

## Stored Carbon in Dominant Seaweeds of Indian Sundarbans

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### ABSTRACT

The stored carbon in the thallus of three seaweed species (*Enteromorpha intestinalis*, *Ulva lactuca* and *Catenella repens*) was estimated in three different seasons (pre-monsoon, monsoon and post-monsoon) from four sampling localities in the deltaic ecosystem of Indian Sundarbans (21°40' N to 22°40' N and 88°03' E to 89°07' E). The average stored carbon content varied from 1022.18 g m<sup>-2</sup> (during monsoon) to 1067.02 g m<sup>-2</sup> (during pre-monsoon) in *Enteromorpha intestinalis*. In *Ulva lactuca*, the stored carbon ranged from 46.41 g m<sup>-2</sup> (during post-monsoon) to 152.43 g m<sup>-2</sup> (during pre-monsoon). In case of *Catenella repens*, the range of stored carbon is 13.70 g m<sup>-2</sup> (during monsoon) to 51.44 g m<sup>-2</sup> (during pre-monsoon). Amongst the seaweed species undertaken in the study, *E. intestinalis* showed uniformity in biomass between sectors ( $p_{\text{cal}} = 1.62 < p_{\text{crit}} = 18.51$ ) and seasons ( $p_{\text{cal}} = 2.43 < p_{\text{crit}} = 4.14$ ), which implies tolerance of the species to variable salinity. Highest values of stored carbon were recorded in *E. intestinalis*, which might indicate its role as potential candidate species in the blue carbon series of Indian Sundarbans deltaic complex.

**Keywords:** Seaweeds, Standing stock, Carbon content, Indian Sundarbans

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### INTRODUCTION

The seas occupies 71% of the earth's surface and plays a dominant role in regulating climate, offering great potential for fixing and removing atmospheric carbon dioxide (Raven & Falkowski, 1999; Falkowski *et al.*, 2000; Pelejero *et al.*, 2010). Although macro-vegetated marine habitats account for 2% of the sea surface, they contribute ~210–244 Tg C year<sup>-1</sup> or ~50% of all carbon sequestered

in the global coastal oceans (Duarte *et al.*, 2005). The carbon storage potential of coastal marine vegetation (mangroves, salt marshes, and seagrass meadows) could be accelerated through various management approaches such as marine area protection, marine spatial planning, area-based fisheries management, regulated coastal development and ecosystem restoration (Laffoley & Grimsditch, 2009). This important floral community, often referred to as blue carbon, is cycled through food chains and metabolic processes in seas and oceans, where it becomes bound or sequestered in natural systems (Nellemann *et al.*, 2009). Seaweeds or benthic macroalgae, being important members in the blue carbon domain, are thallophytes containing photosynthetic pigments that live either in marine or brackishwater environs. Like their terrestrial counterpart, the seaweeds can prepare their own food with the help of sunlight and nutrient present in the seawater. They occupy the intertidal zones between high tide to low tide and up to a depth where 0.01 % photosynthetic light is available.

The primary productivity potential of seaweeds is quite high. Entrapment efficiencies of solar energy have been reported to be maximum in *Enteromorpha intestinalis* (0.64%) and *Ulva lactuca* (0.43%), with an average of 0.35% by this group. A research conducted on this topic indicates that in the deltaic complex of Indian Sundarbans, *E. intestinalis* and *U. lactuca* are the most productive species, followed by *E. prolifera* and *Rhizoclonium grande* (Chaudhuri & Choudhury, 1994).

Unlike other blue carbon sectors (mangroves, seagrasses and salt marshes), kelp forests and seaweed beds do not have such sedimentary substrata. Instead, their carbon-rich biomass detaches and is broken down in food chains by organisms that range in scale from grazing animals to pelagic and seabed bacteria. Knowledge on the scale of conversion of inorganic carbon into biomass, its subsequent sinking to the seabed and its sequestration over thousands of years form the basis of understanding the oceans as a potential sink for increasing levels of atmospheric carbon dioxide (CO<sub>2</sub>). The other modes of fate of seaweed biomass depend on natural processes. The seaweed can be consumed by herbivores, whose faeces sink to the bottom and may remain there for a while. Moreover, distal portions of the fronds disintegrate during the summer season and those fragments enter the detritus food chain (Chung *et al.*, 2013). Exudation as a dissolved organic material can be a critical loss. Therefore, some of the seaweed carbon will return to the water column and be either recaptured during photosynthesis or eventually returned to the atmosphere. However, a significant fraction of the algal carbon can be sequestered on the sea floor for a long period, perhaps centuries depending on location currents, etc. (Smetacek *et al.*, 2012).

Compared to other vegetation, the carbon sequestration potential of seaweeds in estuarine and deltaic environments, are however poorly understood. In this paper, the temporal and spatial variations in biomass production and carbon content

of three major species of seaweeds (*E. intestinalis*, *U. lactuca* and *C. repens*) inhabiting two different sectors of Indian Sundarbans (western and central) with contrasting salinity have been estimated. The results of the present investigation may serve as baseline data of stored carbon in the thallophytic community of this region.

## MATERIALS AND METHODS

### *Sampling Site and Sample Collection*

The Indian Sundarbans is a mangrove dominated deltaic complex situated at the confluence of the River Ganga and the Bay of Bengal. Two sampling sectors were selected each in and around the western and central sectors in the study region (see Fig.1). The western sector of the deltaic lobe receives the snowmelt water of mighty Himalayan glaciers after being regulated through several barrages on the way. The central sector on the other hand, is fully deprived from such supply due to heavy siltation and clogging of the Bidyadhari channel in the late 15<sup>th</sup> century (Chaudhuri

& Choudhury, 1994). Contrasting salinity thus exists in the deltaic complex that has made the region a unique test bed to observe the impact of salinity on biotic community. With this background, four sampling stations (two each in western and central sectors) were selected (Table 1 and Fig.1) to analyse the data of stored carbon in the common seaweed species.

### *Sampling*

Seasonal samplings for biomass and carbon estimation of seaweed species (*E. intestinalis*, *U. lactuca* and *C. repens*) were carried out at ebb tides during May, 2012 (pre-monsoon), September, 2012 (monsoon) and December, 2012 (post-monsoon) during 2012 from the intertidal mudflats. Samples of seaweed species were scrapped and handpicked from sluice gates, mangrove trunk and concrete jetties. Immediately after collection, the thallus of each species was thoroughly washed separately in the ambient seawater, as well as with tap water, to remove adhering debris and sediments.

TABLE 1  
Sampling stations with coordinates and salient features

Station	Coordinates (Lat and Long)	Salient Features
Nayachar Island (Stn. 1)	21° 45' 24" N and 88° 15' 24" E	It is located in the Hooghly estuary and faces the Haldia Port-cum-industrial complex that houses a variety of industrial units.
Sagar South (Stn. 2)	21° 39' 04" N and 88° 01' 47" E	Situated at the confluence of the River Hooghly and the Bay of Bengal on the western sector of Indian Sundarbans.
Gosaba (Stn. 3)	22° 15' 45" N and 88° 39' 46" E	Located in the Matla Riverine stretch in the central sector of Indian Sundarbans.
Annpur in Satjelia Island (Stn. 4)	22° 11' 52" N and 88° 50' 43" E	Located in the central sector of Indian Sundarbans. Noted for its wilderness and mangrove diversity; selected as control zone.

Altogether 10 quadrants (area, 1m<sup>2</sup>) were sampled for each species randomly mixed and weighed accurately in an electronic balance (IRD Balance; Model No. 290). The biomass is expressed in g m<sup>-2</sup>.

*Carbon Estimation*

Seaweed samples were dried in a hot air oven (60°C) for 72 hrs. ([www.academia.edu/755347/seagrasses\\_and\\_seaweeds](http://www.academia.edu/755347/seagrasses_and_seaweeds)) until a constant weight was obtained. Dried

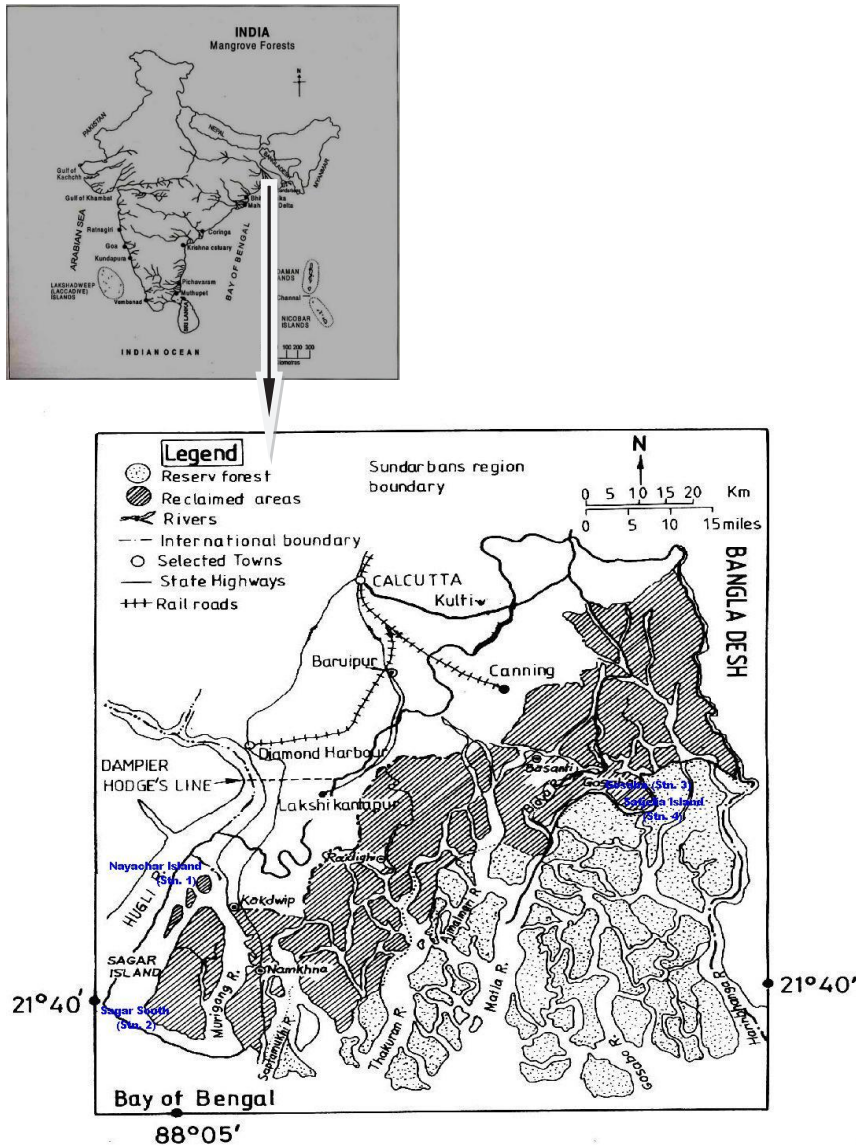


Fig. 1. Location of the sampling stations (marked in blue) in Indian Sundarbans. Stns. 1 and 2 are in the western sector and Stns. 3 and 4 are in the central sector of the study area.

sampled were ground to a fine powder. Direct estimation of percent carbon in the thallus body of each seaweed species for each season and for each sampled locations was separately carried out by Vario MACRO elemental make CHN analyzer, after grinding and random mixing the oven dried seaweed samples. This method is followed for estimating carbon percentage in coastal vegetation (Mitra *et al.*, 2011; Sengupta *et al.*, 2013). At about 990°C, the seaweed sample is mineralized. Formation of carbon monoxide is possible at this temperature even in the presence of excess oxygen. The complete oxidation is reached through a tungsten trioxide catalyst which is passed by the gaseous reaction products. The samples were finally analyzed through CHN mode, which is the most universal of the analysis mode because of the combination of the reagent design and the optimize combustion control parameters and expressed in percentage (Hedges & Stern, 1984). Calibration was done using 2, 5-Bis (5-tert-butyl-benzoxazol-2-yl) thiophene (C% = 72.53; H% = 6.09%; N% = 6.51; O% = 7.43; S% = 7.44%) as calibration standard. Our observation did not show much deviation from the standard (for carbon =  $\pm 1.39\%$ ).

#### *Statistical Analysis*

Sector-wise and station-wise data on biomass and carbon content during different seasons in three seaweed species of Indian Sundarbans were subject to statistical analyses. Analysis of variance (ANOVA) expressed by Wellman (1998) was used

to evaluate whether biomass and carbon content varied significantly between (i) stations (ii) the two sectors and (iii) seasons. Possibilities ( $p < 0.01$ ) were considered statistically significant. All statistical calculations were performed with Statistical Package for Social Sciences (SPSS) 14.0 for Windows.

## **RESULTS AND DISCUSSION**

The recent thrust on global warming phenomenon has generated tremendous interest in the carbon-storing ability of coastal vegetation. Carbon fixation by seaweeds forms an important bio-mechanism to diminish the increment of CO<sub>2</sub> in the atmosphere and thereby alleviate the trend toward global warming. Primary producers of coastal and marine biotopes such as microalgae, seaweed and seagrass are excellent carbon sequestering agents than their terrestrial counterparts (Zou, 2005). The carbon stored in the marine and estuarine floral species is referred to as blue carbon and a number of literatures have addressed the importance of the community to climate change (Nellemann *et al.*, 2009; Duarte *et al.*, 2005). Several researches have been initiated on the carbon fixation capacity of seaweeds for the purpose of developing blue carbon register. One of the important problems in the sphere of blue carbon is the turnover time of the marine plants. According to Smith (1981), most of the terrestrial plants have a relatively high biomass and have a turnover time of several years to decades. On contrary, the turnover time of marine seaweeds is about one year



(Muraoka, 2004), although they have highest biomass among the marine ecosystems. This means that the seaweeds are more effective carbon sinks than phytoplankton, but less effective than the terrestrial ecosystem. The carbon sequestration in this unique producer community is a function of biomass production capacity, which in turn depends upon interaction between edaphic, climate and topographic factors of an area (Mitra *et al.*, 2011; Jana *et al.*, 2013). Hence, results obtained at one region may not be applicable to another. Therefore, region-based potential of storing and sequestering carbon by coastal vegetation on different land types or substratum characteristics needs to be estimated (Mitra *et al.*, 2011). The seaweed carbon is acquired through photosynthetic and non-photosynthetic processes. Carbon assimilation in marine algae is largely accomplished by light dependent photosynthesis. However, there are active and significant light-independent carboxylation pathways operating as well (Cabello-Pasini, 1996). Cabello-Pasini and Alberte (2001) indicated that photosynthetic and non-photosynthetic carboxylation pathways are regulated, atleast partially, by the activity of Ribulose 1, 5 bis-phosphate carboxylase oxygenase (RUBISCO) and phosphoenolpyruvate carboxylase (PEPCK). Furthermore, differences between the *in vivo* and *in vitro* carboxylation in the thallus of *Laminaria setchellii* suggest structural, biochemical and functional differences that impact the dynamics of production of kelp species. Photosynthetic and light-independent carbon fixation

(LICF) processes in marine algae have been shown to vary as a function of seasonal changes in irradiance and temperature, and carbohydrate levels in the tissue (Cabello-Pasini & Alberte, 1997). The seasonal variation of carbon content in seaweeds is attributed to variation in their biomass. The quantity of algal biomass that accumulates is normally stated as the amount of carbon fixed by photosynthesis per unit area of space or volume, per unit of time. Most estimates are expressed as net primary production, taking into account the costs of respiration (Chung *et al.*, 2013).

#### *Enteromorpha intestinalis*

The biomass of *E. intestinalis* ranged from 2844.55 gm m<sup>-2</sup> (at Stn. 3, during pre-monsoon 2012) to 3169.44 gm m<sup>-2</sup> (at Stn. 1, during post-monsoon 2012). The carbon content exhibited lowest value at Stn. 3 (917.62 g m<sup>-2</sup> during monsoon 2012) and highest at Stn. 2 (1141.67 g m<sup>-2</sup> during pre-monsoon 2012) (Fig.2). It is interesting to note that the order of biomass of *E. intestinalis* is post-monsoon (3057.42 g m<sup>-2</sup>) > monsoon (3008.08 g m<sup>-2</sup>) > pre-monsoon (2967.29 g m<sup>-2</sup>) (Table 2). However, the carbon content varied as per the order pre-monsoon (1067.02 g m<sup>-2</sup>) > post-monsoon (1039.14 g m<sup>-2</sup>) > monsoon (1022.18 g m<sup>-2</sup>) (Table 3). The biomass of the species exhibited an almost uniform value in both the sectors and three seasons ( $p < 0.01$ ) as revealed through ANOVA (Table 4), but the carbon content showed a significant

spatial and seasonal variations ( $p < 0.01$ ) (Table 5). The highest carbon content in pre-monsoon may be attributed to congenial temperature and solar radiation in the study area that have positive influence on the photosynthetic rate.

*Ulva lactuca*

Fig.3 shows the seasonal variations of biomass and carbon content in *U. lactuca* that exhibit significant seasonal and spatial

variations ( $p < 0.01$ ) (Tables 4 and 5). The biomass ranged from  $92.34 \text{ g m}^{-2}$  (at Stn. 1, during monsoon 2012) to  $786.52 \text{ g m}^{-2}$  (at Stn. 2, during pre-monsoon 2012). The carbon content showed the lowest value at Stn. 1 during monsoon 2012 ( $25.11 \text{ gm m}^{-2}$ ) and highest at Stn. 2 during pre-monsoon 2012 ( $245.55 \text{ g m}^{-2}$ ). In case of *U. lactuca* the order of biomass is pre-monsoon ( $495.84 \text{ g m}^{-2}$ ) > monsoon ( $249.12 \text{ g m}^{-2}$ ) > post-monsoon ( $160.49 \text{ g m}^{-2}$ ) (Table 2), whereas, the carbon content varied as per the order

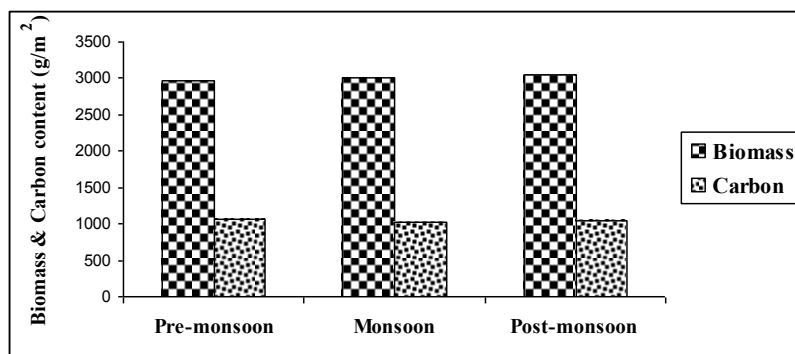


Fig.2: Seasonal variation in Biomass and Carbon content of *Enteromorpha intestinalis* during 2012

TABLE 2

Average seasonal variation in biomass ( $\text{gm m}^{-2}$ ) of seaweeds with standard deviation

Species	Season		
	Pre-monsoon	Monsoon	Post-monsoon
<i>Enteromorpha intestinalis</i>	2967.29 ± 26.85	3008.08 ± 30.63	3057.42 ± 33.25
<i>Ulva lactuca</i>	495.84 ± 9.01	249.12 ± 7.36	160.49 ± 5.54
<i>Catenella repens</i>	229.94 ± 4.52	66.47 ± 2.81	132.0 ± 1.73

TABLE 3

Average seasonal variation in carbon content ( $\text{gm m}^{-2}$ ) of seaweeds with standard deviation

Species	Season		
	Pre-monsoon	Monsoon	Post-monsoon
<i>Enteromorpha intestinalis</i>	1067.02 ± 2.85	1022.18 ± 1.93	1039.14 ± 2.03
<i>Ulva lactuca</i>	152.43 ± 1.88	70.52 ± 1.29	46.41 ± 1.10
<i>Catenella repens</i>	51.44 ± 0.93	13.70 ± 0.70	27.58 ± 0.62

pre-monsoon (152.43 g m<sup>-2</sup>) > monsoon (70.52 g m<sup>-2</sup>) > post-monsoon (46.41 g m<sup>-2</sup>) (Table 3). The highest values of biomass and carbon in *U. lactuca* are again the result of synergistic effect of temperature and solar radiation.

*Catenella repens*

The biomass of *C. repens* collected from the selected stations ranged from 41.30 (at Stn. 1, during post-monsoon 2012) to 312.39 g m<sup>-2</sup> (at Stn. 2, during pre-monsoon 2012). The order of biomass is pre-monsoon

(229.94 g m<sup>-2</sup>) > post-monsoon (132.00 g m<sup>-2</sup>) > monsoon (66.47 g m<sup>-2</sup>) for *C. repens* (Table 2). In the thallus body of the species, the values of stored carbon ranged from 8.03 (at Stn. 1, during post-monsoon 2012) to 74.51g m<sup>-2</sup> (at Stn. 2, during pre-monsoon 2012) (Fig.4). The carbon content in this species varied as per the order pre-monsoon (51.44 g m<sup>-2</sup>) > post-monsoon (27.58 g m<sup>-2</sup>) > monsoon (13.70 g m<sup>-2</sup>) (Table 3). ANOVA results (Table 4 and 5) also confirm significant spatial and seasonal variations in the biomass and carbon content of the species (p < 0.01).

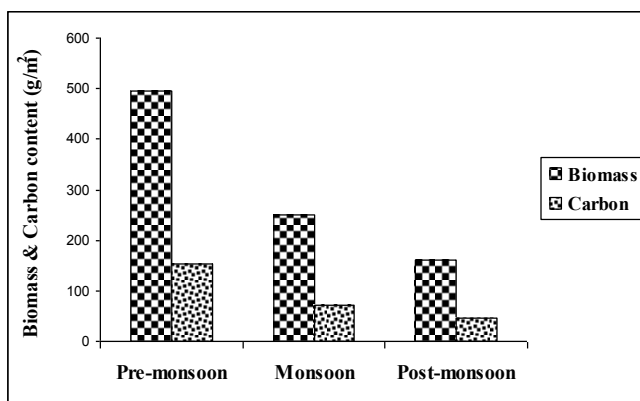


Fig.3: Seasonal variation in Biomass and Carbon content of *Ulva lactuca* during 2012

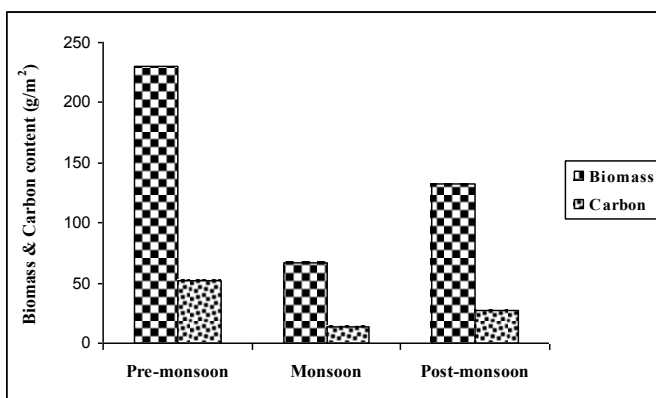


Fig.4. Seasonal variation in Biomass and Carbon content of *Catenella repens* during 2012



TABLE 4  
Results of ANOVA for seaweed standing stock in Indian Sundarbans during (pre-monsoon, monsoon and post-monsoon seasons of 2102)

Variable	F <sub>cal</sub>	F <sub>crit</sub>
<i>Enteromorpha intestinalis</i>		
Between sectors	1.62	18.51
Between stations	7.77	4.76
Between seasons	2.43	4.14
<i>Ulva lactuca</i>		
Between sectors	1.12	18.51
Between stations	3.73	4.76
Between seasons	10.32	4.14
<i>Catenella repens</i>		
Between sectors	7.38	18.51
Between stations	6.89	4.76
Between seasons	14.70	4.14

TABLE 5  
ANOVA for carbon content in seaweeds in unit area in Indian Sundarbans during 2102 (pre-monsoon, monsoon and post-monsoon seasons)

Variable	F <sub>cal</sub>	F <sub>crit</sub>
<i>Enteromorpha intestinalis</i>		
Between sectors	25.15	18.51
Between stations	38.31	4.76
Between seasons	4.64	4.14
<i>Ulva lactuca</i>		
Between sectors	0.84	18.51
Between stations	3.54	4.76
Between seasons	10.34	4.14
<i>Catenella repens</i>		
Between sectors	5.38	18.51
Between stations	5.86	4.76
Between seasons	13.23	4.14

The present study indicates that carbon storage in seaweed species is species-specific in nature. The highest value is observed in *E. intestinalis* (average 1042.77 g m<sup>-2</sup>), followed by *U. lactuca* (average 89.79 g m<sup>-2</sup>) and *C. repens* (average 32.64 g m<sup>-2</sup>). Similar observation was also documented through a study done by Muraoka (2004),

where the carbon absorption capacity by seaweeds varied as per the order *Laminaria* > *Ecklonia* > *Sargassum* > *Gelidium*. The species-wise variation of stored carbon may be attributed to the morphological structure of the seaweed. Unlike *U. lactuca* and *C. repens*, the extremely coiled and spiral structure of *E. intestinalis* exposes more area of the species to ambient water, which enables relatively more capture of carbon through diffusion. Due to presence of high surface area per unit volume of the *E. intestinalis* thallus, the absorption of carbon dioxide from the ambient water is more compared to *U. lactuca* and *C. repens*.

In the present study, *C. repens* is common seaweed under rhodophyceae which is characterized by reddish phycobilin pigments - phycoerythrin and phycocyanin that mask the colour of the chlorophylls (the major photosynthetic machinery that synthesizes organic carbon through photosynthesis). This masking effect may be one of the reasons for lowest carbon content in *C. repens*.

Some interesting observations were documented with respect to biomass and stored carbon in the selected seaweeds species. These observations also point towards the tolerance of the species to ambient environment which is an important criterion for being a potential store house of carbon. In case of *E. intestinalis*, the ANOVA reflects no significant difference in biomass between sectors and seasons which shows a wide range of tolerance of this species to salinity (Table 2). It has also been documented that *E. intestinalis* can thrive

luxuriantly even in freshwater (Kamer & Fong, 2000). *U. lactuca* also exhibits almost similar trend with no statistically significant difference between sectors although the seasonal difference was observed. In case of *C. repens*, sector-wise differences in biomass were not discernible, but temporal variation was documented. A comparative study of biomass between three seaweed species points out that *E. intestinalis* is one of the most potential species for carbon sequestration because of its uniform growth and biomass in different salinity regimes and seasons. Indian Sundarban is characterized with dynamic seasonal salinity profile with high value during pre-monsoon followed by monsoon and post-monsoon seasons. The spatial variation of salinity is also a unique feature of Indian Sundarbans (Mitra *et al.*, 2009; Mitra *et al.*, 2011; Sengupta *et al.*, 2013). In some areas of deltaic

complex (particularly at station 1) the pre-monsoon salinity of ~ 10 psu drops down to 0 psu during monsoon (Mitra *et al.*, 2009). *E. intestinalis* can withstand such a drastic oscillation of salinity, and hence, can be a potential store house of carbon throughout the year (Fig.5). Except few experimental studies that observed the rate of absorption of CO<sub>2</sub>, studies on seaweed carbon are scanty, particularly no baseline data are available on the carbon content in seaweed species collected from different salinity profile for comparative purposes. An experimental study conducted by Kaladharan *et al.* (2009) revealed that the green seaweed *Ulva lactuca* can register 100 % utilization of CO<sub>2</sub> towards carbon fixation from ambient water and beyond 15 mg/l there is a decline of 16%. The researchers also estimated that the seaweed biomass along the Indian coast is capable of utilizing



Fig.5: *E. intestinalis*: the most widely available seaweed species in Indian Sundarbans with highest carbon content

9052 t CO<sub>2</sub>d<sup>-1</sup> against emission of 365 t CO<sub>2</sub> d<sup>-1</sup> indicating a net carbon credit of 8687 t d<sup>-1</sup>.

The findings of the present research suggest that in the aquacultural sector, seaweed culture must be emphasized not only for their nutritional value, but also for their efficiency in storing carbon.

Due to the absence of thick sediment or soil layer beneath, seaweed beds obviously they lack functionality as large carbon sinks. It is, therefore, unlikely that the benefit of these marine resources can be addressed through carbon markets and management strategies that are strictly based on long term (centennial) sequestration. However, there is substantial potential to develop seaweed CDM methodologies by capturing carbon through algal photosynthesis and using the resulting biomass as a substitute for fossil hydrocarbons.

## CONCLUSION

Seaweeds of Indian Sundarbans are potential store house of carbon. The storage efficiency, however, appears to be species-specific with highest carbon content in *Enteromorpha intestinalis*, followed by *Ulva lactuca* and *Catenella repens*. The stored carbon in the studied seaweed species also exhibits a distinct seasonal trend with highest values recorded during pre-monsoon. The uniformity of biomass of the *E. intestinalis* through seasons and sectors suggests that this species may tolerate wide fluctuations in the environmental variables. This characteristic is extremely important for a uniform carbon stock in a species throughout the year and requires a long

term study to test and further validate the conclusion.

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