INTEGRATED ALGA-CULTURE IN INUNDATED COASTAL FARMLANDS OF INDIAN SUNDARBANS AS A SUSTAINABLE ADAPTATION FOR MARGINAL COMMUNITIES TOWARDS CLIMATE RISK REDUCTION

Dipayan Dey, South Asian Forum for Environment, India
Ashoka Maity, Department of Science & Technology, Govt. of India, India

chair@safeinch.org

Algae has a great potential for quick capture of biological carbon and its storage in saltwater-inundated coastal wetlands and can also be introduced as a climate adaptive alternate farming practice. An intervention with native algal flora *Enteromorpha sp.* in enclosed coastal Sundarbans in India on two open water culture techniques, viz. U-Lock & Fish-Bone, shows that growth in native algal stock is influenced by seasonal variations of salinity and other limnological factors. Sundarbans, facing the odds of climate change is fast loosing arable lands to sea level rise. Algaculture in inundated coastal areas can be an adaptive mitigation for the same. Perusal of results show that daily growth rate (DGR%) increases with increasing salinity of the intruding tidal waters to an extent and biomass increment under salt stress results in accumulation of metabolites those are having nutrient values and can yield bio-diesel as well. Algal growth recorded mostly in post monsoon period, has impacts on pH and Dissolved Oxygen (DO) of the ambient water to facilitate integrated pisciculture. The paper suggests that alga-culture has unrealized potentials in carbon sequestration and can be significantly used for extraction of Biodiesel.

Key words: alga-culture, enclosed coast, sustainable aquafarming, sundarbans, climate change, risk reduction

I.INTRODUCTION

Deltaic villages in enclosed coasts of Indian Sundarbans, a world heritage site, are extremely vulnerable to rising sea level and sea surface temperature, rendering farmlands of marginal coastal communities non-yielding, owing to increasing soil salinity. The enclosed coastal habitat has natural resources of mangrove forest and enriched biodiversity that extends several ecosystem services for sustaining life and livelihood. It is also one of the most ecologically threatened areas of the planet [5]. Available brackish water environment of Sundarbans provides favourable substratum for algal communities [28]. *Enteromorpha intestinalis*, *Ulvalactuca* and *Catenellarepens* are the dominant macro-algae growing naturally in this habitat and are ecologically important in accommodating other living organisms as reported earlier [23], [24], [24], [29], [30].

These macro-algae have numerous usages, including production of food, feed, fodder, fertilizer and as well,chemical feedstock and bio-fuel [20], [21], [22], [26], [27]. There is mention of their polysaccharides being used in food, cosmetics, paints, crop, textile, paper, rubber and additionally they are used in areas of pharmacology for their antimicrobial, antiviral, antitumor, anticoagulant and fibrinolytic properties. However, culture methods for propagating these local algal flora for commercial usage are recently known [17]and policy instruments are meager in promoting it as a 'REDD-plus' implication in coastal areas for conservation of mangrove forests, since it can be used for bio-fixation of CO_2 and GHG abatement as it has an estimated potential of sequestering multifold times of CO_2 it emits by respiration.

This paper attempts to assess the bio-economic potentials of integrated alga-culture as an alternative livelihood for marginal communities in inundated coastal areas, who have lost farmland to intruding seawater, in assuring sustainable change management towards poverty alleviation in the milieu of climate change.Reports on eco-physiological studies of brackish water algae of Sundarbans and impact of seasonal variation on the biochemical composition of the green weeds have already been reported [19], however, there is substantial knowledge gap in recommending the commercial utilization of these algae in Sundarbans. Similar research on the nutritional evaluation of the seaweeds has been conducted elsewhere and evaluation of varied species of weeds for multiple industries has been reported [38] as well.

Hence the objective of the present study remains toestimatethe seasonal growth of the flora in biomass and simulate the accumulation of the bioactive components in *Enteromorpha* and *Ulva* that has nutritional values and as well, has potentials for bio-energy alternatives. Further, the intervention also assesses the sustainability of production in alga culture and as well the carbon mitigation potentials of such aquafarming. Reference of this preliminary work would entail developing and establishing the production processes for a range of products in the food and pharmaceutical sector and as well, a newsource for bio-energy, towards creating carbon smart economic alternativesand opportunities for the relinquished community.

II. METHODOLOGY

Experimental Design & Sample: Algal samples of free floating *Enteromorpha intestinalis*, *Enteromorpha prolifera* were collected every month in pre-monsoon (March to June), monsoon (July to October) and post-monsoon (November to February) seasons of the year, from 2012 to 2015, grown from their natural habitat of enclosed coasts of *Sagar* (21^{o}48'N, 88^{o}5'59.9"E), *Jhorkhali* (22^{o}13'20"N, 88^{o}56"43"E) and *Saatjelia* (22^{o}8'39"N, 88^{o}52'40"E)islands in *Gosaba* block of Indian Sundarbans, and as well from aquaculture ponds, where alga-cum-fish culture is improvised in (a) U-Lock Mass Culture ponds of U-shaped interlocking landscapes in enclosed coasts allowing inundation during high tides and split with fine nylon net partitions for making pen-culture enclosures and (b) Fish-Bone Mass Culture techniques, modified from Organization for Marine Conservation Awareness and Research (OMCAR) model for restoration of mangroves in the coastal habitat, wherein a channel of inflowing tidal water is bifurcated in lateral outlets like a fish-bone structure and partitioned with nylon net. The samples were washed with water and prepared for physical and biochemical studies and as well some sun-dried for a few days, since water inhibits transesterification.

Daily Growth Rate (DGR%): DGR% was calculated using a formula [8]

DGR% = ln (Wf / Wo) / t X 100;

Wherein t is the number of culture days. Wo is the initial fresh weight (g) and Wf is the final fresh weight (g) after culturing for t number of days.

Biochemical Analysis: Limnological parameters of water in the growth ponds were estimated by standard methods following APHA & NEERI (2012). Compositional analysis of algal filaments and frond was done followed by official methods of analysis of AOAC International (19th edition, 2012).Afterwards, dried algae were crushed and extracted in n-hexane in a Soxhlet apparatus as per UNE-EN 734-1 (2006). The transesterification process was conducted simultaneously with the extraction in order to avoid the previous step of oil extraction and purification of obtained oil(Karaosmanoglu et al., 1996; Lang et al., 2001). The protein and carbohydrate content of freeze-dried alga was determined spectrophotometrically[1]. Lipids were extracted from the samples [39] and Fatty Acid Methyle Esters (FAME) &Linolenic acid content was estimated using gas chromatographic (GC) methods conforming to the UNE-EN-12424 (2003) standards, using Bruker 450-GC. GC control and data handling was done using BrukerGalaxie™ Software.

Carbon Mitigation Potential: Algae have the ability to fix carbon dioxide efficiently [35], [2]. The carbon content varies with algal strains, media and cultivation conditions. The CO_2 fixation rate can be calculated by applying law of conservation of mass:

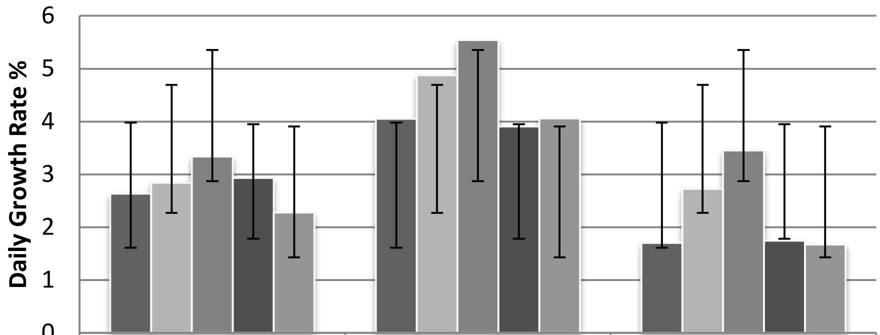
Total CO_2 fixation = K × biomass productivity X fixation efficiency (wherein K is the rate constant with a value 1.89).

Statistical Analysis: Data were analyzed statistically using ANOVA in <excel>to determine the differences in seasonal growth and composition with different initial seed density along with various seasons of culture period.

III. RESULTS AND DISCUSSION

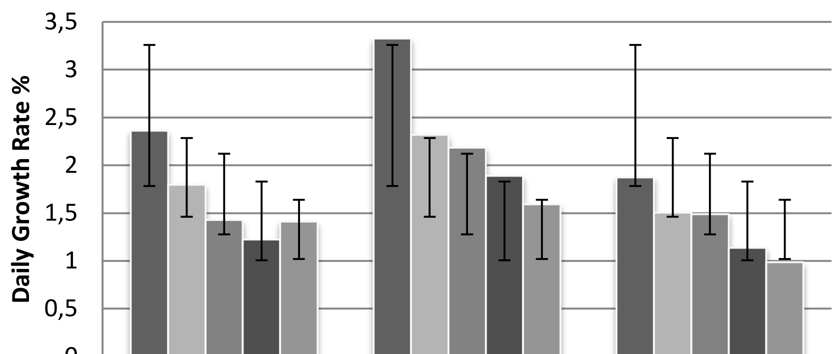
Green seaweed *Enteromorpha intestinalis* (L. Link) have high rate of carbon sequestration potentials. It can also withstand the salinity up to 136 ppt[33] and it has been used to determine the nitrogen sources to estuaries [6]. This was also used as an indicator of nutrient enrichment in coastal estuaries and lagoons [10]. The effect of different salinity regime and varying salinity in the growth rate of *E. intestinalis* has been studied [13]. The positive and negative effect of riverine input in the growth rate of E. *intestinalis* has been published in Hydrobiologia [18]. Herein, the comparative growth rates, components of nutrient values and seasonal changes in carbon mitigation potential are substantiated with data tables and graphs in the following paragraphs of the text.

Perusal of result shows that in culture ponds the DGR% varies with the initial inoculation volume and the season of growth as well (Fig 1(a) & 1(b)), whereas, selected limnological parameters of the culture ponds have been seen to vary seasonally and have a correlation with the varying DGR% during pre-monsoon, monsoon and post-monsoon period (Fig.2).



	Monsoon	Post Monsoon	Pre Monsoon
Initial Wt (50gm/Mt.Sq)	2,637	4,054	1,703
Initial Wt (75gm/Mt.Sq)	2,839	4,879	2,728
Initial Wt (100gm/Mt.Sq)	3,338	5,542	3,454
Initial Wt (125 gm/Mt.Sq)	2,935	3,91	1,747
Initial Wt (150gm/Mt.Sq)	2,281	4,056	1,673

Fig. 1(a): Daily Growth Rate *E. intestinalis*



	Monsoon	Post Monsoon	Pre Monsoon
Initial Wt (50gm/Mt.Sq)	2,362	3,325	1,874
Initial Wt (75gm/Mt.Sq)	1,798	2,317	1,504
Initial Wt (100gm/Mt.Sq)	1,427	2,186	1,489
Initial Wt (125 gm/Mt.Sq)	1,223	1,89	1,138
Initial Wt (150gm/Mt.Sq)	1,413	1,591	0,987

Fig. 1(b): Daily Growth Rate E. *prolifera*

Ambient temperature is maximum during pre-monsoon phase and minimum during winters, showing a negative correlation with salinity. A comparison of variability in DGR% across these seasons and other limnological parameters show direct positive correlation of DGR with salinity. Similar study has reportedly been found in Cyanobacteria that can tolerate higher osmotic stress

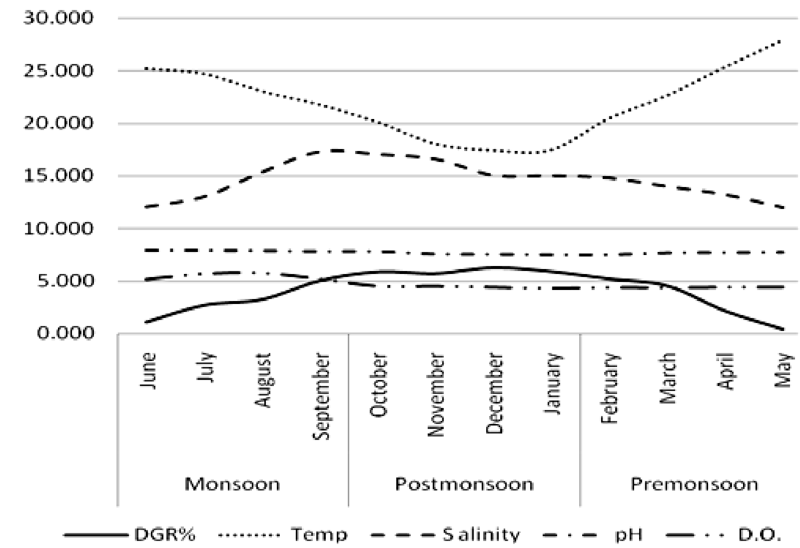
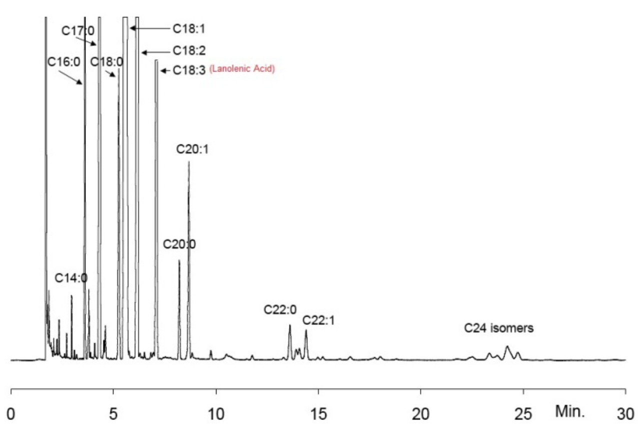


Fig.2: Comparative Analysis of Limnological Fearures & DGR% Trends in *Enteromorpha*

until salinity reached a PSU of 16 with enhanced growth and synthesis of zeaxanthin[16], [4]. Though, green algae and cyanobacteria from freshwater system shows considerable acclimation towards fluctuating pH, the variability of pH in this case was not as dramatic as salinity. Consistent curves of pH and DO hint a sharp compensation of CO_2 release and its utilization buffering the pH with bicarbonates and subsistent release of oxygen through photosynthetic activities [4],[7]. These findings are environmentally relevant to understand the likely impact of salt water intrusion and pH variation on phytoplankton communities in a tropical freshwater system in general and for fish cum algae culture in particular wherein stabilized pH and DO are significant for getting better yield.



The results showed that in post-monsoon season, available oil in *Enteromorpha intestinalis* was maximum ranging up to 0.37% which declined to 0.31% during monsoon when average water salinity lowers down, since vegetative growth rate also decreases during monsoon as found in recent studies [17]. However, convertible biodiesel was as high as 93.27% and Linolenic acid content was 0.24% only (Fig. 3) as also reported earlier [14] [15]. Interestingly, the findings of chromatographic analysis also showed that this particular variety of green seaweed is rich in protein, carbohydrate and omega fatty acids which are nutritionally significant. It has been found that the protein content of *Enteromorpha intestinalis*is as high as 12.9-15.79 %. Also, it reveals that these species contains 53% carbohydrate at an average, which does not show much variation across the seasons, as reported earlier [19], [34]. (Table 1).

Table 1: Average Biochemical Composition of *Enteromorpha*

Biochemical Components	Pre Monsoon	Monsoon	Post Monsoon
Total Lipid (% dry wt)	12.25±0.57	4.58±0.33	14.91±1.03
Protein (% dry wt)	14.66±1.94	12.9±1.58	15.79±1.33
Carbohydrate (% dry wt)	52.6±2.26	53.69±0.91	53.66±1.25

Thus, it is presumed that utilisation of this species as a part of the human diet after conducting toxicity tests may cater to the acute nutritional deficiency in the region. Its extensive utilisation can parallel and bring a radical change in the lives of Sundarbans inhabitants.

Perusal of Carbon Mitigation Potentials data showed that the maximum optimistic carbonaceous biomass fixation capacity is 2392 Metric Tons per hectare per year, obtainable in U-Lock culture technique during post monsoon season in *E.intestinalis*, whereas it is lowest in E. prolifera during pre-monsoon season nearing to 442 Ton of algal biomassper hectare per year only. This estimate is drastically higher than carbonaceous biomass fixation capacity of terrestrial plants [32]. It is therefore evident that the accrued biomass through algal growth is a direct evidence of carbon capture by aquatic flora in inundated waters (Fig. 4), as evidenced earlier [3], [7], [12].

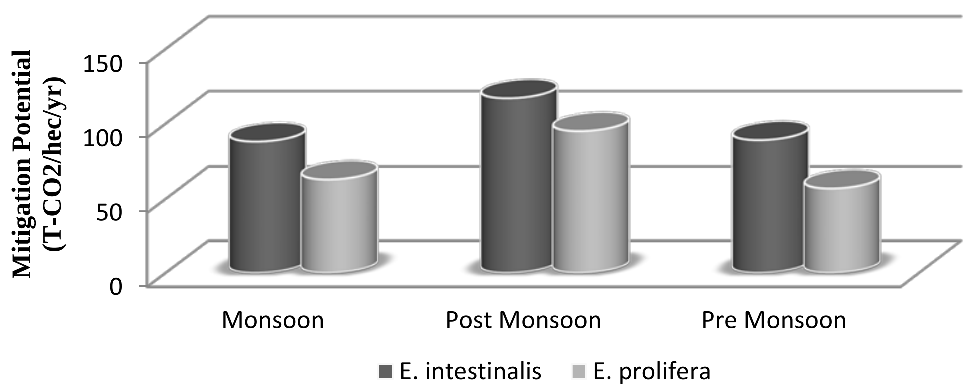


Fig.4: Seasonal Carbon Mitigation Potentials of Algae

The potential for carbon mitigation in Algal biomass was theoretically assessed [36]. Although, they implemented their assessment for microalgae, we estimated theoretical carbon fixation efficiency of the macroalgae, *Enteromorpha intestinalis* in three categories: i) optimistic / maximum yield (11.42%), ii) most likely / probable yield (6%) and iii) pessimistic / minimum yield (3%) [37]. Applying the three categories of theoretical efficiency during winter, we observed that the CO_2 fixation rate was estimated 14.91, 7.84 and 3.92 g CO_2 / m^2 / day for maximum, probable and minimum yield respectively. On the other hand, during summer, the rate was 2.88, 1.51 and 0.76 CO_2 / m^2 / day for maximum, probable and minimum yield respectively.

IV. CONCLUSION

It is obvious that commercial cultivators and end-users for algae shall be interested in the production potentials, availability of food supplements and bio-fuel. The productivity showed sustainable potentials, as may be evidenced in the seasonal rates (Table-2).

Table No 2: Comparative Growth Rates & Harvest Potentials of Free-floating Algae

CULTIVATION MODEL TYPE		*E. intestinalis*		*E. prolifera*	
COMPARATIVE GROWTH RATE & HARVEST POTENTIALS (NATURAL POND WATER)					
Inoculation: Initial Wt=100gm & 50gm/Mt. Sq respectively; SALINITY 2-3 psu					
		Av. DGR (%)	Yield per Week (MT/Hec)	Av. DGR (%)	Yield per Week (MT/Hec)
Monsoon	U-LOCK	3.805	7.63	2.789	6.67
	FISH-BONE	1.982	6.55	1.65	5.93
	FREE-FLOATING	2.806	7.29	1.645	6.06
Post Monsoon	U-LOCK	5.773	9.72	4.293	8.54
	FISH-BONE	3.775	9.03	2.551	7.91
	FREE-FLOATING	4.488	7.45	2.262	6.5
Pre Monsoon	U-LOCK	3.972	6.26	2.011	7.25
	FISH-BONE	3.481	6.59	1.832	6.47
	FREE-FLOATING	2.261	8.81	1.398	5.73
COMPARATIVE GROWTH RATE & HARVEST POTENTIALS (TRAPPED COASTAL WATERS)					
Inoculation: Initial Wt=100gm & 50gm/Mt. Sq respectively; SALINITY 17-18 psu					
CULTIVATION MODEL TYPE		*E. intestinalis*		*E. prolifera*	
		Av. DGR (%)	Yield per Week (MT/Hec)	Av. DGR (%)	Yield per Week (MT/Hec)
Monsoon	U-LOCK	9.88	25.94	8.05	16.68
	FISH-BONE	8.36	23.58	9.5	23.06
	FREE-FLOATING	3.45	9.45	2.98	8.33
Post Monsoon	U-LOCK	18.72	45.79	17.23	43.65
	FISH-BONE	16.71	41.22	17.56	43.12
	FREE-FLOATING	7.79	12.34	3.36	10.24
Pre Monsoon	U-LOCK	8.39	18.91	10.07	15.15
	FISH-BONE	7.62	17.25	7.22	16.73
	FREE-FLOATING	3.28	9.16	3.06	10.08

So, the greenhouse gas benefits from algae culture arise only as offsets when the algal use displaces the combustion of a fossil fuel or used for the production of electricity. Earlier reports from FAO 2010 (http://www.fao.org/uploads/media/0903_CSIRO_Greenhouse_gas_sequestration_by_algae.pdf) showed that it is possible to produce algal biodiesel at less cost and with a substantial greenhouse gas and energy balance advantage over fossil diesel. However, the economic viability is highly dependent upon algae with high oil yields capable of high production year-round, which has yet to be demonstrated on a commercial scale.

This paper substantiates the bio-economic potentials of aqua-farming of the algae *Enteromorpha intestinalis* as a place based climate adaptive intervention in climate vulnerable deltaic Sundarbans of India, since mangrove ecosystems in Indian Sundarbans are known sources for methane, having very high global warming potential [11]. While higher optimistic carbonaceous biomass fixation capacity of *Enteromorpha* can be considered as a direct indication of carbon capture by this aquatic flora in inundated waters, as evidenced earlier [17],[12], perusal of results from the present study shows its estimable potential for being used as a source of both bio-diesel and food supplement.

The relevance of this study finds its significance in the fact that the settlement areas of deltaic Sundarbans has unusually high emission footprints in power and transport sectors as reported by WWF (2012), since these desolate islands are not yet connected to the country's national power grid, whereas loss of agricultural land due to rapid coastal erosion and inundation [31] has accentuated the need for alternatives in food, feed and fodder. This research has all impending merits to find a local need-based solution for combating impacts of global changes.

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