructions for applying an algorithm that convert data into nutrient level data, optionally linked to geographic data; a transmitter for transmitting data from the measuring device or processor to a site remote from the site where the measurement takes place, an early warning system for eutrophication, excessive temperature built-up; and a report generator for producing a report of the amounts of nutrient and algal biomass in the water over an area.

9. Optionally, the data systems of the invention comprise a means for integrating these readings with historical data and present them on a map for visual inspection and reporting. The data systems of the invention can optionally use the readings provide AI to plot the course of a mobile seaweed island to be towed by a vessel or self-propelled within a coastal region. The data systems of the invention can optionally generate signals to a guidance system of the invention to steer or change the course of a mobile seaweed island within a coastal region. The report generator may be any device that is adapted to place the data into a tangible medium, such as a printer, disc burner, flash memory, magnetic storage media, etc. The measurement device can be an optical sensor, polarographic sensor, photosensor, camera, digital camera and video camera, video analytics device plus any commercially available equipment for collecting and analyzing wavelength and geographic data can be used in the present invention.

OCEAN ACIDIFICATION

1. When carbon dioxide enters the ocean, it dissolves in saltwater. First, it forms carbonic acid. Then, this carbonic acid breaks apart – or "dissociates" – producing bicarbonate ions and hydrogen ions. Ocean acidification results from an increased concentration of hydrogen ions and a reduction in carbonate ions due to the absorption of increased amounts of CO2.

2. Clams, mussels, crabs, corals, and other aquatic life rely on carbonate ions to grow their shells and thrive. Acidity is a measure (in units of pH) of the concentration of hydrogen ions in a solution.

3. For millions of years, the exchange of CO2 between the surface of the ocean and the atmosphere remained constant. In the past 150 years, humans have greatly increased the amount of CO2 in the atmosphere by burning fossil fuels and changing land-use practices. As a result, the ocean has absorbed about 29 percent of this additional carbon.

4. This added CO2 has had significant effects on the ocean. Surface waters are now 30 percent more acidic than they were at the start of the industrial era. Ocean acidification is

now happening at a faster rate than at any point in the last 66 million years, and possibly in the last 300 million years. And projections show that by the end of this century, ocean surface waters could be more than twice as acidic as they were at the end of last century if we do not reduce our carbon emissions.

5. The rising concentration of carbon dioxide in the atmosphere is driving up ocean surface temperatures and causing ocean acidification. Although warming and acidification are different phenomena, they interact to the detriment of marine ecosystems. These changes to the ocean aren't occurring at the same rates everywhere: there are significant differences across gradients of temperature, latitude, and depth.

6. The rate at which water absorbs CO2 decreases as water temperature increases. This means that polar regions like Alaska, where ocean water is relatively cold, can take up more CO2 than the warmer tropics. As a result, polar surface waters are generally acidifying faster than those in other latitudes, and on average, warmer regions of the ocean are releasing CO2 into the atmosphere instead of absorbing it.

ORGANISMS

1. The organisms useful in the invention include seaweed, planktivorous organisms and shellfish.

2. As used herein, the term shellfish refers to a member or a group of the following classes.
    a. The terms "shellfish" and "shellfishes" refers to various species of mollusks, crustaceans, and echinoderms that feed on planktons.
    b. The term "shellfish" is used herein as singular and plural interchangeably with the term "shellfishes" regardless of whether one or more than one species is present, unless clearly indicated otherwise.

3. Many of the planktivores and omnivores are filter feeders. They can be pelagic filter feeders or benthic filter feeders. Many species of planktivores develop specialized anatomical structures to enable filter feeding, e.g., gill rakers and gill lamellae. Generally,

the sizes of such structures relative to the dimensions of the plankton in the water affect the diet of a planktivore.

4. Seaweed that are used in the methods of the invention feed on mainly on the nutrient present in the water body which are mainly, dissolved nitrogen, phosphorous and trace elements. In some embodiments of the invention, the population of seaweed used may comprised more variety of planktivores due to the composition of the nutrient in that area. In certain embodiments, one or several major species in the seaweed population are selected.

5. The predominance of one type of seaweed or a mixture of a few with different permutation of planktivores feeders (which are defined by their trophic behavior over another type) or shellfish are highly dependent on the water conditions. This product blend will be a sum of the data collected in the integrated AI system described earlier.

6. Seaweed, planktivorous organisms and shellfish useful for the invention can be obtained from SCU hatcheries, farms or collected from the wild.

7. One or more species of seaweed and or in combination with the planktivores feeders and or shellfish can be used for the biological remediation of the coastal zone or in eutrophic water. In one embodiment of the invention, the population of dominant species of seaweed may constitute greater than about 10%, about 20%, about 30%, about 40%, about 50%, about 60%, about 70%, about 75%, about 80%, about 90%, about 95%, about 97%, about 98% of the seaweed present in the population. In certain embodiments, several major seaweed species may each constitute greater than about 10%, about 20%, about 30%, about 40%, about 50%, about 60%, about 70%, or about 80% of the seaweed present in the population.

8. In various embodiments, one, two, three, four, five major species of seaweed are present in a population. Accordingly, a mixed seaweed population or culture can be described and distinguished from other populations or cultures by the major species of seaweed present. The seaweed population or culture can be further described by the percentages of the major and minor species or the breed(s) of genetically improved or selected seaweed, or

the percentages of each of the major species. It is to be understood that mixed cultures having the same genus or species may be different by virtue of the relative abundance of the various genus and/or species present.

9. Seaweed or macroalgal inhabits most types of aquatic environment, including but not limited to freshwater, brackish, marine, and briny environments. As the present invention can be practiced in any of such aquatic environments, any freshwater species, stenohaline species, euryhaline species, marine species, species that grow in brine, and/or species that thrive in varying and/or intermediate salinities, can be used.

10. Seaweed from tropical, subtropical, temperate, polar, and/or other climatic regions can be used. Seaweed that lives within the following temperature ranges can be used: below 10° C., 9° C. to 18° C., 15° C. to 25° C., 20° C. to 32° C and above.

11. In one embodiment, seaweed indigenous to the region at which the methods of the invention are practiced, are used. Preferably, seaweed species from the same climatic region, same salinity environment, or same ecosystem are used. Most preferably, the seaweed/ macroalgae, planktivores feeders and shellfish are derived from a naturally occurring trophic system.

12. Seaweed, or macroalgae, generally refers to thousands of species of macroscopic, multicellular, marine algae which includes some types of Rhodophyta (red), Phaeophyta (brown) and Chlorophyta (green) macroalgae.

13. The term "Seaweed or macroalgae" does not represent a single taxonomic entity.

14. Molecular phylogeny (gene sequencing) and other characters show they belong to three kingdoms: Kingdom Plantae (chlorophytes and rhodophytes), the Kingdom Chromista (phaeophytes), and the Kingdom Bacteria (cyanophytes).

15. Hence, seaweed from different taxonomic groups can be used in the methods of the invention. It should be understood that, in various embodiments, seaweed within a taxonomic group, such as a family or a genus, can be used interchangeably in various

methods of the invention. It is contemplated that one of ordinary skill in the art could, consistent with the scope of the present invention, use the databases to specify other species within each of the described taxonomic groups for use in the methods of the invention.

16. The shellfishes used in the methods of the invention are preferably sedentary shellfishes, such as bivalves. Depending on the aquatic environment, freshwater, brackish water, or marine shellfishes can be used. The shellfishes of the invention include but are not limited to oysters, mussels, scallops, clams, and more particularly, *Crassostrea* species such as *C. gigas, C. virginica, C. ariakensis, C. rivularis, C. angulata, C. eradelie, C. commercialis, Saccostrea* species such as *S. glomerata, S. cucculata and S. commercialis; Mercenaria* species such as *M. mercenaria* and *M. campechensis; Ostrea* species such as *O. edulis, O. chilensis*, and *O. lurida, Area transversa, Panope generosa, Saxodomus nuttili; Mytilus* species such as *M. edulis* (blue mussel), *M, coruscus, M. chilensis, M. trossulus*, and *M. galloprovincialis* (Mediterranean mussel), *Aulacomya ater, Choromytilus chorus, Tapes semidecussatus; Perna* species such as *P. viridis, P. canaliculus; Venerupis* species such as *V. decussata, V. semidecussata, Sinonovacula constricta* (Razor clam), *Mya arenaria* (soft shell clams), *Spisula solidissima* (surf clams), *Amusium balloti, Argopecten irradians* (bay scallops); *Pectan* species such as *P. alba, P. yessonsis, P. maximus*; and *Chlamys* species such as *C. farreri, C. opercularis, C. purpuratus* and *C. varia.*

17. The shellfishes used in the methods of the invention also include other shellfish such as abalone, cone shell etc.

18. In many embodiments of the invention, shellfishes and seaweed (beside sea weed) are both cultured within the same body of eutrophic water and in certain embodiments, in proximity to each other, or in the same enclosure.

ENCLOSURE

1. The seaweed, planktivorous organisms and shellfish are confined to the systems of the invention in eutrophic water such that they can feed on the nutrient in the water. Some systems of the invention are designed to facilitate easy harvesting and transportability. As

used herein, the term “enclosure” includes any form of physical confinement of the seaweed, planktivorous organisms and shellfish in the water that allows exchange of water between the inside and outside of the enclosure, wherein the seaweed, planktivorous organisms and shellfish grow by feeding on the nutrient in the water. An enclosure is a floating structure. Non-limiting examples of an enclosure include a cage, a net, a barricade for an area, a porous container, a substrate to which shellfishes are attached, and a compartment on board of a vessel.

2. A non-limiting example of a mechanism for water exchange is via the ballast tank of a vessel.

3. In one embodiment of the invention, the enclosure (seaweed island) is moored at a fixed location where local tides and currents provide natural water exchange.

4. In another embodiment, the enclosure is one that can be relocated from one location to another.

5. In another embodiment, the enclosure is free-floating and follows local currents.

6. In another embodiment, the enclosure is free-floating but moved by mechanical propulsion, such as a boat engine.

7. The relocation of an enclosure depends on the nutrient level of the eutrophic water, the density of algal biomass, the oxygen level, weather, and other factors, and can be performed on an ad hoc basis or seasonally.

8. The enclosure can comprise various environmental monitoring systems as well as systems for optional supplemental feeding and aeration, and for moving the enclosure horizontally and/or vertically in water.

9. Flow of water through an enclosure facilitates gas exchange, removal of waste products, and replenishment of plankton.

10. The flow can be generated by wind, wave, tide, or other natural movement of the water, or it can be caused by various means known in the art, including but not limited to the use of fluid pumps, paddles, movement of the cage, power-assisted aeration, etc.

11. Optionally, the volume of flow, the flow rate, and the direction of flow either in or out or both in and out of an enclosure, can be regulated.

12. In one embodiment, the enclosure with its planktivorous organisms is moved continuously through the water.

13. In another embodiment, the water is caused to move through a stationary enclosure. In either case, the enclosure is replenished with seaweed, planktivorous organisms and shellfish from the outside or from within.

14. Many of the commercially available enclosures for aquaculture can be used in accordance with the methods of the invention. Minor adaptations of existing enclosures, if required, can be performed by one, skill in the art with routine experimentation.

15. In certain embodiments, the enclosure is a substrate to which bivalves attach themselves and the substrate, which can be a rope, rack, stick or even a cage and not necessarily enveloping the bivalves.

16. Umbrella culture uses shellfishes that have been attached to ropes and suspended from a central post radiating to anchors like spokes on a wheel, thus taking the shape of an umbrella.

17. Rack culture can be accomplished by constructing racks of recycled seaweed aggregate or any other form of building materials in various forms. Ropes or sticks with shellfishes attached or contained are then placed on the racks for grow out.

18. Any methods known in the art can be used to moor an enclosure or a group of enclosures by a physical link to a fixed point on the seabed or to a fixed structure erected in water.

19. The fixed anchoring structure erected in water can form a part of a seaweed island.

20. In another embodiment, mobile enclosure, such as a towable cage or enclosure is used. Transportable or towable enclosure can be attached to any vessel, such as a trawler or a barge, and be towed from one location to another.

21. The methods of the invention also provide the use of towable enclosure where the enclosures with planktivorous organisms are towed continuously thorough water within a eutrophic zone to ensure a plentiful supply of planktons for the caged planktivorous organisms.

22. The movement of the enclosure through water also generate a water flow through the cage that facilitates aeration of the cage and dilution of waste products.

23. The course of the vessel and the towed enclosure(s) can be steered towards areas of high primary productivity by a guidance system that receives signals generated by the data systems of the invention which gather and integrate remote sensing data and/or water quality information.

24. Accordingly, the enclosures of the invention can also comprise of a guidance system which receives signals from the data systems. In yet another embodiment, the enclosure is inside a vessel, e.g., a compartment of a modified tanker or barge, wherein water is allowed into and out of the compartment at various time.
25. In another embodiment, a mobile & towable enclosure, a self-propelled system will be attached to it; so as to enable it to self-steer towards areas of high eutrophic activities via a guidance system within a geographical vicinity.

BIOFUEL AND FISH MEAL PRODUCTION

1. The Seaweed, planktivorous feeders and shellfish used in the methods of the invention can be set free in a body of water, or used for a variety of purposes, including but not limited to, production of food, fishmeal, biofuel, nutraceutical, pharmaceutical, cosmetic additive and oleochemical products.

2. All references cited herein are incorporated herein by reference in their entirety and for all purposes to the same extent as if each individual publication or patent or patent application was specifically and individually indicated to be incorporated by reference in its entirety for all purposes.

3. Many modifications and variations of this invention can be made without departing from its spirit and scope, as will be apparent to those skilled in the art. The specific embodiments described herein are offered by way of example only, and the invention is to be limited only by the terms of the appended claims along with the full scope of equivalents to which such claims are entitled.

STATEMENTS OF DISCLOSURE:

1. A method for the containment of pollutants presents in the aquatic environment using an offshore floating structural enclosure island (Figure 1) via the method of biological bioremediation method for eutrophication in tropical and temperate coastal zone sea water; relating to the cultivation of various kind of edible & inedible seaweed/ macroalgae in tandem with or without other aquatic organism.

2. A method for the containment of pollutants presents in the aquatic environment using an offshore floating structural enclosure island (Figure No.1) via the method of bioaugmentation & bio stimulation method for eutrophication in tropical and temperate coastal zone sea water; relating to the cultivation of various kind of edible & inedible planktivorous feeders and shell fish in tandem with or without other aquatic organism.

3. A method of a single offshore floating structural enclosure; described as a single floating grid frame with dimension ranging from substantially 1m x 1m , 2m x 2m, 3m x 3m, 5m x 10m or any other dimensions (Figure 6, 7 & 8) with long lines secured. Lines of vertical rope substrate are attached to these long lines for seaweed cultivation. This single platform frame is subsequently joined with 2 or more floating grid to form an Offshore

Floating Structural Enclosure Island formation which can take form in many sizes and shapes (Figure 1 & 2).

4. A method for reducing algal biomass in a body of eutrophic water via the method of bioaugmentation & bio stimulation method comprising of introducing a plurality of seaweed, planktivorous feeders and shellfish that feed on the nutrients existing in a body of eutrophic water, and culturing the seaweed and planktivorous feeders in the eutrophic water, wherein the seaweed, planktivorous feeders and shellfish are confined in the said floating enclosure (Figure No.1 & 2), wherein they feed on the nutrient in the eutrophic water, thereby reducing the feed source for algae and reducing the algal biomass thereafter, and wherein the seaweed, planktivorous feeders and shellfish are harvested to produce alternative protein replacement for fish meal, food, specialty chemicals, nutraceuticals, food, and/or biofuel.

5. A method for systemic reduction of the level of carbon dioxide in our ocean which has a direct impact on global warming. This invention harness on the seaweed and macroalgae's rapid rate of photosynthesis for absorbing and converting carbon dioxide and sunlight into energy and oxygen. This process of turning carbon dioxide and sunlight into energy and oxygen makes seaweed a prime candidate for absorbing carbon out of the environment. This is a potentially potent weapon against global warming; albeit capable of sucking damaging carbon dioxide out of the atmosphere at rates comparable to the mightiest rain forests. "Carbon sinks" are considered essential to controlling greenhouse gases, which trap heat in the atmosphere and are blamed for global warming.

6. A method for reducing the acidification of the ocean through lowering of the levels of Carbon Dioxide in the ocean. Ocean acidification is occurring because excess carbon dioxide (CO_2) in the atmosphere is being absorbed at the surface of the ocean at an increasing rate. This excess CO_2 results in more hydrogen ions, which increases the acidity of the ocean.

7. A method for reducing ocean surface temperature via a floating enclosure also known as seaweed island (Figure No.1 and 2) from the absorption of Carbon Dioxide via the plurality of seaweed cultivated. The rising concentration of carbon dioxide in the

atmosphere is driving up ocean surface temperatures and causing ocean acidification. Although warming and acidification are different phenomena, they interact to the detriment of marine ecosystems. These changes to the ocean aren't occurring at the same rates everywhere: there are significant differences across gradients of temperature, latitude, and depth (Source: Union of Concerned scientists – Published Jan 30, 2019 and updated Feb 6, 2019). When the level of carbon dioxide gas gets higher in the ocean, it obviously affects the whole water. When sea organisms die on the sea beds, their remains pile up and form corals, which is consisting of carbons. Also, these organisms release calcium into the water. These compounds have a far-reaching detrimental impact on the composition of the water as they add to acidity.

8. A method for reducing the temperature (in tandem with item #7) in the water body (ocean, lake, river, waterway or any form of water body) via shade providence in a floating enclosure (also known as seaweed island) which comprised of a plurality of seaweed, planktivorous feeders and shellfish that provides natural shade to the covered areas.

9. The method according to item 1, wherein the seaweeds are confined to an enclosure (figure 6, 7 and 8)

10. The method according to item 2 or 4, wherein the planktivores feeders and/or omnivores are confined to an enclosure (Figure No.4)

11. The method according to any one of items 1- 3, wherein the enclosure is floating (Figure No.1)

12. The method according to item 1 or 2, wherein the step of culturing the plurality of seaweed, planktivorous feeders and shellfish in tandem with or without other aquatic organism comprised of the biological remediation of the eutrophic water in the enclosure without adding an chemicals, bacteria concoction, probiotics and disinfection technique such as use of UV, ozone etc. into the eutrophic water.

13. The method according to item 1 or 2, wherein the step of culturing the plurality of seaweed, planktivorous feeders and shellfish in tandem with or without other aquatic organism comprises of maintaining the level of dissolved oxygen in the eutrophic water in the enclosure above 3 mg per litre.

14. The method according to item 1 or 2, said method further comprises harvesting at least one of the pluralities of seaweed and planktivorous feeders in tandem with or without other aquatic organism after culturing.

15. The method of this invention directed to a proprietary outer protective circular wave breaker (Figure 5) where the design which firstly incorporates curved wave deflectors above water surface to deflect and dampen wave energy from reaching within the enclosure, protecting structures within from wave impact damages.

16. The method according item 15 of the invention where the outer protective circular wave breakers are arranged or installed in a series of more than 2 wave breakers or more (Figure 2,3,4 & 5) above the water surface to deflect and dampen wave energy from reaching within the enclosure, protecting structures within from wave impact damages.

17. The method according to item 2 or 4. where substrates such as vertical lines are secured within the embodiment for mussels' cultivation (Figure 4).

18. A method for producing biofuel and/or alternative fish meal, said method comprising introducing a plurality of plurality of seaweed, planktivorous feeders and shellfish in tandem with or without other aquatic organism that feed on the nutrient in the body of eutrophic water, wherein the seaweed are confined, culturing the seaweed in the eutrophic water where the seaweed feed on the nutrient in the water, harvesting the seaweed, and processing the harvested seaweed to produce biofuel, specialty chemicals, nutraceuticals, food, and/or alternative protein for fish meal replacement.

19. A system for reducing algal biomass in a body of eutrophic water, said system comprising a plurality of seaweed, planktivorous feeders and shellfish in tandem with or without other aquatic organism fishes that feed on the nutrient in a body of eutrophic water which is a major source of food for the algal biomass; wherein the plurality of seaweed are

confined in the body of eutrophic water, and wherein the seaweed are harvested to produce biofuel, specialty chemicals, nutraceuticals, food, and/or alternative protein for fish meal replacement.

20. The system according to item 19, wherein the enclosure is a floating enclosure and or a towable cage.