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An Experimental Study on the Carbon Flux within the Coral Community

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Authors' contributions

This work was carried out in collaboration between all authors. Author PMM managed the experiment, collecting the data and processing of manuscript and also managed the Tank D with authors PN and RKK. Author CJ managed the Tank C and literature survey. Authors MM and JS managed the Tank A and data collection. Authors VVU and PP maintained the Tank B and data collection. Author SC provided the details of the atmospheric carbon and its impact in sea water. The group worked individually and collected the data to avoid any bias on the experiment. All authors read and approved the final manuscript.

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ABSTRACT

The flux of carbon within the coralline ecosystem has been a subject of great interest in the recent decades. So far several studies had been conducted to understand actual process of carbon transfer within this system and it is an elusive factor on science because of the complex process. An attempt had been made to delineate the source and sink of carbon within the coral ecosystem by establishing small experimental set up in the present study. For these study, four experimental tanks, each consisted of a different community of coral ecosystem was set up in Pondicherry University, Port Blair, Andaman Islands, India. The Tank A was set up with a most prevalent sponge species *Stylissa massa,* in this part of the study area, Tank B consisted of sponge *Lamellodysidea* spp., Tank C consisted of macroalgae community i.e. of *Padina* spp. of an area of 620 cm^2 and Tank D had a soft coral *Sarcophyton* spp. All these species were collected from Burmanallha, a region characterized by rich species diversity. The results indicated that the algal and sponge community provided carbon to support the growth of coral reefs. Coral utilized this carbon for their growth. It was also observed that fluctuation of environmental and physical parameters induced biological stress within the life forms resulted in the release of excess

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inorganic carbon to the surrounding water. Whenever, the opportunity were available this carbon was utilized by the system itself and managed full extent without any excess carbon.

Keywords: Macroalgae; sponges; soft coral; DOC; DIC; biological stress.

1. INTRODUCTION

Coral reefs are considered one of the most productive ecosystems despite of their oligotrophic nature. They also contribute to biogeochemical cycles, planet's biodiversity and provide a livelihood for millions of people. This highly established and diversified community is self sustained with strict nutrient recycle. Various studies have shown that coral systems rank among the most productive of marine ecosystems even with the insufficient supply of most essential nutrients such as nitrogen and phosphorous. On the other hand, the continuous release of organic C-rich material by reef-building corals contributes significantly to the biogeochemical processes and rapid nutrient recycling within the coral reef ecosystems. The coral reefs are known for its tight recycling of nutrients in the system, particularly in the corals, in which tiny plants live together in a symbiosis that conserves key nutrients quite effectively.

Organic matter (OM) is a key component that helps to support this major community. The concentration of organic carbon (OC) in sea water is a measure of the OM content. It is assumed that OC constitutes 45% of OM, although other proportions have been reported [1]. Organic matter can be separated into particulate (POM) and dissolved (DOM) fractions. Although the DOM/POM ratio can vary quite widely, its value in coastal areas is from 4 to 6. In relation to the concentrations of dissolved carbon fraction (both inorganic and organic), POC makes up rather a small part of the total carbon pool and DOC is considered the largest organic reservoir in the ocean. Coastal and marginal seas play a key role in the global carbon cycle by linking terrestrial, oceanic and atmospheric reservoirs [2]. Biological process is considered to be the primary factor controlling the accumulation of DOC, but there is a poor correlation between carbon storage as DOC and rates of primary production [3]. Inorganic carbon is obtained from dissolution of calcium carbonate shells, decomposition of organic matters by microorganisms and from atmospheric input.

The ocean is the largest body of water which rapidly exchanging global carbon reservoirs and a major sink for the anthropogenic carbon. The ocean has absorbed carbon dioxide (CO_2) from the atmosphere and is causing chemical changes in this system. The uptake of CO_2 has led to reduction of the pH of surface seawater of 0.1 units, equivalent to a 30% increase in the concentration of hydrogen ions (acidic). The tropical and subtropical seas, corals are severely affected with this implication, for its stability and longevity of the reefs, as well as their associated organisms.

Various experimental studies have been conducted around the world to understand carbon flux within coral reef ecosystem. Sponge is one among the coral reef community provide OC to this environment. Experimental studies on sponge *Theonella swinhoei* by Yahel et al. [4] suggested that this sponge removed bulk quantity (10±7μMC/L) of DOC from the surrounding waters. A laboratorial study carried out by de Goeij et al. [5] on sponge *Halisarca caerulea* explained that it played a major role in recycling the energy within the system and consuming (13.1±2.5 μMC/hr) DOC released by marine macrophytes in experimental conditions, as previously reported by Brylinsky [6], Wetzel and Penhale [7], Moriarty et al. [8], Haas et al. [9] and Kaldy [10]. According to Khailov and Burlakova [11], Brylinsky [6] and Pregnall [12] using ^{14}C addition experiments in the laboratory studies, the DOC release from macroalgae accounted to 1 to 39% of gross primary production. The experimental study by Haas et al. [9] concluded that the net DOC release from fragments of sea grass and algal specimens incubated in beaker under natural daylight conditions were around 1.3±0.5 $mmolCm^{-2}h^{-1}$ and 0.2±0.25 $mmolCm^{-2}h^{-1}$, respectively. Other than this, stress related effect on the biological and metabolic activities during low tide temperature have been reported by various workers [13-15].

However, in Indian context, that also in Island environment, the status of carbon availability and consumption by marine community in nearshore waters yet to be carried out. In this perspective, to understand availability of carbon in the near surface waters, that also close to the shore, the study was carried out during the highly productive period (Mid January to March) of this environment. Moreover, to understand consumption of the same in a coral reef environment, the selected major fauna and flora of the coral reef environment was studied in laboratory condition, mimic the natural environment. During this process, it was evolved carbon transfer between various selected communities of coral reef environment in the laboratory condition which imitate the insitu condition.

2. MATERIALS AND METHODS

2.1 Study Site

The water sample for forty five days (45 days) was collected from the Carbyns Cove beach located (Fig. 1) at east coast of Port Blair, South Andaman (11°38'28.3'' N and 92°44'47.4'' E), which is the nearest point to the laboratory. It is a sandy beach environment and intertidal to nearshore has a good growth of coral community. The live specimens were collected from the Burmanallha, located on the south east coast of Port Blair, South Andaman Island (11°33.233' N, 092°42.979'E). It is a rocky shore environment consisting of pebbles and coral debris covered with algae along with mangrove patches toward the southern end of the beach. It is rich in intertidal fauna diversity. All the specimens and their associated communities were collected from the wild in the intertidal region of Burmanallha, at a depth of two meters and placed in the glass rectangular tank for forty five days.

2.2 Experimental Design

Four experimental tanks, each consisting of a different reef community such as sponge, algae and soft coral were set up and study was conducted for forty five (45) days in the laboratory of Department of Ocean Studies and Marine Biology. The Tank A was set up with a most prevalent sponge species *Stylissa massa*, Tank B consisted of sponge *Lamellodysidea* spp., Tank C consisted of macroalgae community i.e. of *Padina* spp. of an area of 620 cm^2 and Tank D had soft coral *Sarcophyton* spp. Every day the sea water was replaced during noon i.e. around 14.00 to 15.00 hrs regularly to mimic the natural condition.

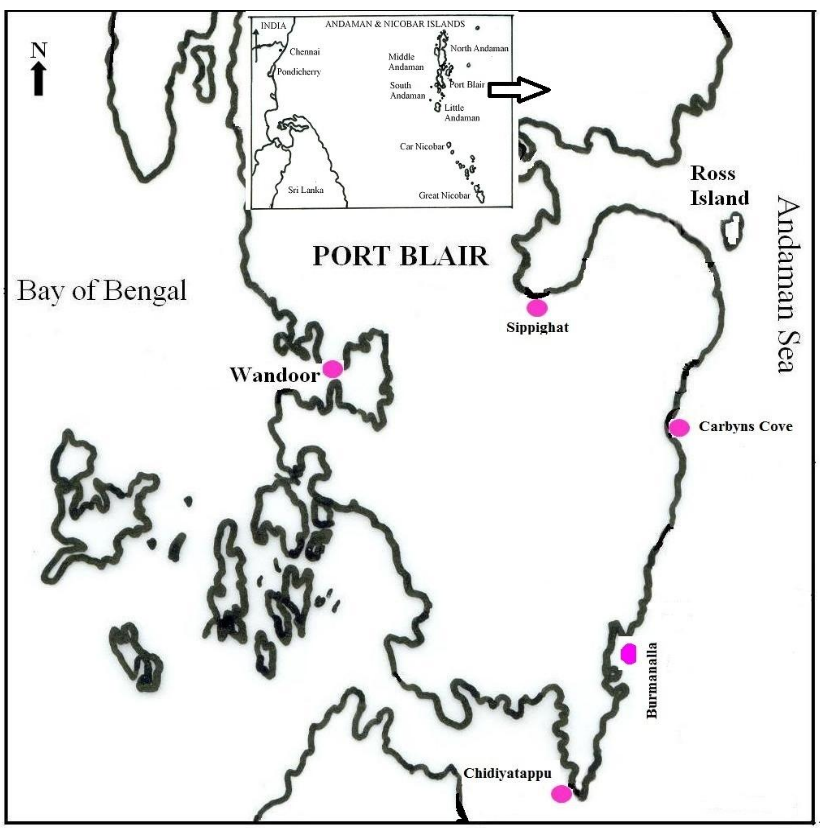

Fig. 1. Location of the study area

The sea water had been collected from the nearest beach where insitu details were collected. The temperature, salinity and pH were measured using portable thermometer, Attago refractometer and digital pH meter in insitu and in experimental tank before changing the sea water. Every day, the collected insitu seawater sample (one liter) was used as standard and after 24 hrs incubation from the experimental tank; one liter seawater was collected and used as an experimental sample. The Standard and Experimental samples were subjected to filtration using a Glass Fiber micro filter paper (Whattman GF/F), acidified with concentrated HCl to a pH of 2 and stored in 120 ml Teflon bottles at -20°C until the analysis was carried out in the TOC Analyser. The DOC and Dissolved Inorganic Carbon (DIC) of the samples were analyzed as reported by Kumari et al. [16]. The analytical error for DOC and DIC is in the range of 0.5 to 1.5% level.

3. RESULTS

The experimental study was carried out for forty five days and the parameters temperature, salinity, pH, DOC and DIC were estimated daily for insitu seawater as well as cultured Tank seawater. The data was presented in Tables 1, 2, 3 and 4.

Table 1. The temperature °C (T), salinity PSU (S), pH (p), dissolved organic carbon µM/L (DOC) and dissolved inorganic carbon µM/L (DIC) estimated in insitu (IN) and experimental tank (ET) seawater during the period 18/01/2015 to 03/03/2015 for Tank A

A	IN-T	ET-T	IN-S	ET-S	IN-p	ET-p	IN-DOC	ET-DOC	IN-IC	ET-IC	Status of tide
18/1/2015	30.0	29.0	30	28	8.0	7.8	066	112	312	444	Low
19/1/2015	30.0	31.0	28	31	8.5	8.1	085	153	033	ND	Low- FM
20/1/2015	29.0	30.0	34	29	8.6	8.2	154	118	ND	ND	High
21/1/2015	30.0	31.0	32	29	8.4	8.2	082	132	016	001	High
22/1/2015	30.0	31.0	32	32	8.2	8.3	081	098	ND	ND	High
23/1/2015	31.0	31.0	32	32	8.2	8.3	036	113	ND	ND	High
24/1/2015	30.0	31.0	31	32	8.1	8.5	082	061	ND	ND	High
25/1/2015	29.0	31.0	33	33	8.1	8.4	064	094	ND	002	High
26/1/2015	32.0	27.0	33	33	8.4	8.1	098	063	ND	ND	Low
27/1/2015	32.0	28.5	33	33	8.3	8.2	078	073	ND	ND	Low
28/1/2015	32.0	29.0	33	32	8.4	8.3	045	089	018	ND	Low
29/1/2015	32.0	29.0	33	33	8.6	8.2	143	047	048	018	Low
30/1/2015	31.5	29.0	33	33	8.5	8.3	112	065	110	ND	Low
31/1/2015	29.9	29.0	33	33	8.0	8.2	130	157	102	088	Low
01/2/2015	30.5	30.0	33	33	8.4	8.4	127	149	098	090	Low
02/2/2015	30.0	29.0	33	32	8.4	8.3	128	111	095	106	High-NM
03/2/2015	31.0	29.5	34	34	8.3	8.4	116	121	103	110	High
04/2/2015	31.0	29.5	33	34	8.3	8.2	094	104	120	113	High
05/2/2015	30.2	31.0	33	34	8.1	8.5	160	091	118	128	High
06/2/2015	30.0	31.0	33	34	8.3	8.5	132	151	122	119	High
07/2/2015	30.0	30.5	33	33	8.2	8.5	128	098	093	133	High
08/2/2015	29.0	31.0	33	33	8.2	8.5	167	189	127	109	High
09/2/2015	30.5	30.0	33	35	8.3	8.3	110	158	123	123	High
10/2/2015	31.0	30.5	32	33	8.3	8.5	098	137	128	142	High
11/2/2015	29.0	30.0	33	33	8.3	8.2	138	183	138	115	Mid
12/2/2015	34.0	30.0	33	34	8.5	8.3	143	140	153	133	Low
13/2/2015	32.0	29.0	32	33	8.7	8.3	166	168	143	158	Low
14/2/2015	31.0	28.0	32	33	8.7	8.2	123	159	161	158	Low
15/2/2015	31.5	29.0	32	32	8.6	8.4	133	193	165	165	Low
16/2/2015	32.0	27.0	31	34	8.5	8.2	155	148	166	192	Low
17/2/2015	31.0	28.0	31	33	8.3	8.3	143	168	172	210	High-FM
18/2/2015	30.5	28.5	34	34	8.3	8.5	113	173	232	210	High
19/2/2015	31.0	29.0	34	34	8.1	8.5	120	149	203	203	High
20/2/2015	31.0	30.0	32	33	8.0	8.5	103	148	239	217	High
21/2/2015	30.0	31.0	32	32	8.2	8.2	082	168	285	234	High
22/2/2015	30.5	31.5	30	33	7.9	8.6	090	135	258	261	High
23/2/2015	32.5	29.0	33	33	8.3	8.3	216	173	342	294	High

A	IN-T	ET-T	IN-S	ET-S	IN-p	ET-p	IN-DOC	ET-DOC	IN-IC	ET-IC	Status of tide
24/2/2015	31.0	29.5	32	32	8.4	8.3	098	138	298	311	High
25/2/2015	34.0	29.0	35	33	8.5	8.3	138	088	345	433	Low
26/2/2015	33.0	29.0	32	35	8.6	8.2	088	179	387	429	Low
27/2/2015	29.0	29.5	33	34	8.6	8.2	118	193	351	415	Low
28/2/2015	33.0	33.0	31	34	8.5	8.3	140	168	368	441	Low
01/3/2015	32.0	31.0	32	33	8.5	8.4	128	165	418	467	Low
02/3/2015	33.0	31.0	33	33	8.5	8.2	093	165	498	523	Low
03/3/2015	33.0	31.0	33	33	8.5	8.3	072	107	533	535	Low

Table 2. The temperature °C (T), salinity PSU (S), pH (p), dissolved organic carbon µM/L (DOC) and dissolved inorganic carbon µM/L (DIC) estimated in insitu (IN) and experimental tank (ET) seawater during the period 18/01/2015 to 03/03/2015 for Tank B

B	IN-T	ET-T	IN-S	ET-S	IN-P	ET-p	IN-DOC	ET-DOC	IN-IC	ET-IC	Status of tide
18/1/2015	30.0	28.0	30	28	8.0	7.9	066	0211	312	3	Low
19/1/2015	30.0	30.0	28	32	8.5	8.0	085	0178	033	449	Low- FM
20/1/2015	29.0	30.0	34	32	8.6	7.8	154	0686	ND	5	High
21/1/2015	30.0	31.0	32	30	8.4	7.8	082	0668	016	ND	High
22/1/2015	30.0	29.0	32	32	8.2	7.9	081	0305	ND	ND	High
23/1/2015	31.0	29.0	32	32	8.2	7.9	036	1125	ND	819	High
24/1/2015	30.0	29.0	31	33	8.1	8.0	082	0168	ND	4	High
25/1/2015	29.0	29.0	33	31	8.1	8.0	064	0157	ND	ND	High
26/1/2015	32.0	27.0	33	32	8.4	8.0	098	0093	ND	ND	Low
27/1/2015	32.0	27.5	33	32	8.3	7.9	078	0120	ND	ND	Low
28/1/2015	32.0	28.0	33	32	8.4	8.0	045	0088	018	ND	Low
29/1/2015	32.0	29.0	33	32	8.6	8.0	143	0092	048	027	Low
30/1/2015	31.5	28.0	33	32	8.5	8.0	112	0105	110	ND	Low
31/1/2015	29.9	28.0	33	33	8.0	8.0	130	0188	102	086	Low
01/2/2015	30.5	29.0	33	33	8.4	8.0	127	0148	098	093	Low
02/2/2015	30.0	28.5	33	32	8.4	8.0	128	0135	095	082	High-NM
03/2/2015	31.0	29.0	34	34	8.3	8.0	116	0123	103	114	High
04/2/2015	31.0	29.0	33	33	8.3	8.0	094	0113	120	119	High
05/2/2015	30.2	29.0	33	34	8.1	8.1	160	0134	118	127	High
06/2/2015	30.0	29.0	33	33	8.3	8.1	132	0165	122	116	High
07/2/2015	30.0	29.0	33	33	8.2	8.1	128	0107	093	132	High
08/2/2015	29.0	29.0	33	33	8.2	8.2	167	0158	127	135	High
09/2/2015	30.5	29.0	33	34	8.3	8.1	110	0126	123	162	High
10/2/2015	31.0	29.0	32	33	8.3	8.2	098	0148	128	158	High
11/2/2015	29.0	29.0	33	33	8.3	8.1	138	0164	138	137	Mid
12/2/2015	34.0	28.5	33	36	8.5	8.1	143	0142	153	125	Low
13/2/2015	32.0	28.0	32	33	8.7	8.2	166	0244	143	193	Low
14/2/2015	31.0	27.5	32	33	8.7	8.1	123	0152	161	183	Low
15/2/2015	31.5	28.0	32	33	8.6	8.2	133	0166	165	205	Low
16/2/2015	32.0	27.0	31	33	8.5	8.1	155	0148	166	178	Low
17/2/2015	31.0	27.0	31	33	8.3	8.1	143	0134	172	233	High-FM
18/2/2015	30.5	27.0	34	34	8.3	8.2	113	0143	232	222	High
19/2/2015	31.0	28.0	34	34	8.1	8.2	120	0123	203	238	High
20/2/2015	30.0	30.0	34	33	8.2	8.2	103	0155	239	236	High
21/2/2015	30.0	31.1	32	33	8.2	8.6	082	0137	285	244	High
22/2/2015	30.5	29.5	30	32	7.9	8.3	090	0057	258	290	High
23/2/2015	32.5	29.0	33	32	8.3	8.1	216	0188	342	333	High
24/2/2015	31.0	29.0	32	32	8.4	8.2	098	0155	298	351	High
25/2/2015	34.0	29.5	35	32	8.5	8.2	138	0115	345	374	Low
26/2/2015	33.0	28.0	32	34	8.6	8.1	088	0125	387	418	Low
27/2/2015	29.0	28.0	33	35	8.6	8.1	118	0118	351	505	Low
28/2/2015	33.0	27.5	31	33	8.5	8.2	140	0155	368	458	Low

B	IN-T	ET-T	IN-S	ET-S	IN-P	ET-p	IN-DOC	ET-DOC	IN-IC	ET-IC	Status of tide
01/3/2015	32.0	29.0	32	33	8.5	8.2	128	0165	418	458	Low
02/3/2015	33.0	29.0	33	33	8.5	8.1	093	0152	498	492	Low
03/3/2015	33.0	30.0	33	34	8.5	8.1	072	0114	533	522	Low

Table 3. The temperature °C (T), salinity PSU (S), pH (p), dissolved organic carbon µM/L (DOC) and dissolved inorganic carbon µM/L (DIC) estimated in insitu (IN) and experimental tank (ET) seawater during the period 18/01/2015 to 03/03/2015 for Tank C

C	IN-T	ET-T	IN-S	ET-S	IN-p	ET-p	IN-DOC	ET-DOC	IN-DIC	ET-DIC	Status of tide
18/1/2015	30.0	29.0	30	28	8.0	7.8	066	138	312	ND	Low
19/1/2015	30.0	30.0	28	32	8.5	8.0	085	390	033	ND	Low- FM
20/1/2015	29.0	30.0	34	32	8.6	7.9	0154	148	ND	ND	High
21/1/2015	30.0	31.0	32	30	8.4	7.8	082	102	016	ND	High
22/1/2015	30.0	30.5	32	32	8.2	7.8	081	103	ND	ND	High
23/1/2015	31.0	31.0	32	32	8.2	7.7	036	107	ND	ND	High
24/1/2015	30.0	30.0	31	33	8.1	7.9	082	064	ND	ND	High
25/1/2015	29.0	30.0	33	31	8.1	7.6	064	098	ND	ND	High
26/1/2015	32.0	27.0	33	32	8.4	7.5	098	128	ND	ND	Low
27/1/2015	32.0	28.0	33	32	8.3	7.2	078	375	ND	023	Low
28/1/2015	32.0	28.5	33	32	8.4	7.5	045	809	018	024	Low
29/1/2015	32.0	28.0	33	32	8.6	7.2	143	765	048	054	Low
30/1/2015	31.5	29.0	33	32	8.5	7.9	112	591	110	118	Low
31/1/2015	29.9	29.0	33	33	8.0	8.0	130	493	102	078	Low
01/2/2015	30.5	29.0	33	33	8.4	8.0	127	212	098	092	Low
02/2/2015	30.0	28.5	33	32	8.4	8.0	128	223	095	077	High-NM
03/2/2015	31.0	29.0	34	34	8.3	8.0	116	192	103	113	High
04/2/2015	31.0	29.0	33	33	8.3	8.0	094	204	120	123	High
05/2/2015	30.2	30.0	33	34	8.1	8.1	160	221	118	121	High
06/2/2015	30.0	30.0	33	33	8.3	8.1	132	183	122	099	High
07/2/2015	30.0	28.0	33	33	8.2	8.2	128	104	093	150	High
08/2/2015	29.0	30.0	33	33	8.2	8.1	167	204	127	131	High
09/2/2015	30.5	29.0	33	34	8.3	8.1	110	226	123	153	High
10/2/2015	31.0	30.0	32	33	8.3	8.0	098	158	128	139	High
11/2/2015	29.0	30.0	33	33	8.3	7.9	138	217	138	138	Mid
12/2/2015	34.0	29.0	33	36	8.5	8.0	143	186	153	166	Low
13/2/2015	32.0	28.5	32	33	8.7	8.1	166	178	143	181	Low
14/2/2015	31.0	27.0	32	33	8.7	8.0	123	223	161	163	Low
15/2/2015	31.5	28.0	32	33	8.6	8.0	133	341	165	250	Low
16/2/2015	32.0	26.0	31	33	8.5	8.0	155	144	166	193	Low
17/2/2015	31.0	27.0	31	33	8.3	8.0	143	183	172	215	High-FM
18/2/2015	30.5	27.5	34	34	8.3	8.1	113	183	232	223	High
19/2/2015	31.0	28.5	34	34	8.1	8.1	120	199	203	213	High
20/2/2015	31.0	30.0	32	33	8.0	8.2	103	175	239	238	High
21/2/2015	30.0	29.5	32	33	8.2	8.3	082	098	285	266	High
22/2/2015	30.5	30.0	30	32	7.9	8.2	090	125	258	267	High
23/2/2015	32.5	30.0	33	32	8.3	8.1	216	140	342	330	High
24/2/2015	31.0	29.0	32	32	8.4	8.1	098	146	298	366	High
25/2/2015	34.0	29.0	35	32	8.5	8.1	138	141	345	379	Low
26/2/2015	33.0	28.5	32	34	8.6	8.1	088	163	387	391	Low
27/2/2015	29.0	29.0	33	35	8.6	8.2	118	148	351	431	Low
28/2/2015	33.0	28.0	31	33	8.5	8.2	140	146	368	448	Low
01/3/2015	32.0	30.0	32	33	8.5	8.2	128	171	418	439	Low
02/3/2015	33.0	30.0	33	33	8.5	8.1	093	063	498	477	Low
03/3/2015	33.0	30.0	33	34	8.5	8.2	098	095	533	571	Low

Table 4. The temperature °C (T), salinity PSU (S), pH (p), dissolved organic carbon µM/L (DOC) and dissolved inorganic carbon µM/L (DIC) estimated in insitu (IN) and experimental tank (ET) seawater during the period 18/01/2015 to 03/03/2015 for Tank D consist of soft coral

D	IN-T	ET-T	IN-S	ET-S	IN-P	ET-p	IN–DOC	ET-DOC	IN-DIC	ET-DIC	Status of tide
18/1/2015	30.0	28.0	30	28	8.0	7.8	066	147	312	ND	Low
19/1/2015	30.0	29.0	28	31	8.5	8.1	085	080	033	481	Low-FM
20/1/2015	29.0	28.0	34	29	8.6	8.2	154	090	ND	ND	High
21/1/2015	30.0	29.0	32	29	8.4	8.2	082	073	16	ND	High
22/1/2015	30.0	29.0	32	32	8.2	8.3	081	064	ND	ND	High
23/1/2015	31.0	28.0	32	32	8.2	8.3	036	049	ND	ND	High
24/1/2015	30.0	28.0	31	32	8.1	8.5	082	100	ND	ND	High
25/1/2015	29.0	27.0	33	33	8.1	8.4	064	078	ND	ND	High
26/1/2015	32.0	26.0	33	33	8.4	8.1	098	054	ND	ND	Low
27/1/2015	32.0	28.8	33	33	8.3	8.2	078	061	ND	ND	Low
28/1/2015	32.0	27.0	33	32	8.4	8.3	045	057	018	ND	Low
29/1/2015	32.0	27.5	33	33	8.6	8.2	143	060	048	028	Low
30/1/2015	31.5	27.5	33	33	8.5	8.3	112	131	110	094	Low
31/1/2015	29.9	28.0	33	33	8.0	8.2	130	136	102	097	Low
01/2/2015	30.5	28.0	33	33	8.4	8.4	127	131	098	098	Low
02/2/2015	30.0	28.0	33	32	8.4	8.3	128	129	095	098	High-NM
03/2/2015	31.0	28.0	34	34	8.3	8.4	116	104	103	103	High
04/2/2015	31.0	28.0	33	34	8.3	8.2	094	097	120	135	High
05/2/2015	30.2	28.5	33	34	8.1	8.5	160	123	118	122	High
06/2/2015	30.0	28.5	33	34	8.3	8.5	132	133	122	105	High
07/2/2015	30.0	29.5	33	33	8.2	8.5	128	077	093	133	High
08/2/2015	29.0	28.0	33	33	8.2	8.5	167	116	127	135	High
09/2/2015	30.5	28.5	33	35	8.3	8.3	110	106	123	135	High
10/2/2015	31.0	28.5	32	33	8.3	8.5	098	138	128	144	High
11/2/2015	29.0	29.0	33	33	8.3	8.2	138	141	138	149	Mid
12/2/2015	34.0	28.0	33	34	8.5	8.3	143	128	153	166	Low
13/2/2015	32.0	27.0	32	33	8.7	8.3	166	156	143	182	Low
14/2/2015	31.0	27.0	32	33	8.7	8.2	123	123	161	173	Low
15/2/2015	31.5	27.5	32	32	8.6	8.4	133	121	165	199	Low
16/2/2015	32.0	26.5	31	34	8.5	8.2	155	134	166	195	Low
17/2/2015	31.0	26.0	31	33	8.3	8.3	143	088	172	217	High-FM
18/2/2015	30.5	27.0	34	34	8.3	8.5	113	110	232	209	High
19/2/2015	31.0	27.0	34	34	8.1	8.5	120	117	203	254	High
20/2/2015	31.0	28.0	32	33	8.0	8.5	103	098	239	241	High
21/2/2015	30.0	31.0	32	32	8.2	8.2	082	103	285	250	High
22/2/2015	30.5	28.5	30	33	7.9	8.6	090	115	258	303	High
23/2/2015	32.5	29.0	33	33	8.3	8.3	216	087	342	371	High
24/2/2015	31.0	28.0	32	32	8.4	8.3	098	131	298	348	High
25/2/2015	34.0	28.0	35	33	8.5	8.3	138	107	345	396	Low
26/2/2015	33.0	27.5	32	35	8.6	8.2	088	085	387	398	Low
27/2/2015	29.0	28.0	33	34	8.6	8.2	118	113	351	459	Low
28/2/2015	33.0	28.5	31	34	8.5	8.3	140	121	368	465	Low
01/3/2015	32.0	28.0	32	33	8.5	8.4	128	078	418	523	Low
02/3/2015	33.0	29.0	33	33	8.5	8.2	093	132	498	503	Low
03/3/2015	33.0	29.0	33	33	8.5	8.3	098	174	533	572	Low

The maximum and minimum temperature, salinity and pH (Table 5) for the insitu seawater were in the range of 29.0°C to 34.0°C, 28.0 to 35.0 and 7.9 to 8.7 with an average of 31.0°C, 32.4 and 8.45, respectively. The DOC and DIC maximum and minimum (Table 5) noticed in the range of 36 µM to 216 µM and ND to 533 µM with an average of 114 µM and 169 µM, respectively.

The experimental Tank A (Table 5) containing *Stylissa massa* sponge community exhibited temperature, salinity and pH for the study period in the range of 27.0°C to 33.0°C, 28.0 to 35.0

and 7.8 to 8.6 with an average of 29.8°C, 32.8 and 8.3, respectively. The DOC and DIC maximum and minimum (Table 5) values for the Tank A were in the range of 47 µM to 193 µM and ND to 535 µM, with an average of 133 µM and 174 µM, respectively.

The experimental Tank B (Table 5) with *Lamellodysidea* spp. community waters minimum and maximum values for the temperature, salinity and pH were in the range of 27.0°C to 31.1°C, 28.0 to 36.0 and 7.8 to 8.6 with an average of 28.7°C, 32.7 and 8.1, respectively. The minimum and maximum values (Table 5) for DOC and DIC were in the range of 57 µM to 1125 µM and ND to 819 µM with an average of 191 µM and 201 µM, respectively.

The Tank C (Table 5) consists of *Padina* spp., in an area of 620 sq cm along with its biota was cultured and maintained. The experimental tank seawaters exhibited temperature, pH and salinity in the range of 26.0°C to 31.0°C, 7.2 to 8.3 and 28.0 to 36.0 with an average of 29.0°C, 8.0 and 32.7. The DOC of tank C ranged from 63 µM to 809 µM, with an average of 216 µM. The DIC was in the range of ND to 571 µM with an average of 174 µM (Table 5).

Tank D (Table 5) contained a soft coral *Sarcophyton* spp. community. The tank D exhibited temperature, pH and salinity in the range of 26.0°C to 31.0°C, 7.8 to 8.6 and 28.0 to 35.0 with an average of 28.0°C, 8.3 and 32.8. The DOC of tank D ranged (Table 5) from 49 µM to 174 µM, with an average of around 107 µM. This experimental tank DIC was in the range of ND to 572 µM with an average of 189 µM.

4. DISCUSSION

4.1 Tank A

DOC concentration (Fig. 2) was higher in the experiment tank (133 µM) than the insitu waters concentration (114 µM).This may be due to the excess carbon provided from the major sponge biota in the water. The stock carbon available in the tank waters was expected to be consumed by the sponge and which then fuelled the detritus pathways by enriching with waste organic matter [17-21]. This may be the reason for the higher concentration of DOC available in the experimental tank water. Even though, Van Duyl and Gast [22] suggested that 10 to 15% increment of DOC in the coral reef environment may be related to coral excreta and related materials, but, the present study suggested that sponge excretes also increases around 15% increment of DOC in the water column, because this experimental tank did not have any coral.

Table 5. The average temperature °C (T), salinity PSU (S), pH (p), dissolved organic carbon µM/L (DOC) and dissolved inorganic carbon µM/L (DIC) estimated in insitu (IN) and experimental tank (ET) seawater during the period 18/01/2015 to 03/03/2015 for Tank A, B, C and D

	IN-T	ET-T	IN-S	ET-S	IN-p	ET-p	IN – DOC	ET-DOC	IN-IC	ET-IC
Tank A										
Minimum	29.0	27.0	28.0	28.0	7.9	7.8	036	0047	ND	ND
Maximum	34.0	33.0	35.0	35.0	8.7	8.6	216	0193	533	535
Average	31.0	29.8	32.4	32.8	8.4	8.3	114	0133	169	174
Tank B										
Minimum	29.0	27.0	28.0	28.0	7.9	7.8	036	0057	ND	ND
Maximum	34.0	31.1	35.0	36.0	8.7	8.6	216	1125	533	819
Average	31.0	28.7	32.4	32.7	8.4	8.1	114	0191	169	201
Tank C										
Minimum	29.0	26.0	28.0	28.0	7.9	7.2	036	0063	ND	ND
Maximum	34.0	31.0	35.0	36.0	8.7	8.3	216	0809	533	571
Average	31.0	29.0	32.4	32.7	8.4	8.0	114	0216	169	174
Tank D										
Minimum	29.0	26.0	28.0	28.0	7.9	7.8	036	0049	ND	ND
Maximum	34.0	31.0	35.0	35.0	8.7	8.6	216	0174	533	572
Average	31.0	28.0	32.4	32.8	8.4	8.3	114	0107	169	189

**** ND – Not Detected*

The DIC concentration (Table 5) available in the experiment tanks waters (ND to 535 µM) also showed almost similar trend with reference to insitu waters (ND to 533 µM). This suggested that the inorganic carbon was not utilized by the organism in the tank. A significant correlation (Tables 6 and 7) between DOC and DIC (0.4286) was also suggested that those factors affect the DOC might also affect the DIC concentration. Further, it also noted that these factors were affected the insitu environment but not at significant level.

Table 6. The correlation coefficient values for Temperature (T), Salinity (S), pH (p), dissolved organic carbon µM/L (DOC) and dissolved inorganic carbon µM/L (DIC) estimated in insitu (IN) seawater values

IN	T	S	P	DOC	DIC
T	1				
S	0.1170	1			
P	**0.4337**	0.1099	1		
DOC	0.0896	**0.2503**	**0.2557**	1	
DIC	**0.4497**	-0.0086	0.1744	0.1283	1

Table 7. The correlation coefficient values for temperature (T), salinity (S), pH (p), dissolved organic carbon µM/L (DOC) and dissolved inorganic carbon µM/L (DIC) estimated in experimental tank A (ET-A) seawater values

ET-A	T	S	P	DOC	DIC
T	1				
S	-0.0956	1			
P	**0.3414**	**0.4409**	1		
DOC	0.0839	0.1976	0.0671	1	
DIC	0.1165	0.173	-0.0102	**0.4286**	1

4.2 Tank B

During the initial days of this study, spawning of sponge was observed between third day to seventh day (19th January 2015 to 23rd January 2015) in this tank. The tank contained grayish white mass coated over the sample of study. This phenomenon was also reflected on the DOC and DIC values, which showed a hike during this period (Figs. 2 and 3). The highest DOC value was noted on seventh day, with a concentration of 1125 µM (Table 2). Hood et al. [23] reported that influence of spawning in the water might have increased of DOC in their study on Salmon fish. Moreover, it was also inferred that pH was influenced the DOC inversely (r = -0.4537).

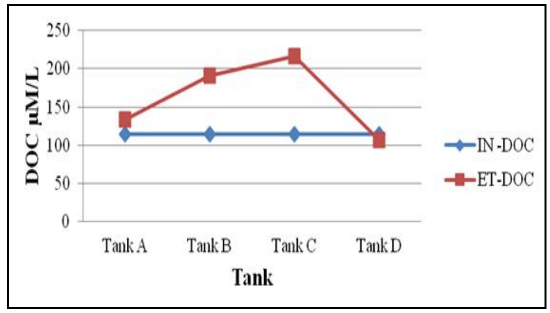

Fig. 2. Average dissolved organic carbon (DOC) in the *in situ* (IN) and experimental tanks (ET)

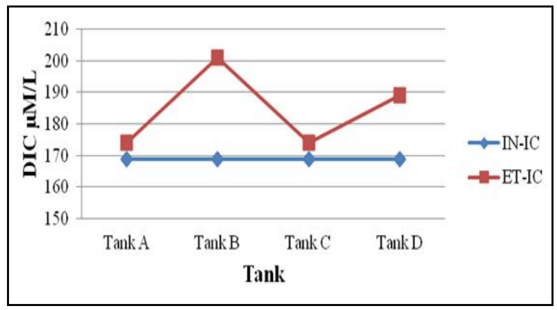

Fig. 3. Average dissolved inorganic carbon (DIC) in the *in situ* (IN) and experimental tanks (ET)

Further, in this study an increase in DIC concentration on the same day was also noted. The DIC increased simultaneously to a range of 819 µM. In the later days the values dropped back to normal (Table 2). Coinciding with the hike in DOC and DIC, a reduction in pH was noted. During this period the pH was in the range of 7.8 to 7.9. So, it is suspected that any changes in the biological phenomenon, within the sponges, which in turn increases the DOC and may alter the surrounding pH values drastically (r=-0.4537). Further, this inference was also supported by the positive correlation values of pH with DIC (Table 8). The increment observed in DOC concentration was solely due to spawning in this experimental tank. According to the correlation values for insitu seawater temperature vs pH and temperature vs DIC gave strong positive correlation and experimental tank values suggested that strong negative values with reference to salinity vs DOC and pH vs DOC also support the above inferences. Further, the positive relationship (r = 0.2497) between DOC and DIC confirms the variation among these two carbons mainly due to the sponge only.

Table 8. The correlation coefficient values for temperature (T), salinity (S), pH (p), dissolved organic carbon µM/L (DOC) and dissolved inorganic carbon µM/L (DIC) estimated in experimental tank A (ET-B) seawater values

ET-B	T	S	P	DOC	DIC
T	1				
S	-0.1517	1			
P	0.0783	**0.4046**	1		
DOC	**0.2818**	**-0.2922**	**-0.4537**	1	
DIC	0.0972	**0.2800**	**0.3367**	**0.2497**	1

The DIC values represented in the study period suggested that there was an increment in the concentration towards the end of experiment. This increment was very gradual in both environment i.e. insitu and experimental tank waters. These changes may suggest that there were stress exerted to biota, possibly due to the increase in surrounding temperature in both the insitu and experiment tank waters. However, the differences between temperatures of these two environments were still kept intact. So, it may be inferred that this stress exerted on the biota through the change in temperature might be a suitable cause for the increase in quantity of DIC released. The strong positive correlation (0.4497) between temperature and DIC in the insitu seawater (Table 6) supports the same. This factor was supported by the different authors [24-27]. Kennedy et al. [28] had explained that 1°C increment was sufficient to initiate mortality or disappearance from the environment of the biota. Over and above the minor variation noticed among the samples suggested temperature as an important factor affecting the dissolution of CO_2.

4.3 Tank C

The algae in the Tank C were degraded in the initial period of study itself i.e. onset of 10th day. The degradation was resulted in the formation of slimy viscous waters which persisted for a week period. Even though, the water was changed on daily basis the water was still slimy and was marked by very low pH. Hence the entire tank was cleaned and community was replaced on the 15^{th} day.

The DOC values (Fig. 2) suggested that the average concentration of Tank C was higher (216 µM) than the average seawater (174 µM) concentration. This may be inferred that the release of DOC might be happened from the community to a significant level i.e. three fourth to equal level of natural dissolution (63/36 = 1.75) in the seawater. The peak level was noticed during the second day of the degradation. This information could be inferred that during the second day of deterioration, maximum amount of carbon released to the water and then which gradually decreased till the stock was exhausted i.e. at least a week time was needed to drop back to the original level. Dissolved organic carbon released by marine macrophytes in experimental conditions had been previously [6-10] reported. According to the laboratorial studies [6,11-12] using ^{14}C addition experiments, the DOC release from macro algae accounted to 1 to 39% of gross primary production. Haas et al. [9] reported that the net DOC release from fragments of sea grass and algal specimens incubated in beaker under natural daylight conditions were around 1.3±0.5 $mmolCm^{-2}h^{-1}$ and 0.2±0.25 $mmolCm^{-2}h^{-1}$, respectively. Other than this, stress related effect on the biological as well as metabolic activities during the low tide temperature have been reported by several workers [13-15].

In the case of DIC (Fig. 3) available in the experimental tank C (174 µM) as well as the insitu (169 µM) seawater suggested that the concentration of tank average DIC was comparatively higher. Further, it had been noticed that a gradual increment of concentration in both the seawaters i.e. ND to 500 µM level suggested that the dissolution of gas may have increased due to lowering of temperature in the experiment tank which was concurrent with the physical law which states that the lowering of temperature decreases the pH and increases the dissolution of gas concentration. When temperature decreases it helped in the dissolution of CO_2 in higher rate and when the atmospheric temperature increased CO_2 would be liberated out and thus shifting back to normal alkaline range of seawater. The positive correlation (Table 6) between temperature and pH (0.4337) support this inference. This phenomenon was also reported [28-29] that the temperature reduction increases the CO_2 concentration. Further, it was suggested that the temperature does not influence directly the increment of DIC. Instead, it increases or decreases the pH which in turn affects the DIC in the system. This was also supported by the strong positive correlation observed between DIC and pH (0.6324) as well as between DIC and salinity (0.4284) and negative correlation between temperature and DIC (-0.0637). Here, a negative correlation (-0.2888) between DOC and

DIC in the experimental tank was (Table 9) also noticed and support that both DOC and DIC were from different sources.

Table 9. The correlation coefficient values for temperature (T), salinity (S), pH (p), dissolved organic carbon µM/L (DOC) and dissolved inorganic carbon µM/L (DIC) estimated in experimental tank A (ET-C) seawater values

ET-C	T	S	P	DOC	DIC
T	1				
S	-0.1661	1			
P	0.1409	**0.4401**	1		
DOC	-0.2344	-0.0743	**-0.5120**	1	
DIC	-0.0637	**0.4284**	**0.6324**	**-0.2888**	1

4.4 Tank D

The DOC values (Fig. 2) suggested that experimental tank values were lower (107 µM) than the insitu (114 µM) seawaters. This may be inferred that the soft coral and sponge community did not release any DOC in to the seawater but instead consumed the DOC from the seawater. This inference was contradicting to the other tanks containing sponge and algae which released a certain amount of DOC to the water. In a study conducted [9] on the DOC release by Caribbean scleractinian corals it was found that of the three corals, two *Porites* spp., were found to release DOC while *Manicina* spp. was known to show a net uptake of DOC. So, the present findings suggested that the soft coral may consumed the CO_2 and not release the same to the aquatic environment.

The DIC concentration (Table 5) suggested that the experimental tank value (572 µM) was higher than the insitu (533 µM) seawater. This may be inferred that the lowering of temperature may be provided the dissolution of DIC from the inorganic carbonate available in the seawater. The similar factor was observed in the remaining tank also support the same inference. The increase of DIC during the end of experimental time may be inferred that there was no possibility of utilization of DIC in the existing experimental condition or due to tidal variation which might have implicated biological stress on the organism forcing the release of more inorganic carbon into the water. As suggested by various authors [13-15], intertidal organisms can be affected by low tide temperatures which are noticeable in their immunity, reproduction, and the acid-base balance. The significant positive correlation (0.3112) between DOC and DIC (Table 10) supports that the variation noticed was interlinked with the biological activity of the organism.

Table 10. The correlation coefficient values for temperature (T), salinity (S), pH (p), dissolved organic carbon µM/L (DOC) and dissolved inorganic carbon µM/L (DIC) estimated in experimental tank A (ET-D) seawater values

ET-D	T	S	P	DOC	DIC
T	1				
S	-0.1792	1			
P	0.009	**0.4409**	1		
DOC	0.0632	0.1217	0.0541	1	
DIC	0.2102	**0.3067**	0.0385	**0.3112**	1

N = 44
Significance at the level of 99.5 = 0.3761
Significance at the level of 99.0 = 0.3420
Significance at the level of 97.5 = 0.2907
Significance at the level of 95.0 = 0.2455
Significance at the level of 90.0 = 0.1925

The DOC and DIC maximum, minimum and average values for the experiment Tank A, B, C, D and insitu seawater were presented in the Table 5. The average values clearly mentioned that the insitu seawater shows lower DOC (114 µM) and DIC (169 µM) when comparing sponge and macro algae experimental tank (Figs. 2 and 3). However, the soft coral tank shows depletion of DOC than insitu seawater values and DIC values exhibited considerable increment than insitu water. The DOC values of tanks were in decreasing order from *Padina* spp. (Tank C) *Lamellodysidea* spp. (Tank B), *Stylissa massa* (Tanks A) and *Sarcophyton* spp. (Tank D), respectively, 216 µM, 191 µM, 133 µM and 107 µM. In the case of DIC also noticed the decreasing trend (Table 5) from *Lamellodysidea* spp. (Tank B), *Sarcophyton* spp. (Tank D), *Padina* spp. (Tank C) and *Stylissa massa* (Tanks A) respectively, 201 µM, 189 µM, 174 µM and 174 µM. So, the result may be suggested that both the sponge community and algal community supplies DOC to the surrounding water. This DOC is the primary dietary source for the coral and its associated community. The supply of organic carbon from the sponge community within the coral ecosystem was sufficient to meet the carbon demand within this system, thus supporting of the major productive environment of the ocean. In case of the DIC content available in the tank tend to increase in the later days which were prominent in the entire experimental tank as well as the insitu seawater. Three possibilities were expected that either no consumption of DIC from the stock or a celestial influence or heat stress - mediated release of DIC into the water by the communities in experimental as well as insitu organisms was suspected. As reported by Anthony et al. [30] temperature increment in the seawater can aggravate the stress effects and increase the CO_2 concentration. However, in reality, the comparatively low temperature in the experimental tank would have increased the dissolution of more CO_2 which in turn increased the DIC concentration in these waters than insitu environment. Moreover, it was observed that it came back to alkaline state within short duration which suggested that the environment balances on its own without any major effect. The positive correlation between temperature vs. DIC, salinity vs. DOC, pH vs. DOC and DIC in the experimental tank (Tables 6, 7, 8, 9 and 10) support the above inferences that the stress induced on sponges due to the variation in temperature and salinity have affected the release or intake of DOC and DIC.

4.5 Tidal Impact

The tidal variation also has shown to affect the concentration of DOC and DIC in the study area. The present forty five days study clearly represented that both the insitu as well as experimental tank values were affected by the lunar cycle. This study period was covered by three high tide period and four low tide periods. In general, it was observed that during low tide both the DOC and DIC were higher in the experimental tank A, C and D, while the DIC alone high for Tank B and insitu seawater. The values are represented in Table 11. Further, celestial influence coordinated with biological phenomenon was also noticed in the insitu and experiment waters which suggested that the stress also lead to increase the DIC values. As suggested by various authors [13-15] reported that intertidal organisms can be affected by low tide temperatures which were noticeable in their immunity, reproduction, and the acid-base balance. Moreover Marshall and Plumb [31] also reported that tidal effect can be considered to a depth of 50-100 m in a homogenously mixed layer. This was also supported by the positive correlation between temperature and DIC in the faunal tank (Tables 7, 8 and 10) and negative relationship within the floral tank (Table 9).

While considering the change in physical parameters in all the four tanks against the insitu seawater, it is being concluded that light availability and temperature play a major role in the dissolution of CO_2, which there in effects the pH of the system. The above results suggested that the experimental tank temperature was lesser than the insitu temperature i.e. up to 1.0°C to 2°C (Fig. 4). This may be due to the differences in the amount of sun light was fallen on the tank as unlike of open sea environment. Current experiment clearly stated that the as the temperature lowers, more amount of CO_2 was dissolved which then brings down the pH (Fig. 5), but what was to be noted here was that this system regains its balance in a short while with the increase in temperature and maintains its alkaline nature. Hereby, it was suggested that temperature increment might not lead to acidification of seawater instead there was always a balance within in system which was nearly constant. In terms of salinity, the average values exhibited a slight variation within the salinity range i.e. around 0.1-0.5 (Fig. 6). This variation may be due to the intake or expulsion of salt content from the experiment animal may be impacted in this values. Further, it was very clearly noticed in all the experiment tanks correlation between temperature vs salinity where experienced negative relation and in the

Table 11. The minimum and maximum values noticed for dissolved organic carbon µM/L (DOC) and dissolved inorganic carbon µM/L (DIC) estimated in insitu (IN) and experimental tank (ET) seawater during the period 18/01/2015 to 03/03/2015 for Tank A, B, C and D

Sl. no.			**Low tide**		
Tank	**ET-A**	**ET-B**	**ET-C**	**ET-D**	**IN**
DOC- µM/L	047 - 193	088 - 244	063-809	054-174	045-166
DIC- µM/L	ND-535	ND-522	ND-571	ND-572	ND-533
Sl. no.			**High tide**		
Tank	**ET-A**	**ET-B**	**ET-C**	**ET-D**	**IN**
DOC- µM/L	061-189	123-1125	064-226	049-138	036-216
DIC- µM/L	ND -311	ND -819	ND -366	ND -371	ND -342

in situ water it was positive (Tables 7, 8, 9 and 10). The pH exhibited a significant reduction in the experiment tank sea water than the insitu sea water. This may be accounted for by the reduction of temperature in the experiment tank which in turn increases the dissolution of carbon in the sea water, leading to the shift of pH towards the acidic region (Figs. 4 and 5). However, with the increase in temperature in the insitu seawater tries to expel the carbon which was coherent with the basic physical law of gas, thereby shifting to alkaline state. Over all, this study suggested that the pH was the function of temperature and any increase in the seawater temperature turns the water more alkaline in nature and thus retains less DOC and DIC. If the temperature decreases then the water tends to be acidic nature and dissolves more CO_2. It was clearly proved that the physical law of the gases i.e. temperature increases it releases the dissolved gas and when it cooling it retains the more dissolved gas. Houghton et al. [29] reported that the rate of physicochemical uptake of CO_2 in the ocean reduced when ocean temperature increased during the year 1850 to 1996. Kennedy et al. [32] also reported that the decrease of temperature increase the CO_2 dissolution in the seawater.

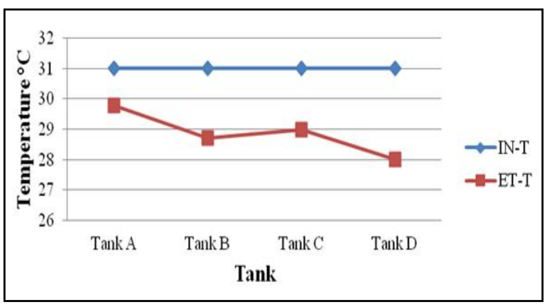

Fig. 4. Average temperature observed in the *in situ* (IN) and experimental tanks (ET)

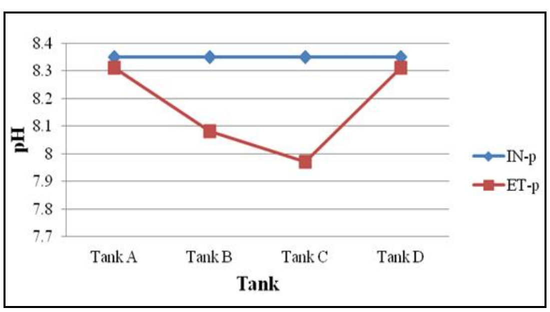

Fig. 5. Average pH observed in the *in situ* (IN) and experimental tanks (ET)

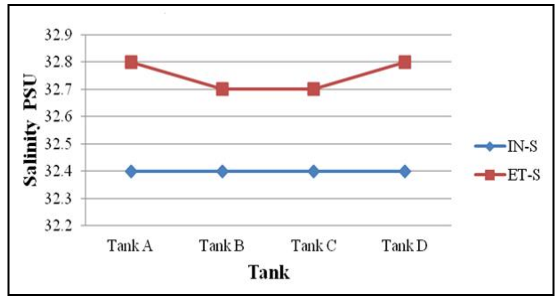

Fig. 6. Average salinity observed in the *in situ* (IN) and experimental tanks (ET)

5. CONCLUSION

Over all, this experiment set up suggested that the sponge and algae may provide DOC to the seawater and coral may utilize the same. Further, it also suggested that the addition of DOC has not influenced the pH permanently. So, the natural balance was managed in the existing coral reef environment without any addition or deletion of DOC as well as maintained pH in alkaline stage with a temporary fluctuation of pH with a movement towards acidic range. Further, it may be inferred that the DIC may be utilized if there was an opportunity should be available otherwise it may be remaining in the water as such and increase its concentration. This opportunity may be available during the celestial change on every day and management was carried out without antagonizing the system. In case of the insitu condition, these celestial factors may have its effect to a considerable depth i.e. up to 50 to 100 m. Based on this study it may considered in this environment carbon was managed fully without any imbalance.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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