Chapter-2

Literature Review

In recent times, each and every component of nature involved in carbon metabolism, either directly or indirectly is studied by various experts in order to identify their role in climate change. Hence coral reefs, being the largest reservoir of calcium carbonate have also been studied to assess their role in the changing climate.

2.1 Carbon storage potential of reef

Rees *et al.* (2004) had studied the carbon stored at the reefs of Rodrigues at Southwest Indian Ocean; Lizard Island and Mac Gillivray reefs at Great Barrier Reef. They evaluated the mass of $CaCO_3$ accumulated by ocean islands in the Western Indian Ocean to be ca. 217 Gt $CaCO_3$ over 5032 years during the Holocene.

2.2 Reef Accretion and Petrography

Grossman and Fletcher studied 32 reef cores (6 cm diameter) collected from Oahu, Hawaii where they achieved maximum depth of 18 m. They got the sample recovery about 35–100% with an average of 68% in the Holocene reef. They found that the presence of subsurface cavities and changes in lithology, reflected by noticeable changes in penetration rate and cutting sound during drilling. They performed radio-carbon and thorium dating and derived the accretion rate ranging from 0.24 to 6.91 mm/years. The petrographic study revealed the presence of five bio-lithofacies bindstone, rudstone, grainstone, massive coral framestone, and branching coral framestone facies. The dominant facies found in the Holocene reef are the rudstone, massive coral framestone, and branching coral framestone facies.

Buddemeier and Smith (1988) studied the impact of eustatic fluctuation on coral reef growth; as a part of this study they found that even the same reef shows difference in accretion rate at different reef zones. They found out model upward accretion rates of 0.6 mm y^{-1} at shallow lagoonal reef systems that increases at reef flat to up to 3 mm y^{-1} and reaches the pick at coral thickets zones to about 7 mm y^{-1}. Hence, the reef flat is accreting slower compare to coral thickets yet, serve to protect coastlines by absorbing wave energy. However, the rising sea level will have positive impact on the accretion rate of reef flat; as due to the raised sea-level, the exposure of the reef flat coral will decrease giving better opportunity of growth and species diversity to the corals inhabiting at reef flat (Kinsey & Hopley, 1991; Smith &

Buddemeier, 1992). Additionally, the corals growing at lagoonal part will also get rid of extreme temperature, salinity and lack of nutrition after the increased sea level (Smith &. Kinsey, 1976; Smith & Buddemeier, 1992).

The vertical accretion rates (VAR) of the specimens of *Siderastrea stellata* collected from Atol Das Rocas reefs ranged from 1.5 mm/year to 3.2 mm/year which gave the core recovery of 40% drilled from the leeward side of the island (Kikuchi and Leao 1997). These VAR figures should be interpreted as minimum growth rates because of possible time averaging caused by the length of time elapsed between coral recruitment and further overgrowth by coralline-algal crusts.

2.3 Significance of coral species to identify Eustatic changes

The co-relation between eustatic changes and reef growth can well be revealed in presence of **important framework builders** such as the coral species *Acropora palmata* and *Acropora cervicornis.* In the Caribbean, these corals are found associated with the coralline algae *Porolithon pachydermum* and *Lithophyllum,* building reefs in high–moderate wave energy environments (Adey 1978; Macintyre 1988).

2.4 Ocean Acidification–factor affecting reef growth

According to Kleypas and Yates (2009), coral reefs were the first ecosystems to be recognized as vulnerable to ocean acidification. So far the research on the effects of ocean acidification has emphasized on calcification rate of corals which has brought forth the result that the main reef-building organisms, corals and calcifying macroalgae, will calcify 10–50% less relative to pre-industrial rates by the middle of this century. This decreased calcification will consequently affect their ability to function within the ecosystem and will almost certainly affect the workings of the ecosystem itself. However, ocean acidification affects not only the organisms, but also the reefs they build. The decline in calcium carbonate production, along with an increase in calcium carbonate dissolution, will diminish reef building and the reefs services like high structural complexity that supports biodiversity on reefs and breakwater effects that protect shorelines and create quiet habitats for other ecosystems, such as mangroves and sea grass beds. The focus on calcification in reefs is warranted, but the responses of many other organisms, such as fish, non-calcifying algae, and sea grasses, to name a few, deserve a close look as well (Kleypas and Yates, 2009).

Latitude is the main factor controlling the variation of light and temperature (Kain, 1989) hence worldwide distribution of corals is significantly affected by latitude linked with temperature and irradiance variations (Kleypas *et al*., 1999).

Additionally temperature and irradiance strongly influence coral growth, physiology and demography (Kleypas *et al.*, 1999; Lough and Barnes 2000).

In general, coral growth decreases with increasing latitude, to a boundary beyond 30°N and 30°S, where coral reef development no longer occurs (Kinsey and Davies 1979).

Another view suggests that coral growth is a function of three related parameters *i.e.*, calcification, linear extension and skeletal density (Lough and Barnes, 2000; Carricart-Ganivet, 2004), and their measurement is essential when assessing the effects of environmental parameters on coral growth, because none of the three is a perfect predictor of the other two (Dodge and Brass, 1984). Analyzing these variables also allows for prediction of the possible effect that climatic changes can have on coral ecosystems (Cooper *et al*., 2008).

2.5 Work done in Gujarat

In Gujarat, a number of studies have been carried out on corals, coral reefs and reef associates as well as reef geomorphology, but no any extensive study has been recorded to find out the carbon storge potential of the coral reefs of Gujarat; however the carbon storage potential of mangrooves and other vegetations have been carried out. The studies reveal that total carbon sequestered by the mangroves of the GoK is 0.2148 million ton (Pandey *et. al.*, 2013 *a*) and total carbon sequestered by trees of urban & sub-urban (selected species of non-forest area) area is 33.66 million ton (Pandey *et. al.*, 2013 *b*).

In case of corals, the inorganic carbon gets stored in large amount giving rise to huge calcium carbonate structures like reef. The process of reef building takes centuries, hence the estimation of calcification rate (reef formation) needs to know the status of reef at various time period before few thousand years. This critically requires the dating of reef using any of the technique *viz.,* Radio carbon or Uranium-Thorium dating. Additionally, Such efforts require the estimation of both accretion and erosion rate of a reef *i.e.*, sediment mass balance of reef. This involves many or some of the methods like reef drilling, age estimation, alkalinity measurement, core lithology and seismic profiling.

Although, the lack of carbon sequestration studies of the coral reefs in Gujarat, a number of studies have focused on the dating of coastal entitis like mollusk shells, foraminifers, or coral reefs. The major objectives of the studies remained to find out the quaternary and holocene sea-level, palaeo-climatic and archeological studies.

A number of factors have been reported to bring forth the shoreline shift of any coastal region such as tectonic disturbance, sedimentological regime causing erosion or deposition, glacio-eustacy etc (Gaur & Vora, 1999). The fluctuations of shoreline directly affects the evolution and devolution of a number of species; especially the species inhabiting intertidal region of the coastal ecosystem. In India, researchers have focused on the study of sea level fluctuations that reveal the prevalence of higher sea level of about 6m before 6000 years. The studies further specifies that the sea level kept decreasing and reached or stabilized at present level at 4000 years BP(Gaur & Vora, 1999).

During middle and late Holocene, the sea level was 1–4 m higher that formed beach rocks along the Indian coastline (Mathur *et al.*, 2005). The radiocarbon dating of several samples along the Gujarat coastline was carried out by the geologist which involves the collection of *Turbo* (mollusc) from Mithapur that came out to be as old as 2100 ± 35 yearss BP and a *Cerithium* from Porbandar (Okha Shell Limestone Member) which is 4080 ± 90 yearss BP (Mathur *et al.,* 2004). It is noteworthy that the samples were collected from 2-4 meter above mean sea level and aged below 6000 years. This indicates the existence of sea-level 2-4 m higher than today before 6000 years. The study also showed transgressive–regressive–transgressive events for Gujarat coast from the Okha shell limestone members. It is also accepted widely that glacio-eustatic sea level was higher before 6000 years (Erinc, 1978; Katupotha, 1988; Pirazzoli, 1991).

Gupta and Amin (1974) made the age estimate of corals near Dwarka area using $^{230}T/^{234}U$ and $^{234}U/^{238}U$ techniques that revealed the occurrence of sea transgression 6000, 30, 000 and 1, 20,000 year BP. Somayajulu dated the coral samples from the same area of Dwarka and found the dates to be 1, 18 ,000 to 1, 76 ,000 year BP.

Gupta S K (1972) carried out age astimation of corals from Saurashtra region, using radio carbon C^{14} technique that came out to be falling in two age classes *i.e.,* 5,000 to 6,000 years BP and 25,000 - 35,000 years BP.

Juyal *et al.,* (1995) studied oyster reefs occurring in Rupen river bed, north of Diu the ages of oyster reefs indicate a 2m higher sea at 2500 and 3300 ka. The oyster bed occurring at 1m AMSL near Khada Bandar has yielded a C^{14} age 3470 ± 110. This suggests the Holocene high sea level of about 2m in Saurashtra which correlates well with the global sea level of this time (Juyal *et al.*, 1995).

Bruckner (1987) explained that Holocene transgression left fossil-beach ridges about 2 m above the HTL along the Konkan coast, before 2200 to 2600 year from present and considered it as the maximum Holocene transgression. Apart from this, there are many other coastal areas where beach rocks collected from 1 and 2 m above the HTL, have provided age 1110 and 4410 yearss BP (Bruckner, 1987; Hashimi, *et al.*, 1995; Rajshekhar & Reddy, 2003).

2.6 Coral bleaching

Coral reefs are among the most sensitive of all ecosystems to temperature changes, exhibiting bleaching when stressed by higher than normal sea temperatures. Corals usually recover from bleaching, but they die in extreme cases. Increased frequency of bleaching events will reduce corals' capacity to recover (Lough, 2000). According to Hayes and Goreau (1991), large-scale bleaching episodes indicate that coral reefs are likely to be one of the first ecosystems damaged or destroyed by global climate change. Sessile tropical coral reefs are unable to relocate the favourable conditions due to which they are uniquely threatened by global warming (Goreau and Hayes, 1994).

Scientists have brought out an interesting correlation between coral bleaching and ultraviolet (UV) radiation flux. It has been reported that coral bleaching had coincided with certain physical characteristics of sea water *i.e.,* low wind velocity, clear skies, calm seas and low turbidity when conditions favour localized heating and high penetration of short wave length (UV) radiation (Fleischmann, 1989). Such warm water has decreased oxygen holding capacity, thus potentially stressful high SST and UV radiation flux could conceivably cause coral reef bleaching on a global scale (Tsonis and Elsner 1989). This ultraviolet solar radiation also pose adverse effect on other reef associates, (Worrest 1982) including reef corals and their symbiotic zooxanthellae (Lesser *et al.,* 1990). However, the reef building corals have the capacity to block the harmful UV radiation with the help of UV-absorbing compounds-*a family of mycosporine-like amino acids (MAA)* (Dunlap and Chalker 1986). The UV concentration around the coral environment triggers the production of such compounds; hence UV absorbing compounds are inversely proportional to the depth (Dunlap *et al.* 1986).

The coral bleaching dates back more than a century but after 1980s the events have occurred globally on larger scale with increased frequency and severity (Glynn, 1993; Goreau and Hayes, 1994; Goreau *et al*. 2000). Such an event of coral bleaching that involves entire reef tracts or regions is considered as *mass coral bleaching* (www. reefresilience.org). Hence, mass coral bleaching is believed to be a serious challenge to the health of the global coral reefs. Bleaching may occur at smaller (Egana and DiSalvo, 1982; Goreau, 1964) or larger geographic scales that may affect entire reef systems and geographic realms (Glynn 1993, Hoegh-Guldberg and Salvat, 1995).

It has been observed that globally the coral reefs have come across 60 major coral bleaching events from 1979 to 1990 whereas only nine were recorded from 1969 to 1979 although both the periods are considered as the years of active reef research (Stone *et al*, 1999). Coral bleaching was also reported during 1983, 1987, 1991 and 1995 from all tropical areas of the Pacific Ocean, Indian Ocean and the Caribbean Sea (Westmacott *et al.*, 2000). Majority of the reefs were bleached during the 1998 bleaching event leading to 16% mortality of corals globally (Wilkinson, 2002).

2.7 Indian scenario

The mass coral bleaching was recorded on all the coral reefs of India at different spatial and temporal scales. The coral reefs of the Palk bay showed mass coral bleaching during the month of April and May, 2010 (Ravindran *et al.*, 2012).

Another important reef of India *i.e.*, coral reefs of Andaman and Nicobar Islands also showed evidences of coral bleaching ranging from 37 to 70% at various sites during the month of April and May 2010 and is thought to be induced by the elevated sea surface temperature (Krishnan *et al.*, 2011). After 2010, the coral bleaching was also recorded on the consecutive year affecting 400 coral species, with the extent of 69.83 to 90 % on different Islands (Mondal *el. al.*, 2014).

Evidences of mass coral bleaching were also reported from Lakshadweep during May and June, 2010 which revealed 76.5% bleached corals, 87.5% of sea anemones and 88% of giant clams (Ajithkumar & Balasubramanian, 2012).

2.8 Work done in Gujarat

Arthur (1995) reported 1.2-1.4% of coral bleaching in the Gulf of Kachchh during summer months of Gujarat and concluded it to be a normal summer response of corals towards the summer temperature rise as the coral species of these latitudes are adapted to a wide range of temperature fluctuation at the intertidal regions. But during the summer of year 1998, he recorded an average of 11% coral bleaching in the Gulf of Kachchh resulted after El Nino Southern Oscillation and considered it as a higher level of coral bleaching than a normal summer response. Ecologists of WTI have also recorded coral bleaching at Mithapur in the Gulf of Kachchh during the year 2010(www.wti.org.in).

Adhavan, *et al.* recorded occurrence of coral bleaching on Pirotan Island in September, 2014 where they found bleaching in 7 scleractinian species *i.e., Favia favus, Favia lacuna, Favia speciosa, Favites halicora, Favites flexuosa, Porites compressa and Porites lichen.* They assumed the SST and sedimentation might be responsible for coral bleaching in Pirotan Island. They added that high SST in the Island might be due to delay in the onset of the southwest monsoon, resulting in prolonged summer period (Adhavan, *et al.,* 2014).

Vivekanandan *et al.,* (2009) studied the vulnerability of the corals and coral reefs of India with reference to temperature. In their study they predicted the future and the fate of the Indian reef. They suggested that the number of catastrophic bleaching events may increase in all the regions, due to the rise in the sea surface temperature.