

**P. Kaladharan**

ICAR- Central Marine Fisheries Research Institute, Kochi

## Introduction

Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide ie, CCS (carbon capture and storage). This is one of the methods of reducing the levels of carbon di oxide (CO<sub>2</sub>) in the atmosphere with the goal of reducing climate change impacts globally. The Paris Conference on Climate Change has set certain targets to reduce greenhouse gasses (GHGs) from atmosphere. To achieve these targets, GHGs should actively be removed from atmosphere and stored safely. The capture and storage of carbon will be key to reducing the future emissions of GHGs. Carbon sequestration is being carried out by many ways. Sequestration of carbon by any living forms especially plants is regarded as bio sequestration of carbon. Storing carbon in underground geological formations is regarded as geo sequestration and deep in ocean means ocean sequestration, whose consequence is not known and cost intensive.

## Carbon in atmosphere and cause of its rise

It is well known that the global average concentration of atmospheric CO<sub>2</sub> rose to 387 parts per million (ppm) in December 2009 (ESRL/NOAA 2009) to 409 ppm on 16 Sept 2018 (NASA, Global Climate Change, 2018) the highest level it has reached over the past 800 000 years (Lüthi et al. 2008) and more than 38% above the pre-industrial value of roughly 280 ppm (Raupach and Canadell 2008). It is generally agreed that the anthropogenic greenhouse gas emission in the globe during the year 2000 - 2010 were the highest in history (IPCC, 2014). CO<sub>2</sub> absorbs and emits infrared radiation at wavelengths of 4.26 µm and 14.99 µm and hence known as GHG which has a vital role to play in regulating the Earth's surface temperature. CO<sub>2</sub> is one of the heat-trapping GHGs which is

released through human activities like deforestation and burning fossil fuels (Solomon et al. 2007). Increasing levels of dissolved CO<sub>2</sub> cause significant drop in pH of seawater which in turn adversely affects the marine life and coastal ecosystem.

### **Why is carbon sequestration needed?**

Another reason carbon dioxide is important in the earth system is that it dissolves into the ocean like the fizz in a can of soda. It reacts with water molecules, producing carbonic acid and lowering the ocean's pH. Since the start of the Industrial Revolution, the pH of the ocean's surface waters has dropped from 8.21 to 8.10. This drop in pH is called ocean acidification. A drop of 0.1 may not seem like a lot, but the pH scale is logarithmic; a 1-unit drop in pH means a tenfold increase in acidity. A change of 0.1 means a roughly 30% increase in acidity. Increasing acidity interferes with the ability of marine life to extract calcium from the water to build their shells and skeletons. Number of studies suggest that the current trend of pH reduction and increasing levels of dissolved CO<sub>2</sub> will have negative impacts on number of marine organisms;

- Calcification impairment in corals (Jokiel, 2008; Marubini et al., 2008).
- Morphological and compositional changes in the skeletons of the newly recruited corals (Cohen et al., 2009).
- Promotes shell dissolution in marine paper shell, *Nucella lamellose* (Nienhuis et al., 2010).
- Recruitment failure in the threatened Caribbean coral, *Acropora palmata* (Albright et al., 2010).
- Dissolution of marine bivalve shells and spines of seurchin (Kaladharan et al., Communicated).

### **Blue carbon sinks**

The carbon (C) sequestered in vegetated coastal ecosystems, especially mangrove forests, seagrass meadows and salt marshes, has been termed *Blue Carbon* and these coastal habitats are known as Carbon sinks. Although their global area is one to two orders of magnitude lesser than that of terrestrial habitats, the contribution of vegetated coastal ecosystems per unit area to long-term C sequestration is much greater, in part because of their efficiency in trapping suspended matter and associated organic C during tidal inundation. It is a point of serious concern that these carbon sinks are being lost at faster rates. Marine primary producers such as planktonic algae and seaweeds are known to

relegate excess CO<sub>2</sub> from seawater (Kaladharan *et al.*, 2009) although they are not considered as true carbon sequesters as the carbon fixed is recycled soon upon decay. Marine macrophyte communities tend to produce excess organic matter that can be stored in sediments or exported to adjacent ecosystems. Seaweeds and seagrasses store about 0.4 and 16% of their net primary production in the sediments, respectively (Duarte and Cebrián, 1996), and some of the excess organic matter they produce can be exported to adjacent waters. The export of organic matter has been reported to account, on average, for 25 and 44% of the net primary production of macroalgae and seagrass, respectively. Dissolved organic carbon (DOC) release from macroalgae represented from 1 to 39% of gross primary production compared to only <5% from seagrasses (Khailov and Burlakova, 1969; Brilinsky, 1977; Pregnall, 1983).

### **Experiment to demonstrate carbon sequestration by seaweeds**

To demonstrate the carbon sequestration potential of seaweeds, following experiment has been designed.

- Live samples of seaweeds, two species each from three groups of seaweeds to be collected.
- Wash thoroughly with excess seawater to remove sand, debris and attached phytoplankton and fauna if any and bring to the laboratory.
- Acclimatize them for three days in a 500 l tank with running seawater (32 PSU) and 12 hour photoperiod.
- Weigh 5g of each seaweed species in separate glass bottles (1 lit) with suitable replicates and label the bottles accordingly.
- Filter the seawater of 32 PSU to remove phytoplankton through 0.45 $\mu$  filter paper.
- Fill carbonated seawater (0, 50, 100, 150 and 200 ppm, using a soda maker) and keep them airtight with lids.
- Check the pH and dissolved CO<sub>2</sub> (Dye, 1958, shown below) levels in each bottle and record the values in data register.
- Introduce each species of seaweeds weighed already in one set of bottles separately and mark them as Experimental and those without seaweeds as Control.
- Incubate them under sunlight for two hours through a running water filter to avoid rise in temperature.
- After two hours quickly check the pH and CO<sub>2</sub> levels in each bottle and record the changes if any.

### **Estimation of dissolved Carbon dioxide (Dye, 1958)**

#### **Reagents:**

- Phenolphthalein indicator

- Standard Sodium hydroxide solution (0.022N): Dilute 22.7 ml of 1 N NaOH (40 g/L) to one L CO<sub>2</sub> free distilled water in a volumetric flask. One ml is equivalent to 1.0 mg of CO<sub>2</sub>. Prepare just before estimation.

OR

- Standard Sodium carbonate solution (0.045N): Dissolve 2.407 g anhydrous sodium carbonate in one L CO<sub>2</sub> free distilled water in a volumetric flask. One ml is equivalent to 1.0 mg of CO<sub>2</sub>. Prepare just before estimation.

***Procedure:***

Collect water samples in a glass stoppered pyrex bottle and completely fill the bottle without leaving any air space.

Add 5-10 drops of Phenolphthalein indicator and shake well. (In the absence of dissolved CO<sub>2</sub> a pink colour appears and absence of pink colour formation indicates the presence of dissolved CO<sub>2</sub>).

Carefully siphon out 100 ml of the sample into 250 ml conical flask and then titrate with standard Na<sub>2</sub>CO<sub>3</sub>/ NaOH solution.

Stir gently using a plunger stirrer until the pink color persists for 30 sec.

***Calculation:***

$$\text{Quantity of dissolved CO}_2 \text{ (mg/l)} = \frac{\text{ml alkali used} \times 1000}{\text{Vol. of sample used}}$$

If one is interested to see the primary productivity of seaweed samples in the presence of CO<sub>2</sub>, siphon out water from each bottles carefully without entangling any air bubbles into 125ml BOD bottles for determining oxygen produced for determining the productivity (GPP and NPP) were measured using Winkler's method. In that case one should measure the dissolved oxygen before the incubation in light.

The difference between the levels of CO<sub>2</sub> before the start of incubation and after the incubation period formed the carbon sequestration potential of different species of seaweeds.

Seagrasses and seaweeds grow more rapidly under elevated CO<sub>2</sub> levels (Zimmerman et al., 1997; Unsworth et al., 2012; Manzello et al., 2012). Seaweed beds along the coastal region act as net sink of atmospheric CO<sub>2</sub>. Seaweed

communities are strongly autotrophic, generating far more organic matter through photosynthesis than consumed by respiration in the ecosystem, and are thus responsible for much of CO<sub>2</sub> capture in marine vegetated habitats (Duarte and Cebrian, 1996). Seaweed mariculture has been recognized as one of the climate resilient aquaculture techniques to mitigate ocean acidification (Kaladharan, 2013; Zacharia et al., 2015; Duarte et al., 2017). An upper limit to the CO<sub>2</sub> capture potential of seaweed aquaculture can be calculated at 2.48 million tons of CO<sub>2</sub> (0.68 Tg C) per year. This upper limit assumes that all of the 27.3 million tons fresh weight produced in 2014 be dedicated to carbon capture with a 100% yield given by the average carbon content of 24.8% of seaweed dry weight (Duarte, 1992). From this it is presumed that one ton wet weight of seaweed can sequester 0.0984 ton of CO<sub>2</sub> per year. Hence large scale seaweed mariculture along the coastal area is the only green and cost effective method of carbon sequestration while the harvested biomass can support alternative livelihood to the coastal fishers.

Table: Change in CO<sub>2</sub> and pH in carbonated seawater with or without live seaweed samples

(Species: ..... )

| Bottle id | CO <sub>2</sub> (ppm) spiked | Initial CO <sub>2</sub> (ppm) | Initial pH | Wt of seaweed (gm) | CO <sub>2</sub> After 2 hours | pH after 2 hours | Δ pH | Δ CO <sub>2</sub> |
|-----------|------------------------------|-------------------------------|------------|--------------------|-------------------------------|------------------|------|-------------------|
| 1         | 0*                           |                               |            | 0                  |                               |                  |      |                   |
| 2         |                              |                               |            | 5.0                |                               |                  |      |                   |
| 3         | 50                           |                               |            | 0                  |                               |                  |      |                   |
| 4         |                              |                               |            | 5.0                |                               |                  |      |                   |
| 5         | 100                          |                               |            | 0                  |                               |                  |      |                   |
| 6         |                              |                               |            | 5.0                |                               |                  |      |                   |
| 7         | 150                          |                               |            | 0                  |                               |                  |      |                   |
| 8         |                              |                               |            | 5.0                |                               |                  |      |                   |
| 9         | 200                          |                               |            | 0                  |                               |                  |      |                   |
| 10        |                              |                               |            | 5.0                |                               |                  |      |                   |
| 11        | 250                          |                               |            | 0                  |                               |                  |      |                   |
| 12        |                              |                               |            | 5.0                |                               |                  |      |                   |
| 13        | 300                          |                               |            | 0                  |                               |                  |      |                   |
| 14        |                              |                               |            | 5.0                |                               |                  |      |                   |

\*Triplicates for each concentration of CO<sub>2</sub> used

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