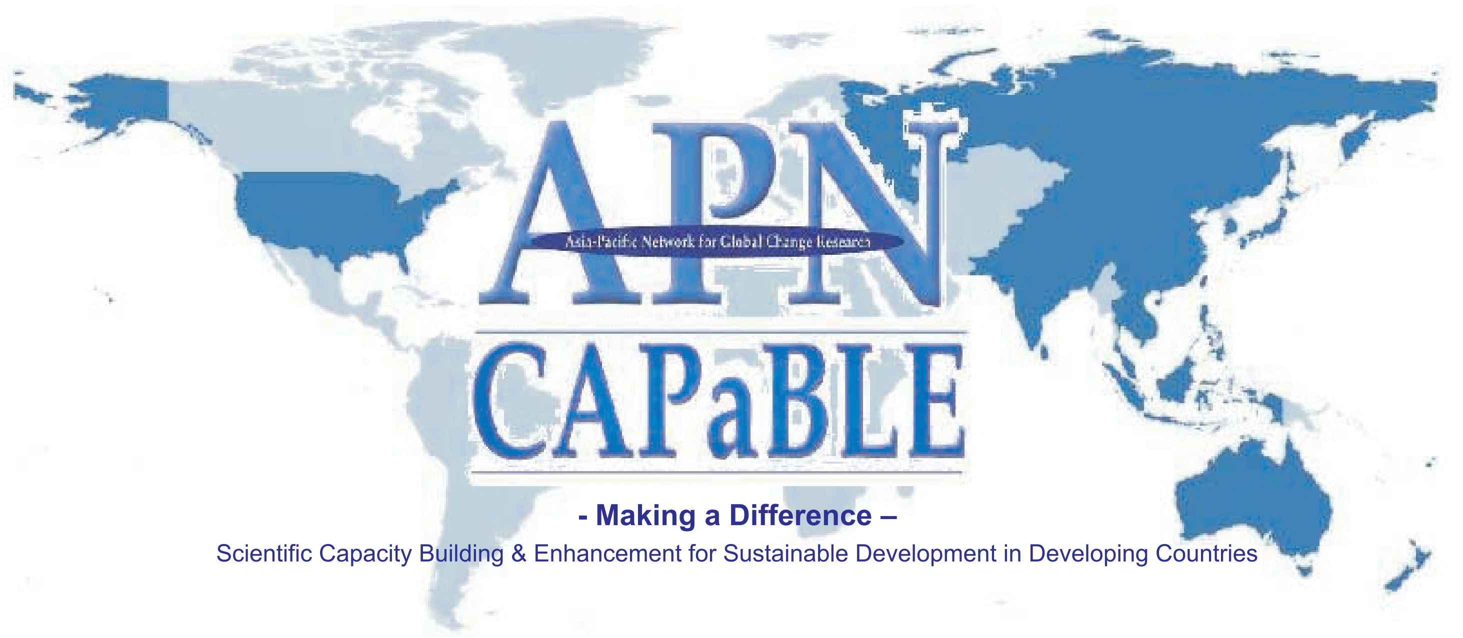
FINAL REPORT for APN PROJECT

Project Reference Number: CBA2013-14NSY-Maity

Promoting Algaculture in Trapped Waters as Sustainable Aquafarming and Adaptive Climate Mitigation in Inundated Coastal Areas



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SOUTH ASIAN FORUM FOR ENVIRONMENT SAFE

KOREA GREEN FOUNDATION

NABARD

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OVERVIEW OF PROJECT WORK AND OUTCOMES

Executive Summary (Non-technical)

The present CAPaBLE programme envisages a capacity building cum action research activity in promoting algaculture in coastal village of Sundarbans in India as a sustainable alternative livelihood option and climate-smart aquafarming for community based and adaptive climate mitigation. Trapped seawater has been used for cultivation of local algal flora suitable for culturing along with fish. The algae can be substantially used as food feed and fodder by the marginal climate vulnerable community. Hands on training on culture preparation, management and monitoring of growth, harvesting of algal biomass and usage has been demonstrated in a technology cooperation module. Carbon sequestered in culture period and economic analysis over return on investment is integral to the programme.

Keywords: Algal culture, salinity, inundated wetlands, carbon capture, climate adaptability

Objectives

1. To demonstrate the cultivation technology of commercially important algae, integrated with fisheries, in brackish and trapped storm surge waters of inundated coastal areas for sustainable alternative livelihood and abating climate change impact.
2. To develop community aptitude in algaculture as a promotional capacity building programme to mitigate climate vulnerability with low cost conservation paradigm for place-based habitat restoration through community intervention
3. To disseminate amongst stakeholders the researched scientific knowledge in regard to carbon sequestration potential of cultured alga as a strategic measure for climate change resilience.

Amount received and number years supported

The Grant awarded to this project was USD 35,000.00 as a support for one year only.

Activity undertaken

Main activities undertaken in the project were

a) Select local algal flora that are economically beneficial and cultivate those with innovative techniques in salt water inundated coastal villages of Indian Sundarbans.
b) Undertake extensive capacity building exercises and awareness campaigns amongst the local climate hit marginal farmers for alga-cum-fisheries as an alternative farming practice that is climate adaptive.
c) Demonstrate alga-cum-fisheries through model-run pilots in the estuarine coastal villages for sensitizing the local communities so as to provide hands on training experiences in algaculture.
d) Conduct scientific workshops and seminars at the national level with regional cooperation to discuss and deliberate on the prospects and scientific interventions of algaculture with young scientists.
e) Undertake scientific research and analysis to understand the growth prospects and carbon mitigation and sequestration potentials of the algal flora cultivated in the project intervention area.
f) Publish the report and disseminate the same for scaling up activities and knowledge economy.

Results

- Improvisation of algaculture-cum-fisheries as a sustainable alternative livelihood for climate hit coastal community, as demonstrable by training fishers, that make them capable to adopt the trade
- Understanding algaculture, from their carbon sequestration potentials, as an alternative for downscaling climate impact in vulnerable coastal habitat and its restoration, as demonstrable by action research.

- Generating academic inquisitiveness amongst young researchers and also stakeholders through various workshops and seminars for technology cooperation, decision support research and policy inputs in promoting alternative climate smart farming.
- Enhancement in climate change awareness and environmental education in relation to coastal habitat and its conservation priorities as demonstrable by positive attitude change towards alternative farming in the project area
- Demonstrating algaculture technique as a low input, low emission, optimal yield farming technique through knowledge economy that can be replicated beyond the regional paraphernalia in Asia for climate vulnerable communities.

Relevance to the APN Goals, Science Agenda and to Policy Processes

Being in genuine agreement with APN goal and science agenda, this proposal advocates algaculture as an alternative livelihood for marginal farmers in inundated coastal areas, who have lost all or part of their farm land to intruding seawater, in assuring sustainable environment development towards poverty alleviation. Algaculture is commercial farming of algal flora that has numerous uses, including production of food, fertilizer, bio-plastics, fodder, chemical feedstock, pharmaceuticals and fuel. Though, culture methods are sparsely known and promotional policy instruments are meager. As REDD plus implication, it is used for biofixation of CO_2 and GHG abatement as it has an estimated potential of sequestering 20X times of CO_2 it emits by respiration. This programme entails capacity building in algaculture for various regional stakeholders and beneficiaries as well, to promote cultivation of locally available edible and commercially important algae as a climate-smart, sustainable alternative livelihood, wherein it disseminates the scientific knowledge of algaculture, kick-start a regional cooperation for developing producers organizations and enrich research potentials of the scientific community in improvising the cultivation prototype by integrating it to

Self evaluation

The program has a very positive spell on the community that was in dire need of an alternative. It has significantly increased the community resilience to climate impacts and preparedness. The program has also significantly impacted the scientific community, policy and stakeholders, media and environmentalists as well who have heartily accepted the innovation, importance and challenges of the program. Scientific research and interventions could have been better and the program needs more time for the same to provide decisive inputs, which can very well be continued with the present set-up. Economic aspects of the farming practice related to serious evaluation and assessment would need special expertise, which remains undone in the project, though inputs on growth and values could be collected. Moreover the impact of the project has been enormous and the beneficiaries have keenly learnt and adopted the same.

Potential for further work

The presented CAPaBLE program has given a very positive constructive and holistic lead for developing the future roadmap on the said activity. These leads, as mentioned hereunder, would define the guidelines for future research and further extended activities for the needful.

4. Extensive research and scientific capacity building is sought now to estimate the carbon sequestration efficacy of these macrophytic algal flora when cultivated under varied climatic conditions and ecological stress in integrated farming practices for more empirical data in decision support research and policy implications. The outcomes that have been acquired under this program on the carbon sequestration potentials of two species show promising results that needs further scientific inputs.
5. The nutrient composition of the algae cultivated under salinity stress show its potentials as both food feed and fodder. Extensive research is the need of the hour to best prove it as a nutritional delicacy. Further, other nutritional and beneficial components like vitamins, food supplements, antioxidants, omega3 fatty acids etc along with estimation of various anti-

nutritional factors and toxicity tests on these flora, growing under ecological stress, are also very important.

6. More technological innovations relating to low cost processing of the algal flora like sun-drying, packaging etc are required for facilitating its marketing from distant coastal locations to the urban markets. Research on the commercial methodologies for extraction of active principles and secondary metabolites of the flora is an immediate need. Once commercialized, the industry would seek interventions on increasing the shelf life of the harvest, extraction of by-products etc.
7. A detailed cost-benefit analysis on the production, harvest, processing and marketing would be urgently required to standardize the selling price, expected returns on investment, internal revenue return and net profit value of the production, which in turn can design a bankable model to facilitate marginal farmers for credit linkages and even crop insurance coverage for risk spreading.
8. Detailed and strategic studies on environmental impact assessment is required for evaluating the natural capital accrual through such habitat restoration and algal farming that can assess the values of environmental services extended to the beneficiaries and can substantially compensate their opportunity costs.

Publications (please write the complete citation)

Maity, A, A Akhand, D Dey (2014): *Potentials of Algaculture for Biological Carbon Capture and Storage in Saltwater Inundated Coastal Wetlands.* Extended Abstract: National Conference on Wetlands, CIFRI ICAR, Barrackpore, West Bengal. Pp 73-78.

Selected References

1. Adam P (1990) Saltmarsh ecology. Cambridge University Press, Cambridge, UK, Pp 461-470
2. Back S, Lehvo A and Blomster J (2000) Mass occurrence of unattached *Enteromorpha intestinalis* on the Finnish Baltic sea Coast; *Annales Botanici Fennici* 35: 155-161.
3. Barik J, P Sanyal, S Hazra (2011) Algae Cultivation Techniques for Sustainable Integrated Fisheries in Sundarbans. Proceedings of the 3rd International Conference on Ecotoxicology and Environmental Science, Kolkata, Pp 222-228
4. Barr NG and Rees TAV (2003) Nitrogen status and metabolism in the green seaweed *Enteromorpha intestinalis*: an examination of three natural populations; *Marine Ecology Progress Series* 249: 133-144.
5. Benemann, J., 1997. CO2 mitigation with microalgae systems. Energ. Convers. Manag., 38: 475-479.
6. Campbell P K, T Beer, D Batten (2012) Greenhouse Gas Sequestration By Algae –Energy And Greenhouse Gas Life Cycle Studies. Transport Biofuels Stream, CSIRO Energy Transformed Flagship PB1, Aspendale, Vic. 3195, Australia
7. Chakraborty P, T Acharyya, P V R Babu and D Bandhyopadhyay (2011) Impact of salinity and pH on phytoplankton community in a tropical freshwater system: An investigation with pigment analysis by HPLC. Journal of Environmental Monitoring vol.13(3): 614-620
8. Chi Z, O'Fallon JV, Chen S Trends Biotechnol (2011) Bicarbonate produced from carbon capture for algae culture. 29(11):537-41. doi: 10.1016/j.tibtech.2011.06.006
9. Chung IK, Beardall J, Mehta S, Sahoo D and Stojko vie S (2011) Using marine macroalgae for carbon sequestration: a critical appraisal; *Journal of Applied Phycology* 23:877–886.
10. Cohen RA and Fong P (2005) Experimental evidence supports the use of δ^{15}N content of the opportunistic green macro alga *enteromorpha intestinalis* (chlorophyta) to determine nitrogen

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TECHNICAL REPORT

Preface

The CAPaBLE programme presented here, envisages capacity building and action research in promoting algaculture in coastal village of Sundarbans in India that are inundated due to rising sea level, as a sustainable alternative livelihood option and climate-smart aqua-farming for community based adaptive mitigation. Farmlands inundated with trapped seawater have been used with modified landscaping for algaculture technique suitable for culturing local seaweeds along with fish. Hands on training on culture preparation, management and monitoring of growth, harvesting of algal biomass and its usage have been demonstrated in a technology cooperation module. Carbon sequestered in culture period across various seasons have been analysed along with cost-benefit assessment over return on investment in the action research programme for prescribing adaptive management and alternative livelihood.

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1.0 Introduction

Alga-culture is commercial farming of algal flora that has numerous uses, including production of food, fertilizer, bio-plastics, fodder, chemical feedstock, pharmaceuticals and fuel. Though, culture methods are sparsely known and promotional policy instruments are meagre, as a REDD plus implication in coastal areas with mangrove forests, it can be used for bio-fixation of CO_2 and GHG abatement as it has an estimated potential of sequestering twenty times of CO_2 it emits by respiration. The presented action research advocates alga-culture as an alternative livelihood for marginal farmers in inundated coastal areas, who have lost all or part of their farmland to intruding seawater owing to sea level rise in coastal villages of India, in assuring sustainable environment development towards poverty alleviation. This program entails capacity building in alga cum fish culture for various regional stakeholders and beneficiaries as well, to promote cultivation of locally available edible and commercially important algae as a climate-smart, sustainable alternative livelihood, wherein it disseminates the scientific knowledge of alga-culture, kick-start a regional cooperation for developing algae producers organizations and enrich research potentials of the scientific community in improvising the cultivation prototype by integrating it to fisheries. The program promises a convergent and sustainable paradigm towards adaptive mitigation and climate resilient agro-farming.

1.1 *Objectives of the program*:

(a) It demonstrates the cultivation technology of commercially important algae, integrated with fisheries, in brackish and trapped storm surge waters of inundated coastal areas for sustainable alternative livelihood and abating climate change impact.

(b) It develops community aptitude in algaculture as a promotional capacity building programme to mitigate climate vulnerability with low cost conservation paradigm for place-based habitat restoration through community intervention

(c) It disseminates amongst stakeholders, the researched scientific knowledge in regard to carbon sequestration potential of cultured alga as a strategic measure for climate change resilience.

1.2. *The 'CAPaBLE' program oriented intervention*:

The intervention strengthened global change research through capacity building and by identifying information and knowledge gaps through applied research, synthesis and assessment studies. In concurrence to the APN thematic area of Resource Utilization and Pathways for Sustainable Development, it also directly enriched the sectors of climate vulnerability and community resilience, coastal biodiversity and habitat restoration that are important thematic areas of APN, with place-based decision support policy research. Further, this research observation has been a cross cutting experience for all communities of natural, socio-economic and political sciences, and non-science stakeholders including decision-makers, managers and the public, as it successfully mainstreamed smallholder agriculture to sustainable rural development along the purview of community based climate change management. Promoting sustainable alga-culture as an agro-based carbon sequestration paradigm for adaptive mitigation in order to develop strategic pathways in approaching socioeconomic planning and as well, enriching practical research interventions at the grassroots that are APN's common objectives, were integral to the intervention. The proposal being a place based (site-specific) integrated research that includes interdisciplinary analyses of the effects and consequences of social, ecological and economic development and potential coping strategies pertinent to the region for augmenting community resilience adheres to the prime concerns of APN's science agenda. Further, in alignment with APN's Institutional Agenda, the proposed project necessarily encouraged communication and collaboration closely with organizations in the global change community to achieve shared goals in the ecoregion. Further, the scope of algaculture is not just restricted to coastal areas only where the land is inundated, though with the growing threats of climate change such inundations will grab more farmlands posing a threat to food security, it can also be cultivated in drought prone areas with limited water stocks or in captive pools that are perennial. In this regard, the species selection needs to be judicious so that priced bioactive materials are obtained from the cultivars and that compensates the cost of production. This extended scope also augments the sustainability coefficients and caters to food security and micronutrient enrichment that are mandates for global change research.

1.3. Background Work & Literature Review

A thorough literature survey on cultivation and utilization of seaweeds on a global scale reveals extensive cultivation of mainly 16 species of algae, under classes *Rhodophyta, Chlorophyta and Phaeophyta*. India also has a vast natural repository of algal resources but till date no attempts have been made to tap these vast potential resources as human food, feed, fertilizer and a source of different bioactive compounds. Neither any quantitative assessment has been done for the exploration of algal resources of Bengal coast in regard to its biological and climate change downscaling potentials. Regarding a global overview on algae, a vivid literature survey brings out that there are about 900 species of green seaweeds, 4000 red species and 1500 brown species found in nature (Khan and Satam, 2003). of these, some 221 species of seaweed are utilized commercially. About 145 species are used for food and 110 species for phycocolloid production (e.g. agar).Currently there are 42 countries in the world with reports of commercial seaweed activity (Khan and Satam, 2003). In India, seaweeds grow abundantly along the Tamil Nadu and Gujarat coasts and Lakswadeep and Andaman and Nicobar Islands. West Bengal coastline also has a huge unexplored resource of commercially important seaweeds,

<u>Seaweed Resources of India</u>*:* The total standing crop varied from 6,77,308.87 to 6,82,758.87 tons (fresh weight) along the Indian coast, while the World natural resources were estimated to be 2,00,54,590 tons (fresh weight). These resources have great potential for the development of seaweed based industries in India (Rao and Mantri, 2006). To utilize seaweed resources in a sustainable manner, conservation as well as proper husbanding of these resources is a prerequisite. Unplanned and continuous harvesting of these seaweeds from their natural habitats resulted in depletion of standing crop. Continuing such activities for longer periods might exhaust these resources completely, without even leaving the basic nuclei needed for propagation in the succeeding season. In order to avoid this, utilization of seaweeds is to be done according to the pattern of growth and life cycle. Certain economically important seaweeds like *Gelidiella acerosa*, *Gracilaria edulis*, species of *Sargassum* and *Turbinaria* have been advocated for proper harvesting after conducting studies on the harvesting procedure (Rao and Mantri ,2006). *Seaweed Resources of India:* India (08.04–37.06 N and 68.07–97.25 E), a tropical South Asian country has a stretch of about 7500 km coastline, excluding its island territories with 2 million km^2 Exclusive Economic Zone (EEZ) and nine maritime states. The seaweed flora of India is highly diversified and comprises mostly of tropical species, but boreal, temperate and subtropical elements have also been reported. In all, 271 genera and 1153 species of marine algae, including forms and varieties have been enumerated till date from the Indian waters. Many of the rocky beaches, mudflats, estuaries, coral reefs and lagoons along the Indian coast provide ideal habitats for the growth of seaweeds. The coast is characterized by mixed tides and generally with narrow intertidal regions. However, due to the geographical, climatic and physiographic influences, the coast harbours predominantly subtidal algal community. There has been no particular zonation in general; however, seaweed vegetation was reported at regions along the east coast, that Mahabalipuram,, Visakhapatnam , the west coast, that Okha ,Diu (Rao and Mantri, 2006).

<u>Seaweed cultivation in India</u>*:* In India, field cultivation of some economic seaweed has been attempted. Cultivation conserves the natural resources and improves the elite germplasm. Cultivation technologies for important agarophytes like *G. acerosa,* and *G. edulis*, and important carrageenophytes like *Hypnea valentiae* and *Kappaphycus alvarezii* have already been developed. Among all the cultivation methods developed for *G. acerosa*, bottom-culture method using coral stone as a substratum is found to be the best-suited for cultivation. A crop yield of 4 tons (dry

weight)/ha/yr was achieved in two harvests over 0.5 ha area by the above mentioned method using coral stone as substrata.

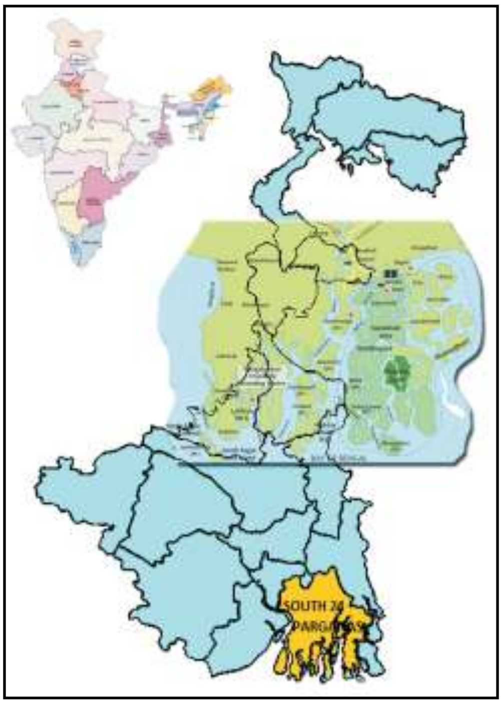
<u>Algal Culture in Bengal Coast</u>*:* Diversity of marine and brackish water algae along the Indian coasts have been studied by a number of authors (Krishnamurthy 1969; Rao and Iyengar 1964; Kaliaperumal and Chenubhotla 1997). Compilations of these data have also been done with a view to assess the standing stock of natural resource of the seaweeds available on the Indian Coast. But from these studies it becomes clear that still now the West Bengal coastline has not been exploited properly as resources of seaweed and other brackish water algae with exception of a few reports. (Sen & Naskar, 2003). Mukhopadhay and Pal (2002) surveyed the dominant Chlorophyceae and Rhodophycean algal flora of estuarine West Bengal to study their cultural behavior and the prospect of these useful algae in mass cultivation programmed, which can be followed with place-based modifications.

1.4. Scope of the Project

a) Improvisation of algaculture-cum-fisheries as a sustainable alternative livelihood for climate hit coastal community, as demonstrable by training farmers and fishers, that make them capable to adopt the trade
b) Assessment of algaculture as an aqua-farming practice from its carbon sequestration potentials, to be an alternative for downscaling climate impact in vulnerable coastal habitat towards its restoration, as demonstrable by action research.
c) Enhancement of climate change impact awareness and environmental education in relation to vulnerable coastal habitat and its conservation priorities as demonstrable by positive attitude change amongst the beneficiaries in the project area
d) Demonstrating algaculture technique as an integrated, low input, low emission, optimal yield aqua-farming technique through knowledge economy that can be replicated beyond the regional paraphernalia in Asia for climate vulnerable communities as an adaptive mitigation.

2.0 Methodology

2.1. Project Initiation

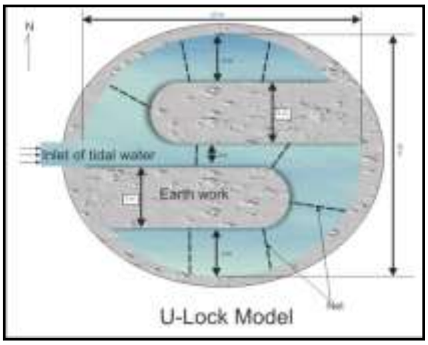


The CAPaBLE program was initiated in June 2013, as an adaptive climate mitigation measure for marginal farmers in three coastal villages of Sundarbans of eastern India, viz. Jharkhali (22°2'8"N 88°41'56"E), Saatjelia (22°8'39"N 88°52'40"E) and Kumirmari (55°30'5''N, 37°20'3''E) in the Gosaba Block of district 24 Pargana in West Bengal as in the map below.

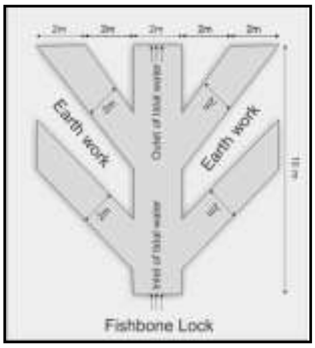
Through community capacity building, on-field demonstration and scientific interventions, it soon became a multi-stakeholder endeavor of collaborators and partner institutes like School of Oceanography and Marine Science, Jadavpur University, National Bank for Agriculture and Rural Development (NABARD), Indian Institute of Technology (IIT), Central Inland Fisheries Research Institute (CIFRI), Dept. of Science and Technology (DST), Govt of India and rural local administration (*Gram Panchayats*) as well. Participatory planning for setting up experimental designs, selection of demonstration sites and identification of beneficiaries that brewed during in-house brainstorming at SAFE and CIFRI was duly shared with the community members during village awareness camps held in Sundarbans and final implementation blueprint was made ready for execution by July end.

2.2. Grounding and Structural Interventions

In the month of July 2013, the project monitoring team comprising of researchers, scholars and scientists, with the research team of SAFE, identified three locations in Sundarbans for grounding project interventions, one each in outer estuarine (Jhorkhali near Saatjelia village), mid-estuarine (Kumirmari village) and inner estuarine (Sagar village), and three cultivation techniques in the sites were initialized, viz. U-Lock, Fishbone and Free-Float model. Ecological survey and habitat evaluation was conducted in all three sites following standard methods. Natural habitats of local algal flora that are economically important were identified from field and seed stocking were made in freshwater ponds at Jhorkhali village near Saatjelia. On completion of the earthwork, algal seeds were inoculated to cultivation beds in all three types of models.

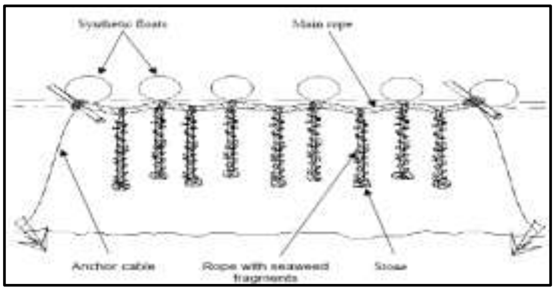


U-Lock Mass Culture: This is an innovative local practice model for slowing down tidal flow and rare fish fingerlings in the estuaries of Sundarbans. This TEK was improvised in inundated farmlands to develop U-shaped interlocking landscapes, split with fine nylon net partitions for making pen-culture enclosures for algae and fish cultivation. Each enclosure was inoculated with algal seed for rapid production, whereas the elevated edges and ridges were used for mangrove plantation, energy cropping or fodder crop plantation as an integrated farming practice.



Fish-Bone Mass Culture: A model initially developed by Organization for Marine Conservation Awareness and Research (OMCAR) for restoration of mangroves in the coastal habitat has been modified here for algaculture, wherein a channel of inflowing tidal water is bifurcated in lateral outlets like a fish-bone structure. The lateral channels are partitioned with nylon net for alga-cum-fish culture. Similarly the ridges were used for mangrove plantation.

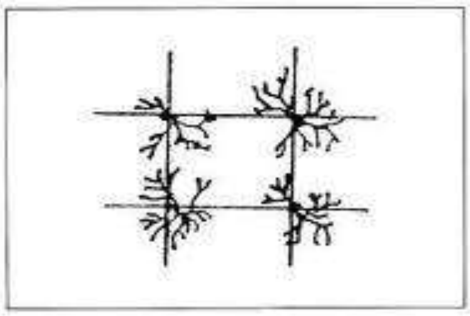
Free Float Culture**:** 3 ponds measuring 0.2 to 0.5 acre and having a depth of at least 1.5 m, connected to tidal water resource were selected for integrated fishery with algae culture. For culture procedure nylon net and nylon rope were used for better durability. Bamboo poles were used for anchoring net or rope.



(a) Culture Technique 1: Single Rope Floating Raft (SRFR) Type: The technique has been developed by Central Salt & Marine Chemicals Research Institute (CSMCRI), Bhavnagar, Gujarat, India. It is suitable for culturing seaweeds in wide area and greater depth (Khan and Satam, 2003) . A long polypropylene rope of 10 mm diameter is attached to 2 wooden stakes or bamboo poles which are anchored by suitable polypropylene cables having a length of twice the depth of the aquatic body (3 to 4 m). The long polypropylene rope is kept afloat with synthetic floats at required intervals. The polypropylene cultivation ropes of 1 m long x 6 mm diameter are hung as rafts from the main floating rope. A stone is attached to the free lower end of the cultivation rope to keep it in a vertical position. The distance between two cultivation ropes is kept at 2 m. Generally 10 fragments of algal species are inserted on each cultivation rope. The classical SRFR technique has been modified to suit the pond ecology in

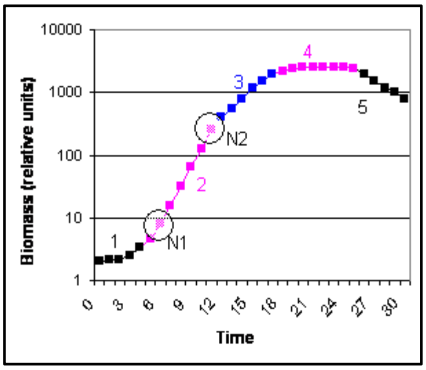
Sundarban. Grazing of the different algal species by the pond fishes is inevitable. In some field experiments, each culture rope encased within a fine meshed nylon net bag (0.5 m length x 0.1524 m diameter) tied with nylon rope at the top has effectively prevented such grazing. This improvisation not only has prevented consumption of algae by pond fishes, it has also helped in their propagation as well.

(b) Culture Technique 2: Net Culture Type (NCT): A floating net of 1 m2 area with floats and tied materials suitable as the substratum for algae like Ulva Sp. in this culture. Nets were supported by side frames of bamboo. The framed net is kept afloat near the water surface with the help of bamboo poles or anchor, holding at the four corners of net. The algae along with holdfasts are introduced into the twist of the coir ropes of the net [Fig: 3(a)]. The nets may be of different mesh sizes according to the requirement



2.3. Algal growth phases including determination of the growth rate and population doubling time

There are 5 reasonably well defined phases of algal growth in batch cultures (Fogg and Thake, 1987). 1. Lag phase; 2. Exponential phase; 3. Phase of declining growth rate; 4. Stationary phase; 5 Senescence phase.



Lag phase is the condition of the inoculums that has strong bearing on the duration of that phase (Spencer, 1954). Inoculums taken from a healthy exponentially growing culture is unlikely to have any lag phase when transferred to fresh medium under similar growth conditions of light, temperature and salinity. The growth rate of algal population is a measure of the increase in biomass over time and it is determined from the exponential phase. Growth rate is **one** important way of expressing the relative ecological success of a species or strain in adapting to its natural environment or the experimental environment imposed upon it. Biomass estimates need to be plotted over time and logistical constraints determine their frequency but once every one to two days is generally acceptable. Cell count and dry weight are common units of biomass determination.

Growth rate; K' = Ln (N2 / N1) / (t2 - t1): Where N1 and N2 = biomass at time1 (t1) and time2 (t2) respectively; Levasseur *et al* (1993). Divisions per day and the generation or doubling time can also be calculated once the specific growth rate is known.

Divisions per day; Div.day^{-1} = K' / Ln2; Generation time; Gen't = 1 / Div.day^{-1}

Declining growth normally occurs in cultures when either a specific requirement for cell division is limiting or something else is inhibiting reproduction. This phase of biomass growth is often very high rated and exhaustion of a nutrient salt, limiting carbon dioxide, fall in temperature or light limitation become the primary causes of declining growth . When biomass is increasing exponentially a constant supply of air (or air plus CO_2) will only be in balance with growth at one point during exponential phase. At low cell densities too much CO_2 may lower the pH and depress growth. CO_2 limitation at high cell densities causes any further biomass increase to be linear rather than exponential (with respect to time) and proportional to the input of CO_2. Cultures enter stationary phase when net growth is zero, and within a matter of hours cells may undergo dramatic biochemical changes. The nature of the changes depends upon the growth limiting factor. Nitrogen limitation may result in the reduction in protein content and relative or absolute changes in lipid and carbohydrate content. Light limitation will result in increasing pigment content of most species and shifts in fatty acid composition. Light intensities that were adequate or optimal for growth in the first 3 phases can now become stressful and lead to a condition known as photo inhibition. It is important that while the measured light intensity within the culture will decrease with increasing biomass if the incident illumination is maintained relatively high then a large proportion of cells may become stressed, photo inhibit and the culture can be pushed into the death phase. This is especially the case if the culture is also nutrient stressed. It is preferable for many species to halve or further reduce the incident light intensity when cultures enter stationary phase to avoid photo inhibition. The shutdown of many biochemical pathways as stationary phase proceeds means that the longer the cells are held in this condition the longer the lag phase will be when cells are returned to good growth conditions. When vegetative cell metabolism can no longer be maintained the death phase of a culture is generally very rapid, hence the term “culture crash” is often used. The steepness of the decline is often more marked than that represented in the accompanying figure.

2.4. Experimental Design:

Initially the growth rates of both the *Enteromorpha* species were estimated with free floating culture techniques. For this, different initial fronds viz. 50g, 75g, 100g, 125g, and 150g were tried for cultivation in ambient environment. In modified SRFR set-up the length of the main rope was taken as 10 mts with side ropes tied at 1mt intervals. Well branched good quality seed materials was inserted in single braid knot (20 braid knots/single rope); thus 400 seed materials were prepared out of 20 ropes in a single raft. Finally the raft was tied at both comers of another raft. Floats were used for anchoring the raft. Similar seeding was done in Net Culture Technique. This phase was initiated to train the farmers how to identify the best growth condition and ambient environments for the growth. Subsequently, the experimental set obtaining the best growth rate was adopted for mass culture techniques in U-Lock and Fish-Bone methods.

After preparing the mass culture pond for the regeneration of *E. intestinalis* in the intervention sites of Sundarban, the ponds were inoculated with algal filaments used as seeds and collected from its natural habitat (road side small water bodies) besides the Kolkata Basanti highway. Salinity of these water bodies was 1.1 to 1.3 ppt and pH was 8.46 to 8.07 during the sample collection. The depth of the culture pond was 4 ft on an average. The culture ponds were separated in four sectors (partitions) by nylon net flanked in a wooden frame, each flank acquairing an area of 0.1 Hectare (approx). In the three sectors, 2 kg, 5 kg and 7.5 kg wet weight of *E. intestinalis* seed was inoculated for regeneration depending on the surface area and depth. The fourth sector was left blank as control pond and for further experiment of fish feed. This culture pond was filled by tidal water from rivers throughout the study period. In natural brackish water pond in Sagar islands, where salinity is much lower, the free float experiment was conducted parallel to the mass culture techniques in Kumirmari and Saatjelia. To save the *E. intestinalis* from the fish, 8 square frames of 1Sq. Mt area and made of plastic rod with nylon net was prepared and measured samples of wet weight were inoculated in each of the frame. Special care was taken during the weighing of the species. It was separated from the gastropods and washed thoroughly before weighing.

2.5. Analytical Protocol for Scientific Studies

Limnochemical studies: Salinity was measured using a multikit (WTW Multi 340 i set; Merck, Germany) fitted with the probe WTW Tetracon 325. pH and water temperature was measured instantaneously with a pH meter (pH 620; Eutech Instruments, Singapore). The glass electrode for pH measurements were calibrated using technical buffers of pH 4.01 and pH 7 before each measurement. Dissolved oxygen (DO) was measured by using Winkler’s titrimetric method. Turbidity was measured in NTU with the help of a turbidity meter (TN-100; Eutech Instruments, Singapore). Biochemical oxygen demand (BOD_3) was estimated followed by APHA (20^{th} Edition, 1998). Dissolved nutrients, like dissolved inorganic nitrogen (nitrate, nitrite and ammonia), dissolved inorganic phosphate and silicate was measured followed by the spectrophotometric method of Grasshoff et al.

(1983). The water samples were collected using a acid washed BOD bottle, taken in non reactive black plastic bottles and sent back in the laboratory keeping the water samples in the ice box until analysis. All the analysis was done within 24 hours of sampling. Compositional analysis of algal filaments and frond (moisture content, ash, chlorophyll, total sugar, cellulose, fibre, protein) of *E. Intestinalis* and Ulva sp. was done followed by official methods of analysis of AOAC International (19^{th} edition, 2012).

Seasonality:

The experiment was conducted for three different seasons viz., post-monsoon, summer and pre-monsoon from January to September 2006. During monsoon season, culture experiment was washout within 5 days due to heavy rain fall and fresh water flow. Daily growth rate was calculated at every 15 days interval.

Daily Growth Rate (DGR):

Daily Growth Rate % was calculated using a formula (Dawes et al 1993) DGR% = ln (W_f / W_o) / t X 100; wherein t is the number of culture days. W_o is the initial fresh weight (g) and W_f is the final fresh weight (g**)** after culturing for t number of days.

Carbon Mitigation Potential

Algae have the ability to fix carbon dioxide efficiently (Richmond 2000, Benemann 1997). Carbon dioxide fixed through photosynthesis is converted to carbohydrates, lipids, proteins and nucleic acids. The carbon content varies with algal strains, media and cultivation conditions. The CO2 fixation rate can be calculated by applying law of conservation of mass:

Biomass molecular formula: $CO_{0.48}H_{1.83}N_{0.11}P_{0.01}$

$M_{Biomass}$ *= 23.2 gram/mol: M CO2 =44 gram/mol*

$4CO_2 + nutrients + H_2O + hv \rightarrow 4\ CO_{0.48}H_{1.83}N_{0.11}P_{0.01} + 3.5\ O2$

Rate constant $K = MCO_2/M_{Biomass} = 44/23.2 = 1.89.$

Total CO_2 *fixation = K × biomass productivity X fixation efficiency*

Statistical Analysis:

Data were analyzed statistically using Analysis of Variance (ANOVA) to determine the differences in seasonal Daily Growth Rate with different initial seed density along with various seasons of culture period.

3.0 Results & Discussion

Green seaweed *Enteromorpha intestinalis* (L. Link) is used as food, fodder and fertiliser throughout the globe. Various other species of Enteromorpha have high rate of carbon sequestration potentials per gm fresh weight (Chung et al. 2011). *E. intestinalis* can also withstand the salinity from 0 ppt to 136 ppt (Read and Russel, 1979) and it has been used to determine the nitrogen sources to estuaries (Cohen and Fong, 2005). This was also used as an indicator of nutrient enrichment in coastal estuaries and lagoons (Fong et al. 1998). It has been found that spores of E. *intestinalis* are highly sensitive to phosphate limitation and ammonia toxicity (Sousa et al. 2007). Back et al. (2000) studied the biomass of *E. intestinalis* in the Finnish Baltic sea coast. Barr and Rees (2003) studied nitrogen status and metabolism in *E. intestinalis* in three natural populations of Auckland, Newzeland. Kamar and Fong (2000, 2001) studied the effect of different salinity regime. Martin et al. (1999) studied the effect of varying salinity in the growth rate of *E. intestinalis* in Portugal. McAvoy and Klug (2005) studied positive and negative effect of riverine input in the growth rate of E. *intestinalis*. Herein, we have been able to properly cultivate two free floating alga, namely *Enteromorpha intestinalis* and *Enteromorpha prolifera* and one substrate bound alga, *Ulva lactuca*, could only be stabilized in the inundated areas. Of all these, the free floating species could be studied for scientific interventions and harvested for two consecutive cycles in November and March. The comparative growth rates, seasonal changes in carbon mitigation potential are substantiated with data tables and graphs in the following paragraphs of the text. A band of reference at the end part of the report would substantiate the detail studies on the subject and the findings of the project can be correlated to the previous researches for the needful.

3.1 Limnological Studies

The limnological parameters of the culture ponds have been seen to vary seasonally and a comparison (TABLE-1) of such parameters during pre-monsoon, monsoon and post-monsoon period in experimental ponds shows that water salinity ranges from 24.4 PPT in post-monsoon to 10.7 PPT in monsoon season, whereas pH and DO demonstrate a more consistent curve showing minimal seasonal changes. Ambient temperature is maximum during pre-monsoon phase and minimum during winters, showing a negative correlation with salinity. 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 CO2 release and its utilization buffering the pH with bicarbonates and subsistent release of oxygen through photosynthetic activities (Chakraborty et al, 2011; Chi Z et al, 2011). 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.

LIMNOLOGICAL PARAMETERS: TABLE 1

Month	Water Temp (C)	Salinity (ppt)	pH	Disolved Oxygen (mg/L)	Turbidity (NTU)	BOD_3 (mg/L)	Dissolved Inorganic Nitrogen (mg/L)	Dissolved Inorganic Phosphate (mg/L)	Silicate (mg/L)
January	25.6	24.4	7.97	6.95	127	34	0.31	0.02	2.5
February	30.3	17.5	8.22	6.9	114	20.9	0.39	0.03	9.2
March	35.2	20.7	8.45	5.45	98.2	8.4	0.58	0.55	10.3
April	36.4	20.5	8.37	4.47	65.7	2.91	0.08	0.03	1.65
May	36.8	22.4	8.66	5.04	69.9	3.11	0.07	0.04	2.22
June	37.1	22.3	8.22	5.45	71.9	3.33	0.07	0.04	10.02
July	35.3	12.7	7.81	5.88	73.77	3.45	0.08	0.04	19.9
August	34.8	10.7	7.52	5.93	80.2	7.77	0.09	0.03	25.2
September	34.6	10.9	7.22	6.2	85.9	9.72	0.08	0.03	20.1
October	33.6	14.1	7.33	6.4	86.1	11.5	0.16	0.02	13.2
November	33	19.3	7.21	6.86	97.8	26	0.33	0.03	10.7
December	28.4	22.2	7.66	6.66	110.4	29.6	0.32	0.03	4.4

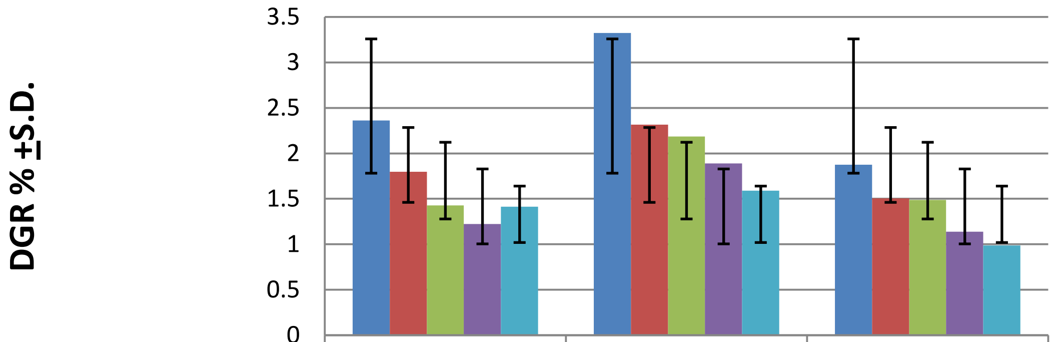
3.2 Free Culture Standardization

Trends of biomass growth in both modified SRFR and Net culture across the three seasons has been illustrated (Fig 1a & Fig 1b). In both cases the growth is maximum during post monsoon season and minimum in pre-monsoon season. Yield has been observed higher in net culture than that in modified SRFR culture. In case of net culture, yield is approximately 2.2 kg from 1 kg seed after a period of 15 days of culture. Whereas in case of raft culture, the yield is 1.5 Kg from the same amount of seed and period of cultivation. But, in spite of lower yield, the Net Primary Productivity (NPP) of the water of the ponds under raft culture technique has been observed to be twice higher than that of the ponds under net culture technique (Barik et al, 2011).

Perusal of result show that initial stocking volume of 100gms/m2 shows the best growth rate in net culture technique where as in modified raft culture initial stalking volume of 50gms/m2 provides the best growth rate. The production has been found to be the maximum in the post monsoon season when the salinity is comparatively higher and temperature is at the minimum. This explains the limits of carrying capacity of maintained culture frame which is significant for mass commercial production. However, the range of variability in the rate of biomass production is highly dependent on seasonal ambience and found to be varying maximum during pre monsoon season as observed in both the culture techniques. The same trend has been observed in both the culture techniques. However, production in net culture exceeded that of modified raft culture in all the three seasons. The enhanced growth in post monsoon period in post monsoon period is attributed to the increased salinity as explained earlier.

Growth Rate for *Enteromorpha prolifera*

(Free-Float Tray)

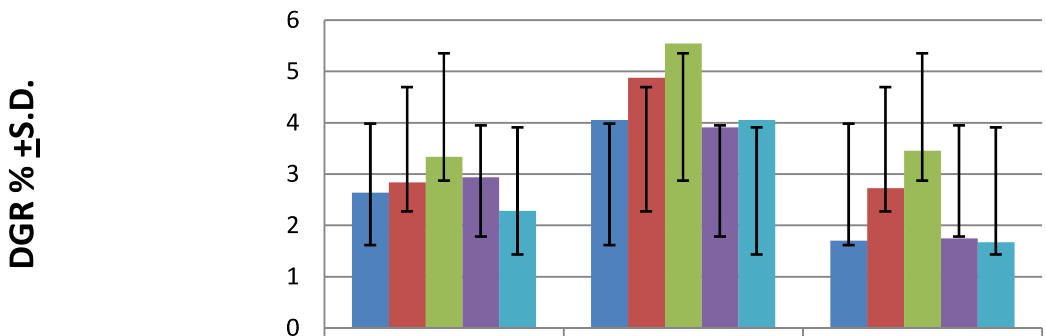


	Monsoon	Post Monsoon	Pre Monsoon
Initial Wt (50gm/Mt.Sq)	2.362	3.325	1.874
Initial Wt (75gm/Mt.Sq)	1.798	2.317	1.504
Initial Wt (100gm/Mt.Sq)	1.427	2.186	1.489
Initial Wt (125 gm/Mt.Sq)	1.223	1.89	1.138
Initial Wt (150gm/Mt.Sq)	1.413	1.591	0.987

Fig 1a: DGR% in Net Culture Technique

Growth Rate for *Enteromorpha intestinalis*

(Free-Float Tray)

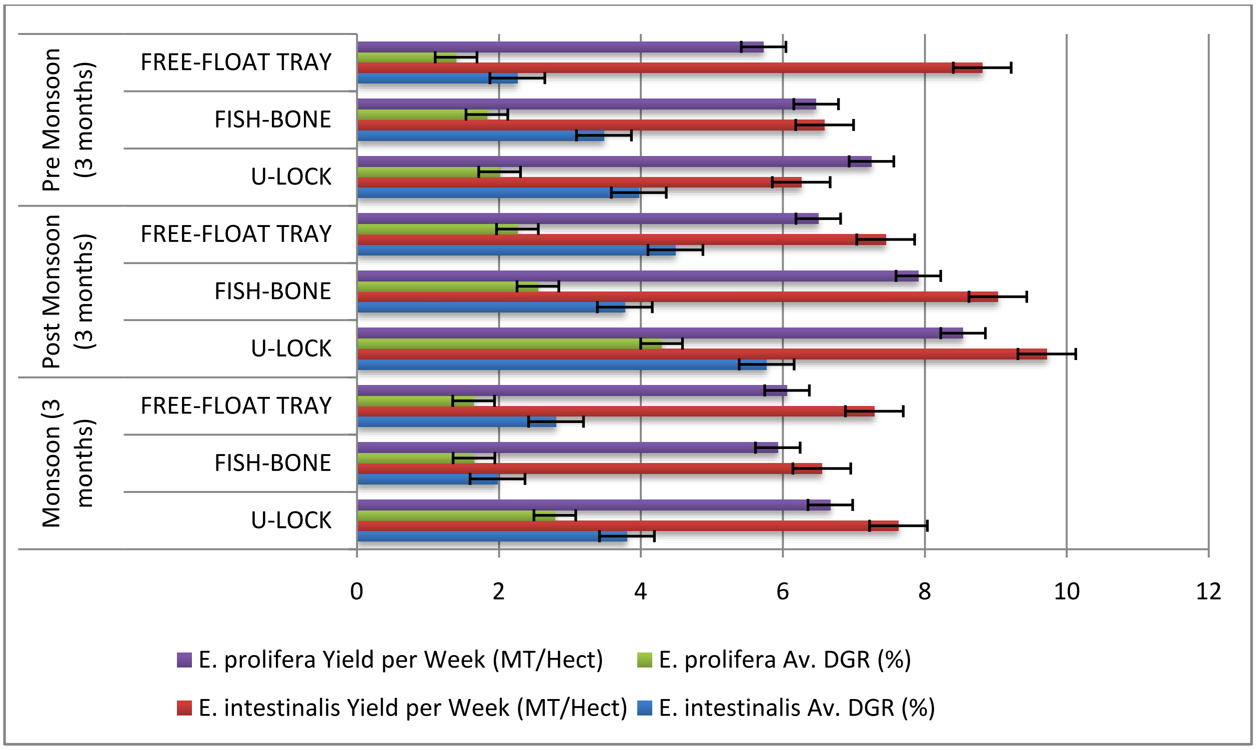


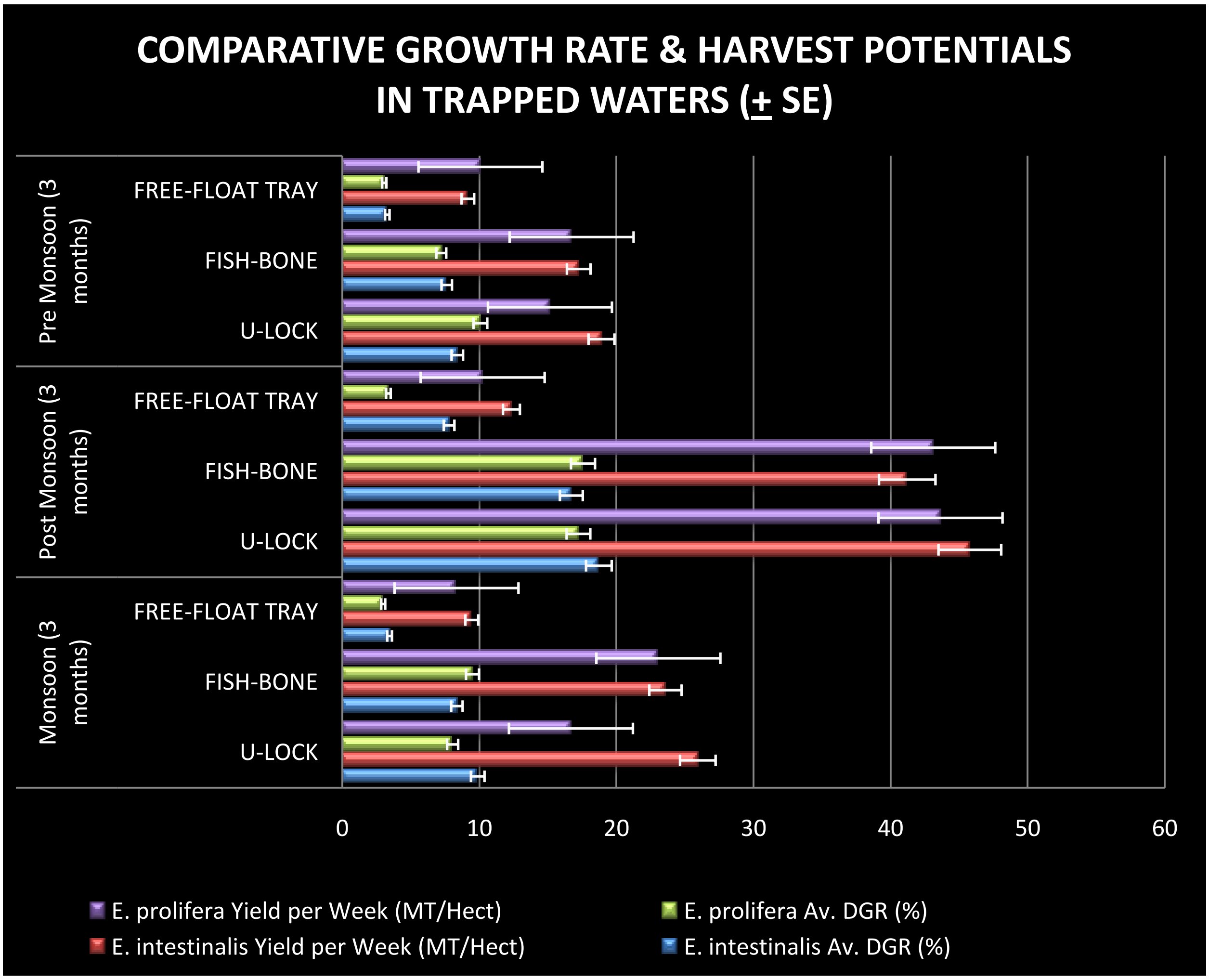
	Monsoon	Post Monsoon	Pre Monsoon
Initial Wt (50gm/Mt.Sq)	2.637	4.054	1.703
Initial Wt (75gm/Mt.Sq)	2.839	4.879	2.728
Initial Wt (100gm/Mt.Sq)	3.338	5.542	3.454
Initial Wt (125 gm/Mt.Sq)	2.935	3.91	1.747
Initial Wt (150gm/Mt.Sq)	2.281	4.056	1.673

Fig 1b: DGR% in Modified Raft Culture Technique

3.3 Mass Culture of Algae: Biomass of the *E. intestinalis* was estimated 803 gm/ m^2 to 953 gm/ m^2 per unit area, varying across the season from pre-monsoon, monsoon and post-monsoon periods. During winter season, the growth rate of the algae culture pond was estimated at 400 gm to 659 gm day^{-1} (13% to 20% day^{-1}), whereas during summer, the growth rate was calculated as 100 gm to 127 gm day^{-1} (5% to 6% day^{-1}). On the other hand, in the natural pond, where the salinity is much lower (0.2 ppt), growth rate of *E. intestinalis* was also in the lower side (10 gm day^{-1}). Our observation is supported by Martins et al. 1999, who stated that growth rate of *E. intestinalis* is highest between 15 and 20 psu salinity whereas the growth rate markedly declines at the salinity of < 5 psu and >25 psu. Kamar and Fong (2000) also stated growth of *E. intestinalis* declines at lower salinity. Hereunder, we table (TABLE 2) the comparative growth rates and harvest potentials of algal flora in normal ponds and in trapped waters of inundated areas.

TABLE2: COMPARATIVE GROWTH RATE & HARVEST POTENTIALS (PONDS)					
Initial Wt=100gm/Mt.Sq & SALINITY 2-3 psu					
CULTIVATION MODEL TYPE		*E. intestinalis*		*E. prolifera*	
		Av. DGR (%)	Yield per Week (MT/Hect)	Av. DGR (%)	Yield per Week (MT/Hect)
Monsoon (3 months)	U-LOCK	3.805	7.63	2.789	6.67
	FISH-BONE	1.982	6.55	1.65	5.93
	FREE-FLOAT TRAY	2.806	7.29	1.645	6.06
Post Monsoon (3 months)	U-LOCK	5.773	9.72	4.293	8.54
	FISH-BONE	3.775	9.03	2.551	7.91
	FREE-FLOAT TRAY	4.488	7.45	2.262	6.5
Pre Monsoon (3 months)	U-LOCK	3.972	6.26	2.011	7.25
	FISH-BONE	3.481	6.59	1.832	6.47
	FREE-FLOAT TRAY	2.261	8.81	1.398	5.73
COMPARATIVE GROWTH RATE & HARVEST POTENTIALS (TRAPPED WATERS)					
Initial Wt=100gm/Mt.Sq & SALINITY 17-18 psu					
CULTIVATION MODEL TYPE		*E. intestinalis*		*E. prolifera*	
		Av. DGR (%)	Yield per Week (MT/Hect)	Av. DGR (%)	Yield per Week (MT/Hect)
Monsoon (3 months)	U-LOCK	9.88	25.94	8.05	16.68
	FISH-BONE	8.36	23.58	9.5	23.06
	FREE-FLOAT TRAY	3.45	9.45	2.98	8.33
Post Monsoon (3 months)	U-LOCK	18.72	45.79	17.23	43.65
	FISH-BONE	16.71	41.22	17.56	43.12
	FREE-FLOAT TRAY	7.79	12.34	3.36	10.24
Pre Monsoon (3 months)	U-LOCK	8.39	18.91	10.07	15.15
	FISH-BONE	7.62	17.25	7.22	16.73
	FREE-FLOAT TRAY	3.28	9.16	3.06	10.08


Pre Monsoon (3 months)
Post Monsoon (3 months)
Monsoon (3 months)
FREE-FLOAT TRAY
FISH-BONE
U-LOCK
0
2
4
6
8
10
12
E. prolifera Yield per Week (MT/Hect)
E. prolifera Av. DGR (%)
E. intestinalis Yield per Week (MT/Hect)
E. intestinalis Av. DGR (%)

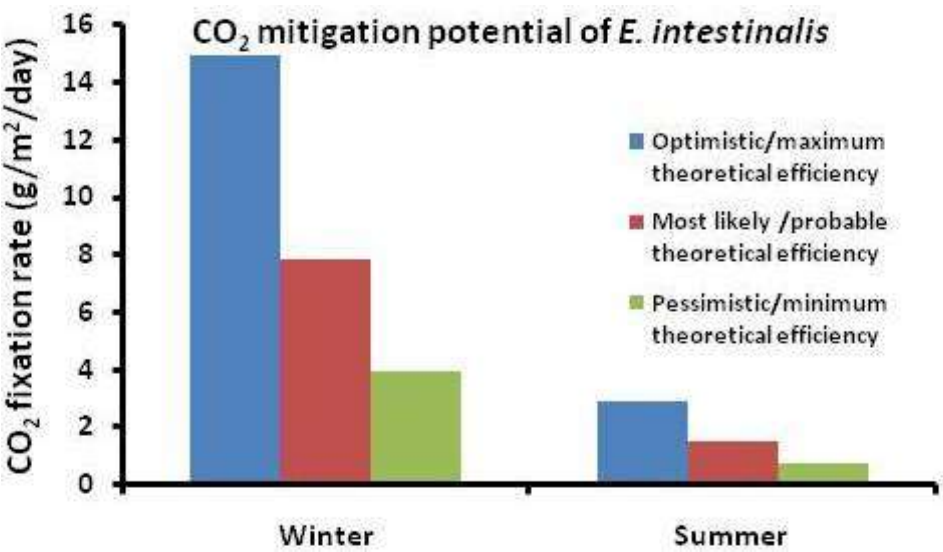

COMPARATIVE GROWTH RATE & HARVEST POTENTIALS IN TRAPPED WATERS (± SE)
Pre Monsoon (3 months)
Post Monsoon (3 months)
Monsoon (3 months)
FREE-FLOAT TRAY
FISH-BONE
U-LOCK
0
10
20
30
40
50
60
E. prolifera Yield per Week (MT/Hect)
E. prolifera Av. DGR (%)
E. intestinalis Yield per Week (MT/Hect)
E. intestinalis Av. DGR (%)

3.4 Carbon Mitigation Potentials

Perusal of 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 biomass per hectare per year only. This estimate is drastically higher than carbonaceous biomass fixation capacity of terrestrial plants (Ravindranath & Bhatt 1997). It is therefore evident that the accrued biomass through algal growth is a direct evidence of carbon capture by aquatic flora in inundated waters, as evidenced earlier (Campbell P K et al, 2010; Chi Z et al, 2011; Kaladharan et al, 2011).

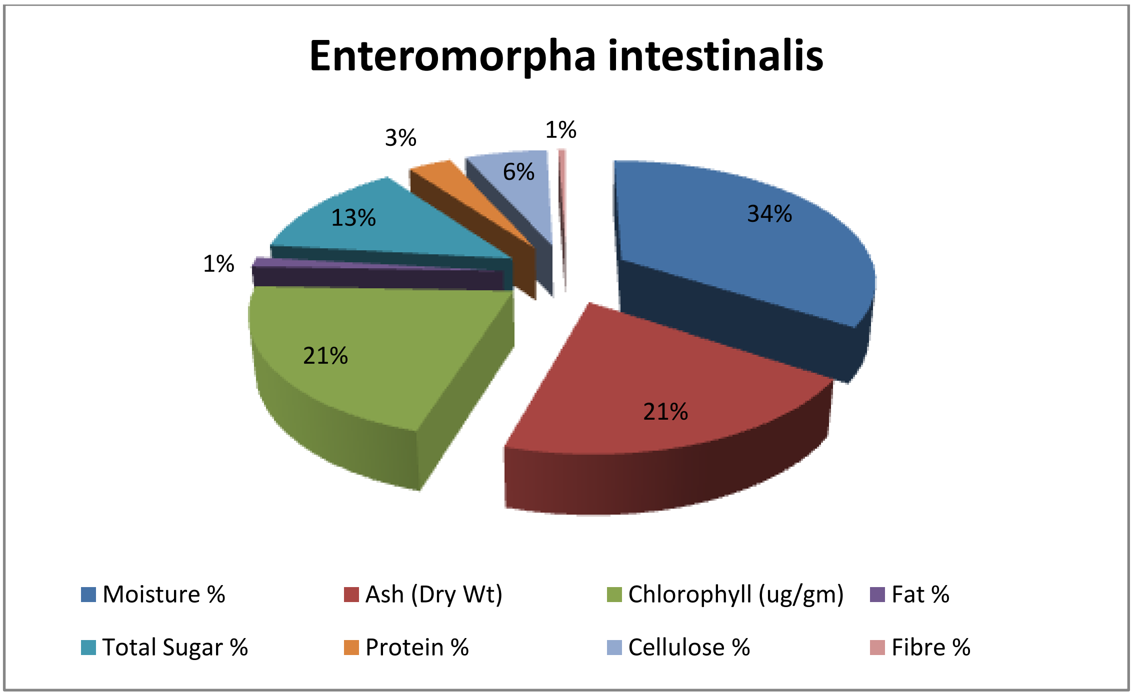
Sudhakar and Premlatha (2012) theoretically assessed algal biomass potential for carbon mitigation. Although, they implemented their study for microalgae, we have estimated theoretical carbon fixation efficiency of the macroalgae, *Enteromorpha intestinalis* in three categories: i) optimistic / maximum yield (11.42%), ii) most likely / probable yield (6%) and iii) pessimistic / minimum yield (3%) (Williams and Laurens, 2010). 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.

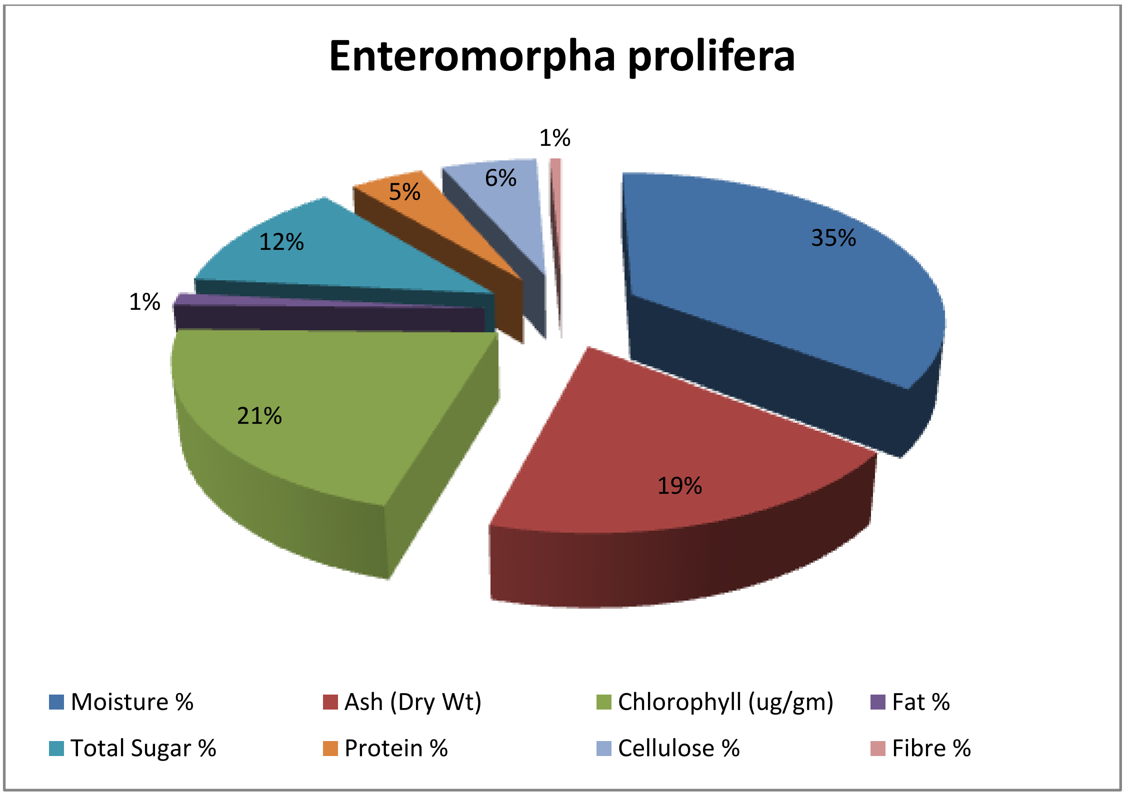
This suggests the photosynthetic efficiency and carbon storage potentials in macro-algal flora that has been already noticed in the present study and explained earlier. The potential of algal culture in low cost carbon stocking has also been explored by using bicarbonates to capture CO_2. The relevance of this study therefore reveals the suitability of fisheries in combination with algal culture in inundated waters as an alternating farming in coastal plains and its ecological significance as a pronounced method of carbon capture in the area.



3.5 Compositional analysis of *E.intestinalis* and *E prolifera*

On trekking the nutritional composition of both species of Enteromorpha some very optimistic and interesting results have been revealed, which can demand future research and observations. The details are as hereunder.





3.6 Fish Production with Algae Culture in Trapped Waters

The cultivation area harbored a batch of endemic native fish stock those are self recruiting. These consists of *Puntius guganio (***Punti***), Glossogotius giuris (***Belay***), Mystus vittatus (***Tangra***), Channa gachua (***Chang***, Channa punctatua (***Lata***), Mastacembetus panalus (***Pankal***), Mastacembetus armatus (Ban), Pisodonophis boro* (**Kucho**), *Ophisternon bengalense* (**Bero**), Badis badis (**Bhada**) etc. all these are nutricious priced species of fishes and since they are self recruiting, a natural stock appeared in the pond. Carp grazing of algal flora was observed in the monsoon season, wherein the fish diversity and growth was maximum. The correlated study is essentially important to understand how much algal biomass is transformed to fish body weight. However, the integrated culture has given better adoption possibilities of the technology in the community.

3.7 Community Interventions on Skill Development

Capacity Building & Community Awareness campaigns

The programme has been extremely inclusive to involve various regional and national stakeholders and local beneficiaries as well, for capacity building in algaculture and to promote cultivation of locally available edible and commercially important algae, wherein it disseminated the scientific knowledge of local algaculture to global practitioners. It did kick-start a regional cooperation for developing producer's organizations in coastal areas and enriched research potentials of the scientific community in improvising the cultivation prototype. Strategically, the project team comprised of young experts from local institutes like Central Inland Fisheries Research Institute (CIFRI), Department of Oceanography & Marine Sciences, Jadavpore University, Kolkata who collaborated for the research components of the programme and shared their expertise for the commons. Various scientific research institutes and university departments, both national and regional have contributed to the workshops and seminar conducted. Community outreach programme, conducted by Research & Community Outreach Department of the proponent organization, South Asian Forum for Environment [SAFE] in collaboration with *Vigyan Prasar*, the official wing of Department of Science & Technology, Govt. of India for scientific capacity building and awareness development has been effective and impactful. Manuals and handouts in local language have been published and a short documentary (with English subtitles) on the process and preparation has been released by the Director, *Prasar Vigyan* who was invited as a resource person in the workshop. SAFE has also disseminated the programme information through its website and network partners like GEF-NGO network, WANGO etc for knowledge economy and technology cooperation. Details of the outreach activities are presented in the following table (Table XX)

SL	Activity Heads	Timeline Dates	Numbers	Details of Activity Heads
1	Intervention sites	June-July 2013	03 sites	Jhorkhali, Saatjelia, Kumirmari,
2	Number of villages covered	Entire period	20 villages	Jhorkhali, Saatjelia, Lauxbanagan, Ainpur, Lahiripur, Jamespur, Sudhangshupur, Sajnekhali, Pakhirala, Chhotomollakhali, Gosaba, Puinjali, Hemnagar, Dayapur 1 & 2, Kachukhali, Tibligheri, radhanagar, Mithakhali, & Chunakhali.
3	Number of Households	Entire Period	3650 households	All households in the project intervention area who participated in the overall survey and feedback.
4	Number of direct beneficiaries	Entire period	1050 farmers	350 marginal farmers in each intervention site, who shared their farmland for intervention, undertook training, participated in community workshops, helped in landscaping and management of site.
5	Number of Farmers Trained	Entire Period	370 farmers	Acquired hands on training in algaculture, identification of local algal flora, stocking and inoculation techniques, water quality test and management of litter, fish cropping and management, harvesting, soaking and drying of algal flora, packaging and storage.
6	Women participants	Entire Period	87 (24%) women farmers	
7	Community	07.07.2013	310 heads	Awareness camp at Saatjelia

	Workshops	17.07.2013	270 heads	Community Workshop at Saatjelia
		22.07.2013	127 heads	Awareness camp at Jhorkhali
		24.08.2013	85 heads	Awareness camp at Saagar Islands
		25.08.2013	210 heads	Awareness camp at Kumirmari
		08.11.2013	164 heads	Community Workshop at Jhorkhali & Sagar
		10.11.2013	217 heads	Community workshop at Kumirmari
		23.11.2013	186 heads	Community workshop at Kumirmari
		03.02.2014	234 heads	Community workshop at Saatjelia
		12.03.2014	208 heads	Community workshop at Saatjelia
8	Scientific Workshops	28.06.2013	40 heads	In-house workshop in Kolkata
		19.02.2014	53 heads	Workshop in Jadavpur University
		02.03.2014	45 heads	Workshop in CIFRI, Barrackpore
9	Seminar	1st–2nd March2014	270 heads	National Seminar in CIFRI Barrackpore (Day 1)
			250 heads	National Seminar in CIFRI Barrackpore (Day 2)

Capacity building workshops were conducted in August, October and November at all three project sites to include identification of the algal species, pond preparation and cultivation management. Usage of pH papers, simple *sacchi* discs and measurements of temperature and tidal levels were important components of training. Beneficiaries were also taught about harvesting, measuring the growth rates in terms of DGR% from filament length and biomass weight. Beneficiaries enjoyed the learning experiences.

4.0 Conclusions

4.1 Scientific Intervention

The perusals of result obtained from mass culture of algal flora in the inundated areas reveals unique opportunities of climate smart agriculture and alternative livelihood for the marginal farmers who have been the victims of climate vulnerability. The most significant findings are noted as hereunder.

a) The production benefits are maximum in the post monsoon period which is a lean period for both agriculture and fisheries, thus it can very well be a sustainable practice in much extended areas that are inundated and/or deemed non-productive otherwise.
b) The magnificent carbon capture and sequestration potential of the farming, owing to rapid biomass growth patterns in the select algal species poses a very suitable climate resilient alternative in agrofarming practice in areas those are vulnerable to climate change
c) The high salinity resistance of the algal species that has been cultivated and its superfluous growth patterns in adverse climatic conditions is a significant finding that can pave the future research roadmaps towards food and fodder security and various environmental benefits like organic farming, habitat restoration, species rehabilitation etc
d) Studies on nutritional components of the algal flora show a tremendous prospect for it in the future food industry. Especially good carbohydrate fat and protein contents and stored cellulosic content are attractive attributes.
e) Local nesting of rich algal flora in the deltaic sundarbans is a natural capital. Cultivation of this local species with a place-based farming procedure that is of low investment and high impact has augmented the scope of research and community based interventions in this alternative aquafarming domain ensuring enhanced community resilience and climate adaptive preparedness for the future.

4.2 Program Sustainability and Impact Assessment

While the community empowerment on technology cooperation led to formation of five Farmer's Clubs for alga cultivation in Kumirmari and another five in Saatjelia, NABARD assisted with financial inclusion programme for the members and encouraged to develop bankable models for alga cultivation for credit linkages. A green techno limited liability company "Greenpoint Environment Services" visited the alga cultivation site and expressed keen interest for buyback option of good harvest, which was encouraging for the farmers. Production of native fishes in the cultivation fields has added values to the farming practices greatly. This clearly showed positive impacts on habitat restoration and enhanced species richness in coastal environment. The entire programme has enhanced the sense of social assurance, economic security and ecological preparedness against vulnerability amongst more than 15,000 marginal people enhancing their resilience to climate change.

The scientific workshops and brainstorming programme engaged national stakeholders and local partners in strategic alliances for the purpose of enhancing research and development to achieve cleaner targeted production and precise product technologies in algaculture towards food and fodder security, including new and additional resources and encouraging the transfer and diffusion of those technologies, in particular to developing countries in the region. It also examined issues of global public interest like food and fodder sufficiency, climate resilience production etc through open, transparent and inclusive workshops eliminating gender bias to promote a better public understanding of such questions. It tried to streamline convergence of resources for promoting education for sustainable development and integrate sustainable development into education systems at various levels of formal and non-formal education in order to promote the knowledge of algaculture as one of the key agent for change favouring climate smart agriculture in inundated coastal areas.

4.3 Policy-relevancy & Links to Policy & International Assessments/Conventions on Global Change

The project has acquired global significance in change management and sustainable development in general and in developing climate resilience amongst marginal farmers of the south globe in particular. The training program successfully established production of alternative bio resources for food security, fodder sufficiency and sustainable environment development to increase the community resilience towards climate preparedness and change management. This is the major concern of global assessments and conventions. The policy relevance of the program lies in mainstreaming the climate vulnerable marginal farmers and fishers towards poverty alleviation which is an important segment in MDG's. The demonstrable use of natural resources, conservation of algal biodiversity and convergence of resources through integrated natural resource management are the direct relevance for this multi-pronged policy implicative programme. This would pioneer a series of community based interventions on multi-partnership effort in translating action research to a carbon smart adaptive mitigation strategy. The global commons in developing south who are the direct and probably the worst affected with climate impacts needs such climate resilient alternatives that not only supports livelihood but can also extend support to food security and livestock management in the absence of definite alternative strategies. Capacity building in algaculture can therefore substantiate in policy framing from local to regional level in south Asia.

The proposed program on algae cum fishery farming has a double pronged approach on coastal habitat conservation and climate impact in inundated coastal areas and as well on livelihood securities of displaced farmers by creating alternative economic opportunity. From the policy implication point of reference it is very much important to signify the stated activity as the national draft on coastal wetlands conservation or coastal zone management clearly states conservation strategies for inundated coastal areas that are socio economically important. This program would help in defining and designing such strategies for its suitable placement in the policy document. The activity has already fetched the attention of policy makers as it created a win- win situation for mitigating climate impact and poverty alleviation through a low cost, low emission community intervention. The civil society sector that usually confronts a social security question from environment hazard affected community members would now have a tool to mitigate the negative link between conservation & poverty through community based intervention. Further, the capacity building program had already enabled them to scale up the same in all verticals to support their livelihood securing targets and conservation priorities. This would help to anchor more beneficiaries to this program thereby ensuring a sustainable growth.

The implementing agency, South Asian Forum for Environment, SAFE being in consultative status with Planning Commission of India, Ministry of Environment & Forest, Government of India, and Natural Resource Management Council of National Bank for Agricultural & Rural Development (NABARD) in India has an added advantage of placing the outcomes directly in the policy decision system, which would be duly done. Eventually, it is expected that algae cum fishery farming would soon find its place as a climate smart alternative livelihood program in various national schemes and financed programs of NABARD and other such rural agricultural schemes of various nationalized banks. It would also invite public private partnership (PPP) in commercial ventures of algae cum fishery owing to its immense market potential, which is meagrely exploited. To expedite better and more structured training programmes, *Vigyan Prasar*, the mass education wing of Department of Science & Technology, Govt. Of India has already consented to publish a manual on algaculture in local languages for the coastal belts of India. This would further drive the awareness and also bring the relevance of such sustainable climate smart practices to the doorstep of commons.

5.0 Future Directions

The presented CAPaBLE program has given a very positive constructive and holistic lead for developing the future roadmap on the said activity. These leads, as mentioned hereunder, would define the guidelines for future research and further extended activities for the needful.

A. Extensive research and scientific capacity building is sought now to estimate the carbon sequestration efficacy of these macrophytic algal flora when cultivated under varied climatic conditions and ecological stress in integrated farming practices for more empirical data in decision support research and policy implications. The outcomes that have been acquired under this program on the carbon sequestration potentials of two species show promising results that needs further scientific inputs.
B. The nutrient composition of the algae cultivated under salinity stress show its potentials as both food feed and fodder. Extensive research is the need of the hour to best prove it as a nutritional delicacy. Further, other nutritional and beneficial components like vitamins, food supplements, antioxidants, omega3 fatty acids etc along with estimation of various anti-nutritional factors and toxicity tests on these flora, growing under ecological stress, are also very important.
C. More technological innovations relating to low cost processing of the algal flora like sun-drying, packaging etc are required for facilitating its marketing from distant coastal locations to the urban markets. Research on the commercial methodologies for extraction of active principles and secondary metabolites of the flora is an immediate need. Once commercialized, the industry would seek interventions on increasing the shelf life of the harvest, extraction of by-products etc.
D. A detailed cost-benefit analysis on the production, harvest, processing and marketing would be urgently required to standardize the selling price, expected returns on investment, internal revenue return and net profit value of the production, which in turn can design a bankable model to facilitate marginal farmers for credit linkages and even crop insurance coverage for risk spreading.
E. Detailed and strategic studies on environmental impact assessment is required for evaluating the natural capital accrual through such habitat restoration and algal farming that

can assess the values of environmental services extended to the beneficiaries and can substantially compensate their opportunity costs.

6.0 References

1. Adam P (1990) Saltmarsh ecology. Cambridge University Press, Cambridge, UK, Pp 461-470
2. Back S, Lehvo A and Blomster J (2000) Mass occurrence of unattached *Enteromorpha intestinalis* on the Finnish Baltic sea Coast; *Annales Botanici Fennici* 35: 155-161.
3. Barik J, P Sanyal, S Hazra (2011) Algae Cultivation Techniques for Sustainable Integrated Fisheries in Sundarbans. Proceedings of the 3rd International Conference on Ecotoxicology and Environmental Science, Kolkata, Pp 222-228
4. Barr NG and Rees TAV (2003) Nitrogen status and metabolism in the green seaweed *Enteromorpha intestinalis*: an examination of three natural populations; *Marine Ecology Progress Series* 249: 133-144.
5. Benemann, J., 1997. CO2 mitigation with microalgae systems. Energ. Convers. Manag., 38: 475-479.
6. Campbell P K, T Beer, D Batten (2012) Greenhouse Gas Sequestration By Algae –Energy And Greenhouse Gas Life Cycle Studies. Transport Biofuels Stream, CSIRO Energy Transformed Flagship PB1, Aspendale, Vic. 3195, Australia
7. Chakraborty P, T Acharyya, P V R Babu and D Bandhyopadhyay (2011) Impact of salinity and pH on phytoplankton community in a tropical freshwater system: An investigation with pigment analysis by HPLC. Journal of Environmental Monitoring vol.13(3): 614-620
8. Chi Z, O'Fallon JV, Chen S Trends Biotechnol (2011) Bicarbonate produced from carbon capture for algae culture. 29(11):537-41. doi: 10.1016/j.tibtech.2011.06.006
9. Chung IK, Beardall J, Mehta S, Sahoo D and Stojko vie S (2011) Using marine macroalgae for carbon sequestration: a critical appraisal; *Journal of Applied Phycology* 23:877–886.
10. Cohen RA and Fong P (2005) Experimental evidence supports the use of δ^{15} N content of the opportunistic green macro alga *enteromorpha intestinalis* (chlorophyta) to determine nitrogen sources to estuaries; Journal of Phycology 41: 287–293.
11. Coles, SM (1979) Benthic microalgal populations on intertidal sediments and their role as precursors to salt marsh development. In: Jefferies, RL & AJ Davy, eds. Ecological processes in coastal environments. Blackwell Scientific Publications, Oxford, UK pp 25-42
12. Dawes C J, C Kovach and M. Friedlander (1993) Exposure of Gracilaria to various environmental conditions II. The effect on fatty acid composition. Botanica Marina 36: 289-206
13. Fong P, Boyer KE and Jedler JB (1998) Developing an indicator of nutrient enrichment in coastal estuaries and lagoons using tissue nitrogen content of the opportunistic alga, *Enteromorpha intestinalis* (L. Link); *Journal of Experimental Marine Biology and Ecology* 8(3): 251–258.
14. Grasshoff, K. 1983. Determination of nutrients, p. 125–187.In K. Gras-shoff, M. Ehrhard, K. Kremling [eds.], Methods of seawater analysis. Verlag Chemie.
15. Guha Bakshi B N, P Sanyal, K R Naskar (1998) Sunadarban Mangals. Naya Prakash, Kolkata, Pp 771-778
16. Kaladharan P, S Veena and E Vivekanandan (2011) Working Paper, Visakhapatnam Regional Centre of Central Marine Fisheries Research Institute, Visakhapatnam 530 003, India
17. Kamar K and Fong P (2000) A fluctuating salinity regime mitigates the negative effects of reduced salinity on the estuarine macroalga, *Enteromorpha intestinalis* (L.) link; *Journal of Experimental Marine Biology and Ecology* 254: 53-69.
18. Kamar K and Fong P (2001) Nitrogen enrichment ameliorates the negative effects of reduced salinity on the green macroalga *Enteromorpha intestinalis*; *Marine Ecology Progress Series* 218: 87-93.

19. Khan S and Satam S B (2003) Seaweed Mariculture: scope snd potential in India. Aquculture Asia 8: 26-29
20. Liua W, Doris W T , Donald M. Andersonb, Paul K S Lama & Rudolf S S Wua (2010) Effects of nutrients, salinity, pH and light: dark cycle on the production of reactive oxygen species in the alga Chattonella marina. Working paper No 162, Centre for Coastal Pollution and Conservation, City University of Hong Kong, Kowloon, Hong Kong SAR, China
21. Martins I, Oliveria JM, Flindt MR and Marques JC (1999) The effect of salinity on the growth rate of the macroalgae *Enteromorpha intestinalis* (Chlorophyta) in the Mondego estuary (west Portugal); *Acta Oecologica* 20(4): 259–265.
22. McAvoy KM and Klug JL (2005) Positive and negative effects of riverine input on the estuarine green alga *Ulva intestinalis* (syn. *Enteromorpha intestinalis*) (Linneaus); *Hydrobiologia* 545:1-9.
23. Montague CL & RG Wiegert (1990) Salt marshes. In: Myers, RL & JJ Ewel, eds. Ecosystems of Florida. UCF Press, Orlando, FL, USA, 765 pp
24. Odum WE & JK Hoover (1988) A comparison of vascular plant communities in tidal freshwater and saltwater marshes. In: Hook, DD, McKee Jr., WH, Smith, HK, Gregory, J, Burrell Jr., VG, DeVoe, MR, Sojka, RE, Gilbert, S, Banks, R, Stozy, LH, Brooks, C, Matthews, TD & TH Shear, eds. The ecology and management of wetlands, volume 1: ecology of wetlands. Croom Helm. London, UK, pp 526-534
25. Odum WE (1988) Comparative ecology of tidal freshwater and salt marshes. Annual Review of Ecology and Systematics 19: 147-176
26. Ravindranath, N.H. and P.R. Bhat, 1997. Monitoring of carbon abatement in forestry projects-case study of western ghat project, Mitigation and adaptation strategies for Global change, 2: 217-230.
27. Reed and Russel (1979) Adaptation to salinity stress in populations of *Enteromorpha intestinalis* (L.) Link; *Estuarine and Coastal Marine Science* Volume 8, Issue 3, March 1979, Pages 251–258.
28. Richmond, A., 2000. Microalgal biotechnology at the turn of the millennium: a personal view. J. Appl. Phycol., 12: 441-451.
29. Sen Neera and Naskar K R (2003) Algal Flora of Sundarbans Mangal. Daya Publishing House, Delhi, Pp 318-327
30. Sousa AI, Martins I, Lillebo AI, Flindt MR and Pardal MA (2007) Influence of salinity, nutrients and light on the germination and growth of *Enteromorpha* sp. Spores; *Journal of Experimental Marine Biology and Ecology* 341: 142–150.
31. Sudhakar, K & M. Premlatha (2012) Theoretical Assessment of Algal Biomass Potential for Carbon Mitigation and Biofuel Production. Iranica Journal of Energy & Environment 3 (3): 232-240, 2012
32. Wiegert RG & BJ Freeman (1990) Tidal marshes of the southeast Atlantic coast: a community profile. US Department of Interior, Fish and Wildlife Service, Biological Report 85 (7.29). Washington, DC
33. Williams, P.J.L. and L.M.L. Laurens, 2010. Microalgae as biodiesel and biomass feedstocks: review and analysis of the biochemistry, energetics and economics, Energy Environ, Sci., 3: 554-590.

Community meeting

Field Preparation

Community training workshop

Scientific research on field

Harvesting

Processing

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