Review on Dissolved Organic Carbon and Particulate Organic Carbon in Marine Environment

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Abstract

Quantification the Dissolved and Particulate organic carbon in marine waters is an essential step towards ecosystem modeling and understanding carbon sequestration processes. A detailed view of estimated and recorded carbon concentration from Arctic to Antarctic is the prime goal of this review. This review compiles some of the important research work carried out in quantifying the organic carbon available in off shore and open waters and in coral reef environment. The cited literatures were collected, grouped and carefully analyzed to give a comprehensive view on current status of marine environment with regard to distribution of dissolved and particulate organic carbon.

Keywords: DOC, POC, continental shelf waters, open sea waters, coral reef environment.

Introduction

The removal, capture and storage of carbon dioxide from the atmosphere by ocean, forest and land have been designated as carbon sequestration (Green Facts). Recent years, sudden increase in the atmospheric CO_2 due to reduction of forest cover, burning of fossils fuels and emissions of greenhouse gases by other anthropogenic activities has been an issue of great concern. Several awareness programs and initiatives have been executed by governing bodies to curb this rise. Various alternative methods have been adopted to sequester the carbon dioxide from the atmosphere to the oceans, which has been considered as the most significant and safe sink zone. Despite various initiatives and trials have been done to understand these processes and associated consequences, the area to be explored is still large. At this juncture, the larger level data base on carbon availability in the form of organic and inorganic fraction in the nearshore and open ocean environment with close interval has to be acquired to test the future initiatives in well suited methodology. Even though, various studies had been carried out all over the world to estimate and delineate this mystery, the real understanding and quantification of the process have not reached up to the minor level accuracy. This may be due to the cumbersome process involved in the estimation, the cost of the operation, difficulty in sampling due to adverse environmental conditions, manpower shortage to study this aspect, etc., are the certain constraints to complete this task at best.

Understand the status of existing works for the dissolved organic carbon (DOC) and particulate organic carbon (POC) in the open ocean environment as well as nearshore environment a study was carried out and their outcome has been provided here as a review. The existing literatures on these aspects were classified into three major divisions such as continental shelf waters, open waters and coral reef environment. Each of these major divisions was further classified for DOC and POC. The fresh water inputs from the terrestrial environment also play a role to enhance the carbon concentration in the coastal region as a dissolved inorganic carbon (DIC).

In this paper all the values in relation to DOC and POC are converted and expressed in µmolol for the ease of comparison. The converted factors are given below:

Mole (mole) to Micromole (µmolol)= Value x 10^6

Microgram (µgr) to Micromole (µmolol)= Value/ 12 (Molecular mass of C)

Milligram (mg) to Micromole (µmolol)= Value x 1000 /12

The nutrient rich coastal waters are the source of autotrophs which can fix the atmospheric carbon through the photosynthetic process. It has been already proved that the higher planktonic productivity increases the carbon fixation to greater level which is termed as blue carbons. The sink of

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carbon from the atmosphere to water would be taken place when the surface water pressure is lesser than the atmosphere. The sea water partial pressure is mainly controlled by different physico-chemical parameters of the same (Omstedt *et al.,* 2009). Most of the DIC and DOC which are dissolved in the nearshore waters are retained in the coastal waters and a very limited or small amount might be entered deep sea (Tsunogai *et al.,* 1999; Liu *et al.,* 2000; Ducklow and McCallister, 2004). As reported by Hedges (1992) the concentration of DOC in oceanic water (≈ $0.6x10^{18}$ gC) almost equal to atmospheric carbon. Cauwet *et al.* (1990) reported that DOC is uniformly distributed in ocean waters except in the bottom where a slight increment can be noticed. Moreover, Cauwet *et al.* (1997) explained that nearshore regions surface waters always show a higher concentration of DOC (80 to 200µmolol.kg^{-1}) than the open ocean waters (40µmolol.kg^{-1}). Dittmar and Kattner (2003) discussed that tropical and subtropical waters exhibited high DOC values (70-80µmolol.kg^{-1}) and subpolar to circumpolar southern ocean exhibited low concentration (40-50µmolol.kg^{-1}) due to the mixing of deep waters. The increased DOC concentration in subtropical and tropical waters was attributed to the phytoplanktons and poleward advections, respectively, by Taki and Suzuki (2001). Here the reports are described from the Arctic to Arctic covering Pacific Ocean, Indian Ocean, Antarctic and Atlantic Ocean. The reports are further subdivided into temperate (above 40ºLatitute) and tropic and subtropics (0-40ºLatitute).

Continental Shelf Waters

The temperate waters of the Arctic Ocean, Southeast Bering Sea, Sagami, East China Sea, Ross Sea, Black Sea and Roseway Basin, were reported to have a DOC concentration of 174±1µM, 76±9µmolol, 67-145µmolol, 30-42µM, 210-280 µmolol and 75-170µmolol (Ogura *et al.,* 1975; Kepkay and Well, 1992; Carlson *et al.*, 2000; Cauwet *et al.,* 2002; Guo *et al*., 2004; Cooper *et al.*, 2005; Ducklow *et al.,* 2007). The highest concentration of DOC in the waters of the Black Sea was attributed to the mixing of fresh water in this region, which enhances the microbial activity at low salinity leading to an increased N/P ratio and reduction of phosphorous. The phosphorous deficiency restricts the phytoplankton bloom and in the other hand increases the decomposition of carbohydrates, leading to accumulation of DOC during summer.

While in the tropical waters of California Current, East China Sea, Mediterranean and Western Mediterranean, DOC concentration of range 105µM, 40-170µM, 58-88µM and 50-100µM was reported by Zheng-bin *et al.* (1997), Hung *et al.* (2000), Hill and Wheeler (2002), Santinelli *et al.* (2002; 2006) and Ogawa *et al.* (2003). Also, the studies of Trabelsi and Rassoulzadegan (2011) suggested an accumulation of 90µM of DOC in Northwestern Mediterranean, while Ribes *et al.* (1999) reported an annual accumulation of 213±15 µMgC.L^{-1} in the nearshore waters. The waters of, Mid Atlantic Bight and Gulf of Mexico were reported to have DOC concentration ranging from, 40-165µM and 60-80µmolol (Guo *et al.,* 1995; Kepkay, 2000; Vlahos *et al.,* 2002).

The POC fraction of organic matter available through primary production, detritus, fecal pellets, river inputs, etc., constitutes nearly 50% of the organic carbon in the seawater (Johannes, 1967; Fabricius and Dommisse, 2000; Chester, 2003; Wild *et al.,* 2008). The average POC in the water column of surface to 4000m accounts 8333000µmolol.m^{-3} and total $1,66,66,000x10^{18}$µmolol in total oceans (Wangersky, 1974; 1976). Dzierzbicka-Głowacka *et al.* (2010) have reported that the ratio of DOM/POM varies between 4 and6 in coastal waters. Even though different proportions with reference to POC and POM reported, the maximum acceptable range is 45% of the POC from the total POM (Chester, 2003) whereas, Wangersky (1977) has reported that the POC accounts to the amount of POM in the marine environment. The reason for the varying POC concentration in these waters was mesoscale eddies, primary production, diatom frustules, zooplankton fecal pellets and downward flux. While looking into the temperate waters, the surface water POC concentration for northern Baffin Bay and Coast of Peru to Galapagos were reported so far as 8770-27000µmolol $Cm^{-2}d^{-1}$ and 1-8µmolol C.L^{-1} (Menzel, 1967; Amiel *et al.,* 2002).

Meanwhile, tropical offshore waters of the North Eastern Pacific ocean, Oregon, Bay of Bengal, Nicobar and Malaysian coastal waters were reported to have a POC concentration in the range of 37µmolol, 21-63µmolol, 5-15µmolol, 5-29µmolol, 18-89µM and 2-14µmolol, respectively (Ichikawa *et al.*, 1987; Gupta and Sarma, 1997; Hill and Wheeler, 2002; Karp-Boss *et al.,* 2004; Khodse *et al.,* 2009; Fernandes *et al.,* 2009; Mohan *et al.,* 2012; Sarma *et al.,* 2012). The variation of POC concentration in these waters due to primary production, water mixing, the fertilizer role of river inputs, upwelling, terrestrial input from the river waters, *etc*. Cauwet *et al.* (1997) reported a concentration of 40-130µmolol in the Mediterranean Sea and Ribes *et al.* (1999) reported an annual concentration of 32µmolol of POC in the North Western Mediterranean Sea.

Coral Reef Environment

The coral reef community is one of the important nearshore ecosystems. The coral reef environment supports and sustains vast and varied marine communities as well as considered as a highly productive ecosystem in the oligotrophic waters. However, in terms of carbon cycling system, the calcification and primary production with reference to zooxanthellae and its coralline host, plays a crucial role to balance the carbon availability in the seawater and serves to balance the carbon production and consumption (Broecker and Peng, 1982; Frankignoulle *et al.,* 1994). The carbon balance system is estimated by the ratio P:R which equals to 1.68. However, the factors like temperature, salinity, alkalinity, etc., play a major role in maintaining this equilibrium. These factors together determine the source or sink nature of each coralline ecosystem.

Even though many studies had been carried out all over the world, the sufficient information on the carbon cycle is yet to be gathered for the worldwide coral reef environments. Presently our knowledge of carbon cycling within the coral reef ecosystem is considerably vague and it requires thorough and detailed understanding of these systems to reach the goal of "blue carbon sequestration". Several works have been carried out in recent years to understand the actual phenomena occurring in these productive environments. Reports by Fabricius and Dommisse (2000) points out that suspended particulate matter and detritus represent a major food source in reef communities. Studies have also suggested that the mucous released by coral reefs also act as a source for the nearby zooplankton community (Johannes, 1967). The works of Ferrier-Pages *et al.* (2000) and van Duly and Gast (2001) established coral mucus provides DOC in this environment which can sustain the reef communities in oligotrophic waters. Several other workers had reported that nearly 50% of the organic carbon produced by coral in symbiotic association with zooxanthellae will be released as POC and DOC in the surrounding waters (Muscatine *et al.,* 1984; Wild *et al.,* 2004). The studies of Naumann *et al.* (2012) in the northern Gulf of Aqaba revealed that the particulate organic carbon from coral reef was estimated to be 3800±1100µmolol.m^{-2}.d^{-1} in the surrounding waters. Haas *et al.* (2010) reports on the coral reef environment existed in Caribbean lagoon stated that the POC release into this environment accounts to 683-1033µmolol.m^{-2}.h^{-1}. Ningaloo reef in Western Australia exhibited 24,000-2,50,000µmolol.m^{-2}.d^{-1} of POM production, which is almost equal to the biological utilization of this region (Wyat *et al.,* 2013). The Tioman Island of Malaysia exhibited POC concentration in the water column 15,741-21,216µmolol.m^{-3}, which is mainly used as a feed to meso zooplankton (Nakajima *et al.,* 2011). As per the reports of Nair and Pillai (1972) the coral reef environment off Port Blair in Andaman sea produces 9,99,96,000µmololC.m^{-2}.y^{-1}, as well as the Minicoy reefs of Lakshadweep produces 24,99,90,000 µmololC.m^{-2}.y^{-1}. While, Kumari *et al.* (2015) reported average DOC ranges from 1334-1641µM in the western side of Andaman and Nicobar Islands to 1494-1358µM in the eastern side of the Island. Similarly the average DIC values were reported as 1371-1505µM and 1588-1580µM, respectively, in the western and eastern sides of the Island for surface to 20m waters. Recently, Mohan et al. (2016) suggested that the waters of South Andaman (Chatham-Carbyns cove) exhibited average DOC and DIC in the range of 71-106µM.L^{-1} and 103-138µM.L^{-1}, respectively, for surface to 15m depth waters. While in Palk Bay, POC ranged from 23-271µmololC.L^{-1} was reported by Sridhar *et al.* (2008).Addition to the natural environmental studies in the coral reef, the experimental work in situ conditions were also carried out for POC and DOC concentration in the surrounding waters. It had been found out that the POC released per hour in the range of 744-883 µmolol.m^{-2}.h^{-1} (Nakajima *et al.,* 2010) and DOC was in 1248-1603 µmolol.m^{-2}.h^{-1}. As per the studies of Wild *et al.* (2009), the in situ release of DOC and POC in the coral reef environment of Red Sea is nearly 58-933 µmolol.m^{-2}.h^{-1} and 4-26 µmolol.m^{-2}.h^{-1}. However, another experimental work by Wild *et al.* (2010), in a controlled environment suggested DOC and POC release accounted to 125-148µM.L^{-1} and 7-8 µmolol.L^{-1}. The sponge specimens available in the coral reef environment of Curacao, Netherlands Antilles are reported to remove DOC and bacterioplankton from the surrounding waters at a rate of 13-15µmolol.cm^{-2}.h^{-1} per sponge (de Goeij *et al.,*2008).

Open Sea Waters

Open ocean and continental shelf regions are considered a major carbon sink zone. Deep waters have a very constant and narrow concentration of carbon in the range 45-55µmolol.L^{-1} (Dittmar and Kattner, 2003). Moreover, sometimes the influence of river inputs on surface waters can also be observed (Cauwet *et al.,* 1990). The DOC concentration in temperate waters of the Atlantic Ocean and North Atlantic Ocean, were reported as 58µmolol.L^{-1} and 55000-80000µmolol, respectively (Menzel, 1967; Kahler *et al.,* 2010). The high accumulation of DOC in North Atlantic Ocean is due to increased net production and partial export of carbon. The open Ocean region of Sargasso Sea, the DOC concentration was found to be 7-100µmolol (Kepkay and Well, 1992). The Arctic water DOC

concentration reported so far ranged 30-84µmolol (Benner *et al.,*2005; Griffith *et al.,* 2012).

The tropical and sub-tropical waters of the equatorial Pacific Ocean reported to exhibit DOC in the range of 68µmolol.L^{-1} DOC in the surface water (Hansell *et al.,* 1997). However, the Southern California Bight, North Eastern Pacific Ocean, Eastern Pacific Ocean and Western South Pacific Ocean concentrations ranged 62-103 µmolol, 74 µmolol, 85µmolol.L^{-1} and 80µmolol.L^{-1}, respectively (Hansell *et al.,* 1993; Hansell and Waterhouse, 1997; Doval and Hansell, 2000; Hill and Wheeler, 2002). The Indian Ocean and central Indian basin have reported to have a DOC concentration of 120-160µmolol and 191-41µmolol (Menzel, 1964; Sardessai *et al.,* 2001; Doval and Hansell, 2000), although the western Indian Ocean DOC concentration reported was of 50-230 µmololC (Kumar *et al.* (1990). Nicobar waters,as reported by Mohan *et al.* (2012), DOC concentration was in the range of 18-89µM. Moving east towards the Southwest Atlantic Ocean, Arabian Sea, Equatorial Atlantic Ocean and Mid Atlantic Bight DOC are reported in the range of 83µmolol C.L^{-1}, 65-300 µmolol C.L^{-1}, 46-97µmolol and 49-165µmolol C (Menzel, 1964; Kumar *et al.,* 1990; Guo *et al.,*1995; Thomas and Lara,1995; Hansell and Peltzer, 1998; Vlahos *et al.,*2002).

The POC of open ocean waters in the temperate region of North Pacific, Northeast Pacific, and Japan Sea have reported to accumulate POC in the range of 3-46µM C.L^{-1}, 0.018-4µmolol.L^{-1} and 2µmololC.L^{-1} (Ichikawa, 1982; Sherrell *et al.,* 1998). The Southern ocean POC concentration of a range 50000µmololm^{-2}.d^{-1} (Buesseler *et al.,* 2001), while studies by Morán *et al.* (2001) suggested a concentration of 38µmololC.m^{-3}.h^{-1} obtained from the phytoplankton through an experimental incubation study using the Antarctic waters and a concentration of 3-14µmololC was reported by Doval *et al.* (2001) in the Atlantic Sector of Southern Ocean. The POC concentration in Atlantic Ocean, North Equitorial Atlantic, North Atlantic and North Polar Atlantic were reported so far as 2-10µM C.L^{-1}, 2-6 µM.L^{-1}, 46µM and 4167-33332 µmolol.m^{-3}, respectively (Wangersky and Gordon, 1965; Stramska and Stramski, 2005; Stramska, 2014). However, the Ross Sea to Southern Baltic Sea, the POC concentration varied from 3-107µMC, and 8583-85997µmololC.m^{-3} (Carlson *et al.,* 2000; D-Głowacka *et al.,* 2010). The Baltic Sea concentration of carbon was a resultant of zooplankton, phytoplankton and detritus available in the surface waters. The Arctic POC concentration was reportedly low, because the majority of the organic matter released constituted the DOC and a limited POC flux rate was observed. The range varied from 2µmolol (Griffith *et al.,* 2012). The particulate organic matter in the Arctic Ocean shelf was approximately at the level of 40 to 50%, while the slope and basin water represented 90% of the organic matter in the dissolved form. The Antarctic waters POC concentrations ranged from 17-43µmolol.L^{-1}, which was several times higher than the mean open oceanic waters (Menzel and Ryther, 1968; Rakusa-Suszczewski, 1972; Artemev and Melnikov, 1974; Pecherzewski, 1978; Morán *et al.,* 2001).

The tropical and subtropical POC concentrations in the Westernnorth Pacific, Eastern Pacific Ocean, Northeastern Pacific Ocean, South China Sea, Equator and Central Indian Ocean reported, 3500-9833µmololC m^{-2}.d^{-1}, 1µmololC.L^{-1}, 13µmolol, 1µmolol.L^{-1} and 44µmolol, respectively (Ichikawa, 1982; Bacon *et al.,*1996; Doval and Hansell, 2000; Hill and Wheeler, 2002; Shih *et al.,* 2015). The Southwest Atlantic Ocean and Sargasso Sea the POC were reported in the range of 3-18µmolol and 5µmolol (Menzel, 1967; Lara *et al.,* 2010).The Northwestern Pacific Ocean had highest concentrations at the boundaries of mesoscale eddies. The reports by Shih et al. *et al.,* (2015) suggested that the presence of denuded diatom frustules and fecal pellets from zooplankton were responsible for the increased concentration of POC.

Discussion

Carbon sequestration is a process of removal, capture and storage of carbon from the atmosphere. Recent years the increment of temperature in the atmosphere was ascribed to rise of carbon dioxide level in the atmosphere. The rise of carbon dioxide in the atmosphere may be due to the reduction of forest cover, burning of fossil fuels, emission of greenhouse gases by anthropogenic activities, etc. Now, scientists are working out different methodologies to remove the excess carbondioxide from the atmosphere and to curb this rise. The ocean has been considered one of the important sink zones to store the carbondioxide in larger quantities. For this process, to understand and estimate the dissolved and particulate organic carbon, different methodologies were considered and are being worked out for their practicability. However, in this regard, to understand the basic process involved in carbon sequestration in the marine environment, cursory analysis was carried out and it was found that there is a lacuna in the existing data base of above mentioned factors. The studies on these aspects with reference to different environment suggested that the following problems to be addressed without any ambiguity before initiating these studies.

The existing literatures on the availability of DOC and POC in the marine environments were classified into three major categories such as the Continental Shelf waters, Open Seawaters and Coral reef waters. The sea waters were further divided into temperate and tropical environments based on the geographical locations. The temperate continental shelf waters represented DOC values of 30-280µmolol.m^{-2}.d^{-1} and tropical water varied from 40-102µmololC. However, the POC concentration in the temperate and tropical coastal waters ranged 1-500000 µmolol.m^{-2}.d^{-1} and 1.5-130 µmolol.m^{-2}.d^{-1} (Table 1. and 3.).

The open sea waters DOC concentration for temperate and tropical regions, ranged between 5-80,000 µmolol.m^{-3} and 18-300 µmolol.L^{-1}, respectively. The exhibited POC concentrations for temperate and tropical regions were between 0.018-33332µmololC.m^{-3} and 0.1-9833µmololC.m^{-2} (Table 2. and 4.).The coral reef waters were not categorized as temperate or tropical regions however, data were presented as DOC and POC prevailing within the reef boundary. The total DOC and POC ranged between 71.06-1,641 µmolol.L^{-1} and 7-12411 µmolol respectively (Table 5.). The above review suggested that the quantification of carbon availability does not follow uniform unit for expression of carbon concentration available in the marine waters, which possess difficulty in standardizing the status of carbon availability in the different major environments existing in the marine waters.

The next important factor understood from the literature review is that, only limited studies had been carried out in this regard and also lacks a repeatable time frame with same basic objectives. The existing literatures also do not clearly establish the nearshore processes involved in the increment or decrement of DOC and POC values in this dynamic environment. Contribution of coastal waters to the overall carbon budget is not clearly understood and quantified. The influence of physical factors such as temperature, salinity, submarine ground water discharge and pH on the retention or release of DOC and POC in the marine environment has to be studied widely. The oligotrophic waters of coral reef environment concern, the establishment of DOC and POC availability, other than primary productivity to be quantified in a closed grid.

The existing literatures clearly stated that the temperate waters of offshore as well as open ocean has larger quantum of DOC and POC than the tropical waters, this factor should also be established in concrete manner. The published reports also did not reveal the contribution of upwelled waters to the concentration of DOC and POC for the particular environment.

Table 1. Dissolved Organic Carbon (DOC) concentration present in Continental Shelf Waters

Continental Shelf waters -DOC Concentration - Temperate Regions				
SL.NO	DOC concentration	Concentration in µmol	Location	Reference
1	174 ± 1 µM	174 ± 1µmol	Arctic Ocean	Cooper *et al.,* (2005)
2	76±9µmol	76±9µmol	Southeastern bering sea	Guo *et al.,* (2004)
3	0.8-1.7mg C.L^{-1}	66.66-144.66µmolC.L^{-1}	Sagami Bay	Ogura *et al.,* (1975)
4	30-42 µM C	30-42µmol C	Ross Sea	Carlson *et al.,* (2000)
5	210-280µmol	210-280µmol	Black Sea	Cauwet *et al.,* (2002); Ducklow, (2007)
6	75-170µmol	75-170µmol	Roseway Basin	KepKay and Wells, 2002
Tropical and Sub Tropical				
7	105µM	105µmol	California Current	Hill and Wheeler, 2002
8	40-170µmol.L^{-1}	40-170µmol.L^{-1}	East China Sea	Zheng-bin *et al.,* (1997)
9	65-75µM	65-75µmol	East China Sea	Ogawa *et al.,* (2003)
10	61.2-95.2µM	61.2-95.2µmol	East China Sea	Hung *et al.,* (2000)
11	58-88µmol	58-88µmol	Western Mediterranean (Tyrrhenian Sea, Sardinia Channel and Algerian Sea)	Santinelli *et al.,* (2002)
12	50-100µM	50-100µmol	Mediterranean Sea	Santinelli *et al.,* (2006)
13	90µmolol C.L^{-1}	90µmolC.L^{-1}	North-western Mediterranean Sea	Trabel and Rassoulzadegan (2011)
14	2560µg.C^{-1}.L^{-1}	213µmol	North Western Mediterranean Sea	Ribes *et al.,* 1999
15	67-90µmol	67-90µmol	Mid Atlantic Bight	Guo *et al.,* (1995)
16	45-102µM C	45-102µmol C	Middle Atlantic Bay	Kepkay (2000)
17	60-80µmol	60-80µmol	Gulf of Mexico	Guo *et al.,* (1995)

Table 2. Dissolved Organic Carbon (DOC) concentration present in Open Sea Waters.

Open Sea waters - DOC Concentration - Temperate Waters				
SL.NO	DOC concentration	Concentration in µmol	Location	Reference
1	55-89µmol C.L^{-1}	55-89µmol C.L^{-1}	Pacific Ocean	Taki and Suzuki, 2001
2	84.7-177±6.9 µmol	84.7-177±6.9µmol	North Pacific Ocean	Tanoue, 1992
3	43-85 µmol C	43-85µmol C	Northern South China Sea	Hung *et al.,* 2007
4	35 to 85 µmol	35 to 85µmol	Northwestern Pacific	Williams and Druffel, 1987
5	30-50/µmololol dm^{-3}	30-50µmol	Northwestern Pacific	Sugimura and Suzuki, 1988
6	52µmol C	52µmol	Indian sector of Southern ocean	Wiebinga and Baar, 1998
7	0.06 mgC m^{-3}h^{-1}	5µmolC m−3h−1	Antarctic waters	Morán *et al.,* 2001
8	0.7 mg.L^{-1}	58.33µmol	Atlantic Ocean	Menzel, 1967
9	55-80 mol.DOCm^{-2}.a^{-1}	55000-80000 µmol m^{-2}.a^{-1}	North Atlantic ocean	Kahler *et al.,* 2010
10	7-100µmol	7-100µmol	North Atlantic ocean (Sargasso Sea)	Kepkay and Wells, 2002
11	54-84µmol	54-84µmol	Arctic water	Benner *et al.,* 2005
12	30-70 µmol	30-70µmol	Arctic waters	Griffith *et al.,* 2012
		Tropical and Sub Tropical		
13	62-103µmol	62-103µmol	Southern California Bight	Hansell *et al.,* 1993
14	75µmol	75µmol	California Current	Hill and Wheeler, 2002
15	68µmol C	68µmol	Equatorial Pacific Ocean	Hansell *et al.,* 1997
16	85µmol	85µmol	Eastern Pacific Ocean	Hansell and Waterhouse, 1997
17	80µmol C	80µmol C	Western South Pacific Ocean	Doval and Hansell, 2000
18	120-160µmol	120-160µmol	Indian Ocean	Menzel, 1964
19	41-191 µmol	41-191µmol	Central Indian Basin	Sardessai *et al.,* 2001
20	68-73µmol	68-73µmol	Central Indian Ocean	Doval and Hansell, 2000
21	17.91-88.57µM	17.91-88.57µM	Nicobar	Mohan *et al.,* 2012
22	50-230µmol C	50-230µmol C	Western Indian Ocean	Kumar et al., 1990
23	1mg C.L^{-1}	83.33µmol C.L^{-1}	South West Atlantic Ocean	Menzel and Ryther, 1968
24	80µmol C	80µmol C	Northern Arabian Sea	Menzel, 1964
25	80-300µmol C	300µmol C	Arabian Sea and Indian ocean	Kumar *et al.,* 1990
26	65-100µmol C	65-100µmol C	Arabian Sea	Hansell and Peltzer, 1998
27	97-46 µmol C	97-46µmol	Equitorial Atantic ocean	Thomas and Lara, 1995
28	50-75 µmol	50-75µmol	Mid Atlantic Bight	Guo *et al.,* 1995
29	49-165µmol C	49-165µmol C	Mid Atlantic Bight	Vlahos *et al.,* 2002

Table 3. Particulate Organic Carbon (POC) concentration present in Continental Shelf Waters.

Continental Shelf waters -POC Concentration - Temperate Regions				
Sl.No	POC concentration	Concentration in µM	Location	Reference
1	8.77-27.47 mmolCm^{-2}d^{-1}	8770-27000 µmol Cm^{-2}d^{-1}	Northern Baffin Bay	Amiel *et al.,* 2002
2	10-100µg C.L^{-1}	0.83-8.33µmol C.L^{-1}	Coat of Peru to Galapagos	Menzel, 1967
		Tropical and Sub Tropical		
3	37µM	37µmol	California Current	Hill and Wheeler, 2002
4	21-63µM C	21-63µmol C	Cape perpetua	Karp-Boss *et al.,* 2004
5	5-15µmol.L^{-1}	5-15µmol.L^{-1}	Western Bay of Bengal	Gupta and Sarma, 1997
6	4.80 - 29.12µM	4.80 -29.12µmol	Bay of Bengal	Khodse *et al.,* 2009
7	3.1-11.1µM	3.1-11.1µmol	Bay of Bengal	Fernandes *et al.,* 2009
8	18-162µg.L^{-1}	1.5-13.5µmol.L^{-1}	Malaysian Coastal waters	Ichikawa *et al.,* 1987
9	40-130µmol	40-130µmol	Mediterranean Sea	Cauwet *et al.,*1997
10	387µg/ C.L^{-1}	32µmol	North Western Mediterranean Sea	Ribes *et al.,*1999

Table 4. Particulate Organic Carbon (POC) concentration present in Open Sea Waters.

Open Sea waters - POC Concentration - Temperate Waters				
Sl.No	POC concentration	Concentration in µmol	Location	Reference
1	35- 550µg C.L^{-1}	2.92-45.83µmol C.L^{-1}	North Pacific and the Bering Sea	Ichikawa, 1982
2	0.21-42.73µg.L^{-1}	0.018-3.56µmol.L^{-1}	Northeast Pacific	Sherrell *et al.,*1998
3	23µgC.L^{-1}	1.92µmol C.L^{-1}	Japan Sea	Ichikawa, 1982
4	10-50 mmol C m^{-2} d^{-1}	10000-50000µmol m^{-2} d^{-1}	Southern Ocean	Buesseler *et al.,* 2001
5	0.45 mgC m^{-3}h^{-1}	37.5µmol C m^{-3}h^{-1}	Antarctic waters	Morán *et al.,* 2001
6	3.4-14.1 µmol C	3.4-14.1µmol C	Atlantic sector of Southern Ocean	Doval *et al.,* 2001
7	20-120µg C.L^{-1}	1.67-10µmol C.L^{-1}	Atlantic Ocean	Wangersky and Gordon, 1965
8	21-70µg.L^{-1}	1.75-5.83µmol.L^{-1}	North Equitorial Atlantic ocean	Stramska and Stramski, 2005
9	550µg C.L^{-1}	45.83µmol	North Atlantic ocean	Wangersky *et al.,* 1979
10	7-100µmol	7-100µmol	North Atlantic ocean	Kepkay and Wells, 1992
11	50-400mg m^{-3}	4166.5-33332µmol m^{-3}	North polar Atlantic ocean	Stramska 2014
12	3-107µM C	3-107µmol C	Ross Sea	Carlson *et al.,* 2000
13	103-1032mg.cm^{-3}	8582.99-85996.561µmolC m^{-3}	Southern Baltic Sea	D-Głowacka *et al.,* 2010
14	1.5-3.8µmol	1.5-1.8µmol	Arctic waters	Griffith *et al.,* 2012
15	54-80µmol	54-80µmol	Arctic water	Benner *et al.,* 2005
Tropical and Sub Tropical				
15	7µg C.L^{-1}	0.58µmol C.L^{-1}	South China Sea	Ichikawa, 1982
16	42-118mgC .m^{-2}.d^{-1}	3499.86-9832.94µmol C.m^{-2}.d^{-1}	Western North Pacific Ocean	Shih *et al.,* 2015
17	12.6µmol	12.6µmol	North Eastern Pacific Ocean	Hill and Wheeler, 2002
18	0.1-0.8µmol.L^{-1}	0.1-0.8µmol.L^{-1}	Equator	Bacon *et al.,* 1996
19	43±0.9 µmol	43±0.9µmol	Central Indian Ocean	Doval and Hansell, 2000
20	100µg C.L^{-1}	8.33µmol C.L^{-1}	South West Atlantic Ocean	Menzel, 1968
21	3-18µmol	3-18µmol	Southwestern Atlantic	Lara *et al.,* 2010
22	60µg C.L^{-1}	5µmol C.L^{-1}	Sargasso Sea	Menzel, 1967

Table 5. Dissolved Organic Carbon (DOC) and Particulate Organic Carbon (POC) in Coral Reef Environment.

Coral reef Environment-DOC/POC Concentration				
Sl.No	DOC concentration	DOC Concentration in µmol	Location	Reference
1	1334-1641µM	1334-1641µmol	Western side of Andaman and Nicobar Islands	Kumari *et al.,* 2015
2	1494-1358µM	1494-1358µmol	Eastern side of Andaman and Nicobar Islands	Kumari *et al.,* 2015
3	71.06-106.31µM.L^{-1}	71.06-106.31µmol.L^{-1}	South Andaman	Mohan *et al.,* 2016
4	1.1±0.5 mmol.m^{-2}.d^{-1}	1100±500µmol.m^{-2}.d^{-1}	Gulf of Aqaba	Naumann *et al.,* 2012
5	14.98 ± 4.26mg.C.m^{-2} hr^{-1}	1248.28±354.99µmolC.m^{-2} hr−1	Experimental work	Nakajima *et al.,* 2010
6	0.7-11.2mg.L^{-1}	58.33-933.30µmol.L^{-1}	Experimental work-Red Sea	Wild *et al.,* 2009
7	1501-1778µg.L^{-1}	125.17-148.17µmol.L^{-1}	Experimental work-Red Sea	Wild *et al.,* 2010
	POC concentration	Concentration in µmol	Location	Reference
8	0.28-3.25mg C.L^{-1}	23.33-270.82µmol C.L^{-1}	Palk Bay	Sridhar *et al.,* 2008
9	3.8±1.1 mmol.m^{-2}.d^{-1}	3800±1100µmol.m^{-2}.d^{-1}	Gulf of Aqaba	Naumann *et al.,* 2012
10	8.2±4.2mg m^{-2}.h^{-1}	683.31±349.99µmol.m^{-2}.h^{-1}	Caribbean reef lagoon	Haas *et al.,* 2010
11	188.9 (± 65.7) mg C m^{-3}	12410.73±5474.78µmol C.m^{-3}	Tioman Island, Malaysia	Nakajima *et al.,* 2011
12	8.93 ± 1.67mg C m^{-2}.h^{-1}	744.14±139.16µmolC m^{-2}.h^{-1}	Experimental work	Nakajima *et al.,* 2010
13	0.05-0.31mg.L^{-1}	4.17-25.83µmol.L^{-1}	Experimental work-Red Sea	Wild *et al.,* 2009
14	85-95µg.L^{-1}	7.08-7.92µmol.L^{-1}	Experimental work-Red Sea	Wild *et al.,* 2010

Conclusion

Until the above discussed factors were not established beyond doubt, the development of different processes for carbon sequestration would not be complete and may also lead to some futuristic unexpected problems. So, the scientific community should establish these factors by opting a uniform methodology, presentation of results and establishment of factors for increment and decrement of carbon in the different parts of the marine environments.

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