Seaweed Farming as a Climate Resilient Strategy for Indian Coastal Waters

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Abstract—*In the context of climate change and its impacts on global as well as regional levels, it is of necessity to develop effective climate resilient strategies. This paper focuses on the scope of seaweed farming along Indian coastal waters as a climate resilient strategy. Biofuels from various biomass feedstocks serves as an alternative energy production route leading to reduced dependency on fossil fuels and is widely accepted strategy to combat global warming. The prospects of seaweed as a feedstock for biofuel production are reviewed through this paper. Carbon sequestration ability of seaweed makes its farming an option to combat ocean acidification and we envisagefurther bulk conversion of the substrate into stable bio char which offers additional long term soil C sequestration means. Improved water as well as nutrient holding capacity of bio char makes it feasible to apply in agricultural lands that are affected with low precipitation induced by climate change. Scope of seaweed bio char for agricultural resilience is further explored in this study. Climate change had negatively affected the rural livelihoods of fishermen community in several coastal villages. Seaweed farming, its harvest and processing requires manpower and hence poses as an opportunity to enhance the rural livelihoods, which is also discussed through this paper. The suitability of Indian coastal waters for seaweed farming is also reviewed. The present study thus calls the attention towards developing seaweed farming as a climate resilient strategy which has multiple benefits of usage as alternative energy feedstock, as an option to combat ocean acidification, as a mitigation method for agricultural adversities and also as a means to improve coastal livelihoods.*

Keywords*: Seaweed farming, climate resilient strategy, biofuel, seaweed biochar, coastal livelihoods*

1. INTRODUCTION

In spite of the controversies regarding whether the cause of global warming is anthropogenic or natural, climate change has been occurring across the globe with several devastating impacts. Need of the hour calls for development of resilient strategies to adapt and mitigate with climate change impacts.Perceptions should be broadened to develop sustainable climate resilient strategies that shall have additional benefits than mere carbon foot print reduction, so that even if the common scientific consensus over anthropogenic contributions went wrong, the scientific efforts shall bear fruit through the delivery of additional benefits.

IPCC [9] points out anthropogenic contributions of green house emissions as a very likely reason for elevation in global average temperature. Based on the IPCC report on global and regional impacts of climate on agriculture, food security and other sectors, National Academy of Agricultural Sciences, India through a policy document calls for Climate Resilient Agriculture (CRA) along with need to identify 'No Regrets' adaptation strategies[16].

Agriculture can play a significant role in carbon sequestration andtechnologies are advancing for the conversion of biomass resources into biofuel. Though several biomass serves as source for alternative energy, its competition for cultivable land of food crops leading to further stress on food security is of concern. Harnessing non-conventional agricultural energy sourcesand explorations of feedstocks, that are non-competent with food crops is a more sustainable approach. In this paper we review the prospects of seaweed as a feedstock for biofuel generation.

Ocean acidification is another impact of climate change induced due to the mixing of atmospheric Carbon with seawater. Carbon sequestration ability of seaweeds has beenreported[10] and is considered as a means to combat ocean acidification. Harvested seaweeds can be processed as biofuel feedstock which shall offer additional carbon sequestration potential. We envision conversion of the seaweeds into biochar which have agricultural applications. The prospects of seaweed biochar as a climate resilient product are reviewed through this paper.

Fish resources has been widely shifted and distributed due to habitat changes and stresses induced by climate change, which in turn negatively affected the livelihoods of many fishermen communities to a larger extent. Resilient strategies are being developed to enhance coastal livelihood and the potential of seaweed farming in this regard are also highlighted in this paper.

The prospects of seaweed farming in India have been reported by many researchers for several applications and products such as food, pharmaceuticals, cosmetics, agars, alginates, etc. Besides these applications, attempt is made through this paper to focus on the aspects of climate resilience potential of seaweed farming.

2. SCOPE OF SEAWEED FARMING AS A CLIMATE RESILIENT STRATEGY

Seaweeds are globally harvested either from naturally growing wild species or from cultivated seaweed farms. The past decade witnessed 50 % increase in production of seaweed farms for non-energy purposes. In the current processing technologies of agar, carrageenan and alginate from seaweeds, major portion of the biomass is unutilized and is left as residue. Investigationshave to be warranted for sustainable conversion of these residual seaweeds as feedstocks for bioethanol production. Several seaweeds are rich sources of polysaccharides which can be converted into ethanol using appropriate technologies[3], [18], [15]. Though several researchers report ethanol production from various seaweeds[8], [1], [7], [13], [12], [6], [20] the bioethanol conversion research are at nascent stage in India.

Successful large scale conversion of seaweed into bioethanol shall provide immense climate resilience benefits. In a nation like India where automobile emissions are high, a swing to alternative energy such as bioethanol shall have greater impact in carbon sequestration potential as well as in lessening the dependency on fossil fuels. Non competence of seaweed with terrestrial food cropsand fertilizers makes it a promising 3rd generation biofuel production feedstock.Based upon the composition [19], [14], suitable seaweed species can be selected and farmed as a feedstock for bioethanol production in India. Seaweed biomass as well as shall enhance food and livelihood security. Concept of seaweed farming as a non-conventional feedstock for biofuel production is in tune with the objectives of Climate Resilient Agriculture. Collective focus has to be made to develop seaweed farming an effective climate resilient strategy.

Seaweed farming shall have additional advantages in terms of mitigation towards ocean acidification. Marine vegetation utlilises the atmospheric C,acts as a good sink to $CO_2$and thereby contributes towards carbon sequestration.Seaweeds are proved to be the excellent bio-remediating agents and are capable of improving water quality by uptake of dissolved metals, ammonia, nitrates and phosphates. It is estimated quantitatively that seaweeds are also capable of sequestering dissolved CO_2 at the rate 80.5 mg/g wet weight / day while their rate of emission through respiration is only 10 mg/g wet weight/day as majority of brown and green seaweeds are capable of utilizing the respiratory emission of CO_2 within the cells for photosysnthesis[10].

As areas of seaweed farming increases, the scope to balance the anthropogenic C emissions shall also increase. Steps should be taken for effective promotion of its cultivation and harvest.

Since seaweed farming is a low cost technology with manpower requirement, India can implement it as an effective resilient strategy across its coastal waters. With proper investments from government funding agencies along with Corporate Social Responsibility (CSR) funds, associated biorefineries can also be developed for the processing of harvested seaweeds or else options would be limited to supply seaweeds as raw materials to the existing biorefineries.

Climate change may induces heavy rainfalls and floods leading to runoffs containing fertilizers, nutrients, effluents, etc which shall eventually reach oceans thereby posing threats to aquatic lives and their habitats. Coastal areas are even more vulnerable to extreme climatic changes leading to enhanced pollution risks. Seaweed farming zones can act as a sink for pollutants from runoff waters and can be considered as a mitigation strategy towards marine ecosystem management.

India has a coastal line of around 7,500 km and potential seaweed farming zones can be identified along the coastal states. Manpower needed for the seaweed farming and processing can be met considerably from the fishermen communities that are vulnerable to climate changes and thereby can enhance their livelihoods. Seaweed farming can be considered as a supplementary income source of livelihoods and it is not advisable in this stage to depend as a main or sole means of income for fishermen community. Seaweed farming and its associated preliminary processing stages can be taken up in community or village levels as a strategy of adaptability and resilience in the context of climate change.

Culture of seaweeds in Indian coastal waters started with cultivation of *Gracilariaedulis*due to its high regenerative capacity and recently the cultivation of *Kappaphycus* was also introduced. Indian research institutes that attempted mariculture of seaweed are mainly Central Marine Fisheries Research Institute (CMFRI) Cochin, Central Salt and Marine Chemicals Research Institute (CSMCRI) Bhavnagar and National Institute of Oceanography (NIO) Goa. PepsiCo commercially cultivates seaweed farming at Tamil Nadu coast. Fishermen group of Orissa and Tamil Nadu is also practicing seaweed farming. However seaweed farming option so far did not gain leading focus in India unlike other nations. The carbon sequestration efficacy of three species of seaweed *Gracilariacorticata, Sar gassumpolycystum*and *Ulva lactuca*were estimated in laboratory scale and reported[10] and is as tabulated in Table.1

Table 1: Efficacy of seaweeds species to absorb CO_2 [18].

Seaweed Species	Efficiency to absorb CO2 (mg/g wet wt/ h)
Gracilariacorticata (red)	1.60
Sargassumpolycystum (brown)	2.35
Ulva lactuca (green)	4.10

Based on the estimates of standing crop of seaweeds in the Indian coastal waters (2,60,876tonnes) comprising 14% agar and carrageenan yielding red seaweeds, 16% algin yielding brown seaweeds and 70% green seaweeds [5] the CO_2 assimilation rate per day was computed for green algae represented by *Ulvalactuca*, brown algae represented by *Sargassumpolycystum*and red algae represented by *Gracilariacorticata*and is as tabulated in Table.2.

Table 2: CO_2 sequestered by the seaweed resources of Indian waters

Seaweed Species	Standing crop (ton wet wt)	CO2 absorbed (ton/day)
Green	182613	7487
Brown	41740	981
Red	36523	584

It is estimated that the seaweedbiomass along the Indian coast is capable of utilizing 3,017 t CO_2/d against its emission of 122tCO_2 /d indicating a net carbon credit of 2,895 t/d[10].

Seafarming potential of seaweed in India is estimated to 2 million tonnes by the year 2020. Hence large scalecultivation of seaweeds which is a green technology, employing species of *Gracilaria, Gelidiella*for agar, *Kappaphycusalvarezii* for *k*-carrageenan and *Ulva* and *Caulerpa* for their nutraceuticals and other secondary metabolites can help mitigate major green house gas and can check ocean acidification, while the seaweed farmers can make a living out of the harvest[11].In the context of climate change steps has to be taken to enhance the carbon sequestration through seaweeds. This can be attained by extending seaweed cultivation to more hectors of area. Conversion of seaweeds into bioethanol shall also scale up the carbon sequestration.Since the existing production of seaweedis less than that of the current industrial demand and applications, the optionof venturing with seaweed farming as climate resilient strategy shall be in tune with the ‘No Regrets’ policy.

3. SCOPE OF SEAWEED BIOCHAR AS A CLIMATE RESILIENT PRODUCT

Biochar is the porous carbonaceous solid produced by thermo chemical conversion of organic materials in an oxygen depleted atmosphere which has the physicochemicalproperties suitable for safe and long-term storage of carbon in the environment and, potentially useful for improvement of soil quality. Biological charcoal known as biochar can be produced from a wide range of biomass through pyrolysis technique. Biochar have multiple climate resilience applications and hence is considered as a climate resilient product.

Biomass after decomposition liberates carbon back to atmosphere. The concept of biochar emerged as a means to sequestrate the carbon release from biomass. Huge volumes of biomass can be converted into product biochar by combustion in oxygen limited condition, through which the C content shall be modified into a stable recalcitrant form. Biochar with long term carbon sequestration potential could be applied to the soil, so that the C which may otherwise liberated back to atmosphere shall remain locked beneath the soil for many years.

Seaweeds can also be converted into biochar and reports are available on high yield of seaweed biochar rich in nutrients N,P,K[4]. Elemental composition of seaweed biochar varies based on the species of seaweeds. In India scope exists to convert the seaweed residues as well as seaweeds itself into biochar which can be used for climate resilient applications. Seaweed biochar can sequestrate C to an extent and can also be used as a soil amendment.

Climate change induces variations in precipitation pattern and several agricultural areas would become water scarce areas. In such scenarios biochars from seaweed and other biomass can impart mitigation measures. Biochars generally have improved water holding capacities as well as its porous structure and enhanced surface area makes it a suitable product to hold nutrients. If applied as soil amendment in water scarceagricultural lands, the requirement on volume of irrigational water can be brought down. Since biochar have nutrient holding capacity, the requirement of volume of fertilizers can also be brought down.

Seaweed biochars can be applied as a mitigation strategy in agricultural lands affected with high rainfall and floods too. In such cases the soil fertility may be lost due to runoffs and nutrient leeching. Application of seaweed biochars beneath affected soil shall offer enhanced nutrient holding capacity and also shall prevent the nutrient leeching to a greater extend. Reduction in quantity of fertilizers to be applied can also be attained. Nutrient profile of biochar makes it a feasible soil amendment and reports are available on enhanced crop yield due to the application of biochars.

Biochars also have bioremediation applications in restoring the heavy metal contaminated lands as well as marine ecosystems. Climate induced floods shall inundate contaminated lands and immobilize contaminants into flood waters[2]which shall eventually reach the marine ecosystems. Biochars can be employed to absorb the contaminants from the marine as well as land eco-system and it shall offer another mitigation or resilient strategy towards climate change impacts.

Other maricultural residues can also be converted into biochar and owing to the multiple benefits towards climate resilience, seaweed biochars and other mariculturalbiochars can be developed as a significant climate resilient product.

4. CONCLUSIONS

Seaweed farming can be considered as sustainable climate resilient strategy with multiple benefits as feedstock for bioethanol production, as means of carbon sequestration and ocean acidification mitigation, as supportive option for coastal livelihood improvement, etc. In order to enhance climatic resilience, existing seaweed farming of Indian coastal waters has to be extended to a greater extent with identification of suitable farming zones along the coastal states. Research and funding focus has to be channelized to promote seaweed farming for biofuel production, which shall be a non conventional alternative energy source. Seaweed biochar is a significant climate resilient product, which can be explored further for field trials.

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REFERENCES

[1] Adams, J.M., Gallagher, J.A., Donnison, I.S., Fermentation study on Saccharinalatissima for bioethanol production considering variable pre-treatments. *J. App l.Phycol*. 21 (5), 2008, 569–574.

[2] Ate Visser, JoopKroes, Michelle T.H. van Vliet, Stephen Blenkinsop, Hayley J. Fowler, Hans Peter Broers., Climate change impacts on the leaching of a heavy metal contamination in a small lowland catchment *Journal of contaminant hydrology*. 127, 2012, 47-64.

[3] Benjamin, M., Methods and compositions for producing metabolic products for algae. *US Patent No. 5,270,175*. 1993.

[4] David A. Roberts, Nicholas A. Paul, Symon A. Dworjanyn, Michael I. Bird and Rocky de Nys., Biochar from commercially cultivated seaweed for soil amelioration.*Scientific Reports* , 5: 9665, 2015. DOI: 10.1038/srep09665.

[5] Devaraj, M. Pillai, V. K., Appukuttan, K. K. Suseelan, C.Murty, V. S.R.,Kaladharan, P., Rao, G.S., Pillai, N. G. K., Pillai, N. N., Balan, K.,Chandrika, V.,George, K. C. andSobhana, K. S.,*Packages o f Practices for Sustainable Ecofriendly Mariculture (Land-based Salin e Aquaculture a nd Seafarming).***In**: Aquaculture and the Environment. Mohan Joseph, M,**(ed.)***Asian Fisheries Society* , Mangalore, 1999, 33-70.

[6] Ge, L., Wang, P., Mou, H., Study on saccharification techniques of seaweed wastes for the transformation of ethanol. *Renew. Energ.* 36 (1), 2011, 84–89.

[7] Goh, C.S., Lee, K.T., A visionary and conceptual macroalgae-based third-generation bioethanol (TGB) biorefinery in Sabah, Malaysia as an underlay for renewable and sustainable development. *Renew. Sust. Energ. Rev*. 14, 2009, 842–848.

[8] Horn, S.J., Aasen, I.M., Ostgaard, K., Production of ethanol from mannitol by Zymobacterpalmae. *J. I nd. M icrobiol. Biotechnol*. 24, 2000, 51–57.

[9] IPCC. “Summary for Policymakers,” In: S. Solomon, *et al.* , Eds., *Climate Change* 2007: *The Phys ical Scien ce Basis*, Cambridge University Press, Cambridge., 2007.

[10] Kaladharan,P, Veena, S and Vivekanandan, E., Carbon sequestration by a few marine algae : Observation and projection. *J. Mar. Biol. Assn. India*, 51(1): 2009, 21 – 24.

[11] Kaladharan, P., Seaweed mariculture for carbon sequestration and livelihood support. Presented to the *International Symposium on Greening Fisheries* organized by the SOFTI and CIFT at Ernakulam during 21-24th May 2013.

[12] Karunakaran, S., Gurusamy, R., Bioethanol production as renewable biofuel from rhodophytes feedstock. *Int. J. Biol. Biotechnol*. 2 (2), 2011, 94–99.

[13] Meinita, M.D.N., Kang, J.Y., Jeong, G.T., Koo, H.M., Park, S.M., Hong, Y.K.,.Bioethanol production from the acid hydrolysate of the carrageenophyteKappaphycusalvarezii (cottonii). *J. Appl. Phycol*. 2011. doi:10.1007?s10811-011-9705-0

[14] Mitsunori Yanagisawa, Kanami Nakamura, Osamu Ariga, KiyohikoNakasaki., Production of high concentrations of bioethanol from seaweeds that contain easily hydrolysable polysaccharides. *Process Biochemistry*, 46, 2011, 2111- 2116.

[15] Myra G. Borines, Rizalinda L. de Leon, Joel L. Cuello., Bioethanol production from the macroalgaeSargassum spp. *Biores. Technol*. 138, 2013, 22-29.

[16] NAAS. Climate Resilient Agriculture in India*. Policy Paper No. 65*, National Academy of Agricultural Sciences, New Delhi: 2013, 20 p

[17] Nellemann C, Corcoran E, Duarte CM, Valdés L, De Young C, Fonseca L, Grimsditch G., Blue carbon. A rapid response assessment. *United Na tions Environment Pr ogramme*, GRID-Arendal, 2009. www.grida.no

[18] Paulo Iiboshi Hargreaves, Carolina AraújoBarcelos, Antonio Carlos Augusto da Costa, Nei Pereira Jr., Production of ethanol 3G from Kappaphycusalvarezii: Evaluation of different process strategies. *Biores. Technol.* 134, 2013, 257-263.

[19] SiddhantaA. K., Mahesh U. Chhatbar, Gaurav K. Mehta, Naresh D. Sanandiya, Sanjay Kumar, Mihir D. Oza, Kamalesh Prasad, RamavatarMeena., The cellulose contents of Indian seaweeds. *J ApplPhycol*, 23: 2011, 919–923. DOI 10.1007/s10811-010-9599-2.

[20] Yasmin Khambhaty, KalpanaMody, Mahesh R. Gandhi, SreekumaranThampy, PratyushMaiti, HarshadBrahmbhatt, Karuppanan Eswaran, Pushpito K. Ghosh., Kappaphycusalvarezii as a source of bioethanol. *Biores. Technol*. 103, 2012, 180-185.