Chapter-1

Introduction

1.1 Corals and Coral reefs

Planet Earth is occupied by two major elements the hydrosphere and the lithosphere. The interface between both of these is the coastline, where they interact extensively and intensively. Hence, the 1,634,701 km long coastline is significantly affected by the activities and phenomena taking place on both land and ocean (Burke, *et al.*, 2001). A number of geomorphological structures and benthic morphology affect the area and consequently give rise to a variety of biome/ ecosystems on the coastline. One of such ecosystem is the coral reefs. Coral reefs are the underwater wonderlands of incredible diversity. The term coral refers to marine, sedentary and mostly colonial animals. The basic unit of the colonies is termed as polyp. It resembles sea anemone *i.e.*, having radial symmetry and a crown of tentacles at the free end and the other end is attached at the hard substratum. The size of the polyp varies from few mm to up to a meter. Taxonomically the animals belong to the phylum cnidaria having the characteristic of tentacles armed with stinging cells (cnidoblast) that is often used to paralyse the tiny animals (plankton) that they eat (Goreau *et al.*, 1979). The polyps secrete calcium carbonate surrounding its body and form a cup shape in which the soft polyps retract for protection.

In a coral colony, the outer thin veneer is the only live tissue and rest beneath is the calcium carbonate skeleton, secreted by the polyps. The colony grows by means of asexual reproduction such as budding, fission etc., whereas the formation of new colonies is the result of sexual reproduction. As a result of asexual reproduction, the colony may result in any of the growth form like massive, sub-massive, encrusting, foliose, plate like or branching (Figure 1.1) which is species specific. The branching corals show the rapid growth compared to colonies with other growth forms (Oliver *et al.*, 1983). The massive coral colony grows at comparatively slower rate as well as it grows uniformly over its hemispherical surface (Connell, 1973). All except branching growth forms are observed on the reefs of the Gulf of Kachchh. However, the dead remnants of branching corals are found at many reefs on the Gulf of Kachchh. Many such colonies together form reef which harbours a number of flora and fauna interacting with one another to give rise to a complex ecosystem. Thus, coral reef ecosystems are spectacular natural wonders rivalling rain forest in terms of diversity and density. The Great Barrier Reef of Australia extending 2000 km long is a complex living structure (Venkatraman, 2003).

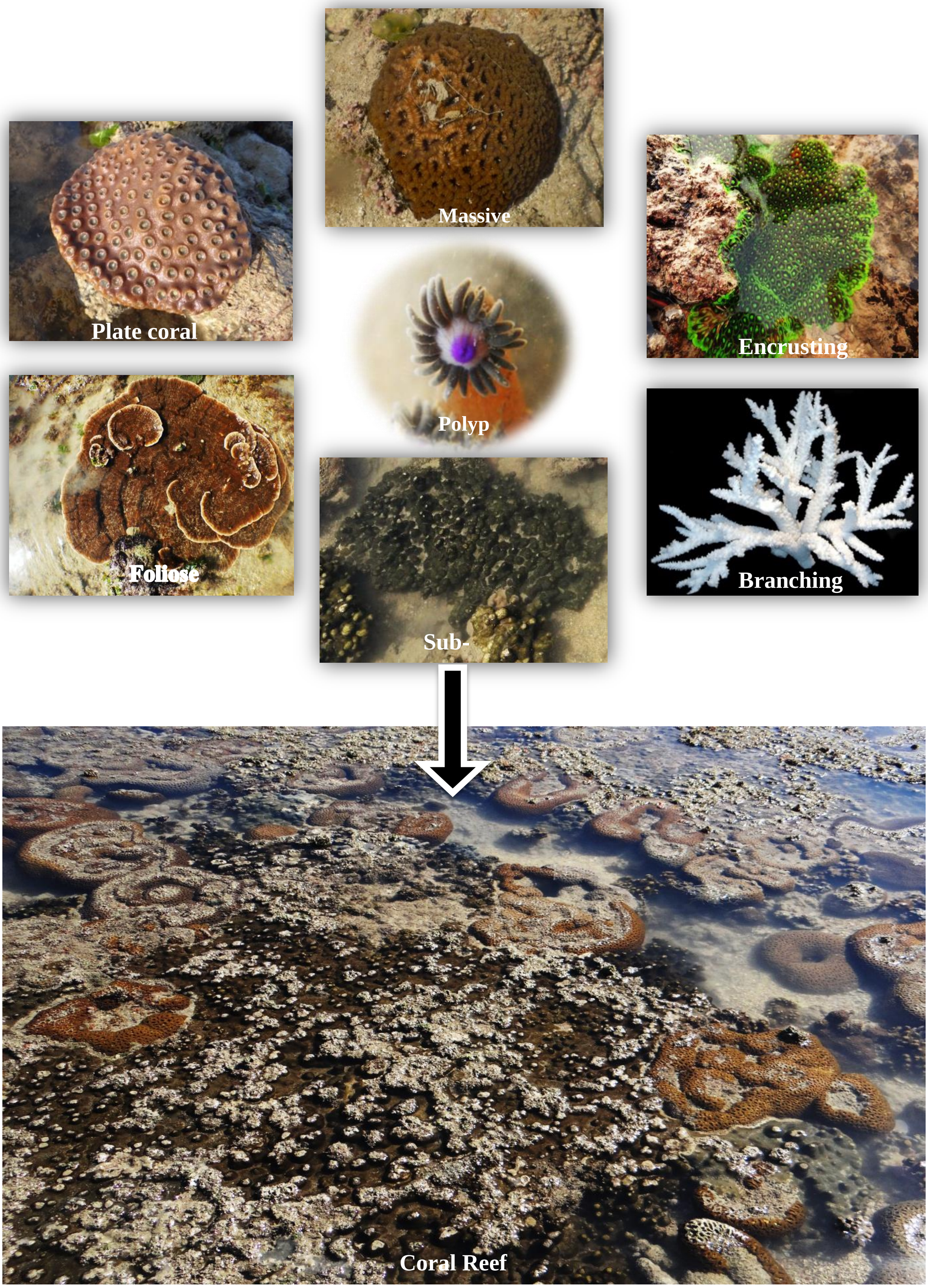

Figure: 1.1 Showing coral reef formation: Polyps together form various types of coral colonies and various coral colonies build up coral reef

1.2 Distribution of Coral reefs

Coral reefs are found in about 110 countries worldwide, majority lying between the tropics of Cancer and Capricorn, extending further north and south where warm currents provide a favourable habitat (Table 1.1; Figure 1.2; Figure 1.3).

It has been observed that reef usually flourish on the eastern coasts of landmasses either large continents or islands. This is attributed to the circulation patterns of the currents in the western part of the sea and ocean that allow reef growth and development at eastern seaboards of landmasses. In rare conditions, the reef building is also supported by the western coasts of the continents if appropriate necessary environmental conditions prevail.

The largest fringing reef in the world is situated at the North West coast of Australia called the Ningaloo reef. The reef is 260 km long and is Australia's largest fringing coral reef and the only large reef positioned very close to a landmass (NASA, 2008). The term Ningaloo means promontory that is *high land expanding into sea*.

The present day distribution of coral reefs is the result of a number of factors affecting its evolution and factors required for its survival, growth and reproduction. This reveals the dispersion of the stem species of the ecosystem to various part of the ocean. Hence, as a result of a number of known and unknown factors occurring since centuries ago to till date, with their variations today's coral reefs are distributed on shallow seas between the tropic of Cancer and Capricorn around the globe. The coral reefs occupy an approximately 2, 84, 300 km^2 area (Spalding, *et al.,* 2001) worldwide which is only 0.089% of the global ocean, indicating the coral reef to be a rare ecosystem. The coral reef covers less than 1.2 percent of the world's continental shelf area. The global distribution of coral reefs show a clear contrast *i.e.*, majority of the reefs are concentrated in the eastern Indian Ocean and western part of Pacific whereas the other ocean *i.e.*, Atlantic, Caribbean and eastern Pacific representing very limited coral reef area. In addition to this, the Central Atlantic and the West African coastlines show almost absence or rare occurrence of coral reefs as per the investigations so far (Spalding, *et al.,* 2001). The horizontal span of Indo-Pacific region stretches include from Red sea to up to central Pacific which includes major coral reef area situated in Red sea and Gulf of Aden, Arabian Gulf and Arabian Sea, Indian Ocean, Southeast Asia and Pacific region.

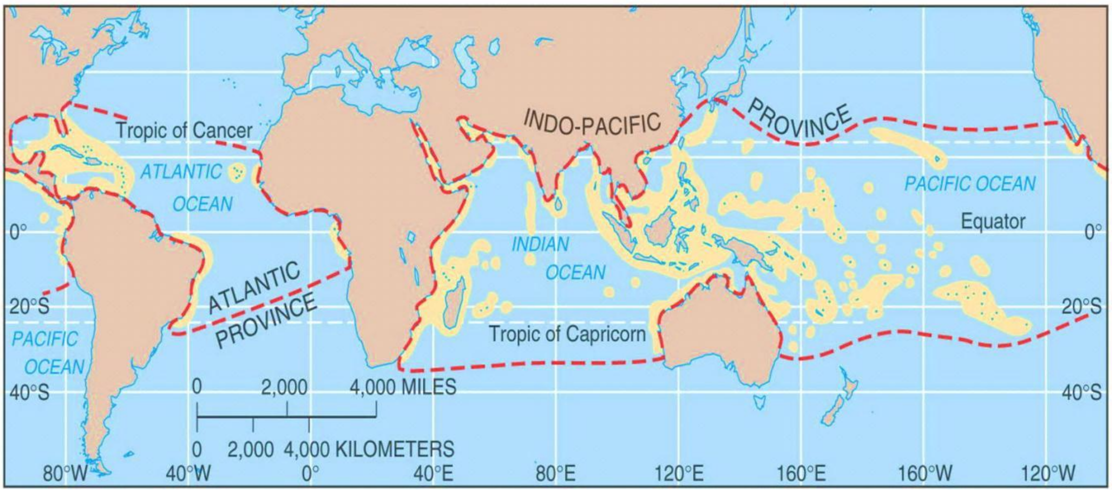

Figure 1.1 Global distribution of Coral reefs (Source: http://clasfaculty.ucdenver.edu)

Indonesia is the largest coral reef nation in the world, followed by Australia and the Philippines. There are other countries, geographically small but having significant contribution in terms of reef area *i.e.*, Papua New Guinea, Fiji, the Maldives, the Marshall Islands, Solomon Islands, Bahamas and Cuba.

Table 1.1 Global Coral reef area (km^2) and % of total reef area (Source: Spalding, *et al.*, 2001)

Region	Area (km^2)	% of world total
Atlantic and Caribbean	**21600**	**7.6**
Caribbean	20000	7
Atlantic	1600	0.6
Indo-Pacific	**261200**	**91.9**
Red sea and Gulf of Aden	17400	6.1
Arabian Gulf and Arabian Sea	4200	1.5
Indian Ocean	32000	11.3
Southeast Asia	91700	32.2
Pacific	115900	40.8
Eastern Pacific	**1600**	**0.6**
Total	**2, 84, 400**	

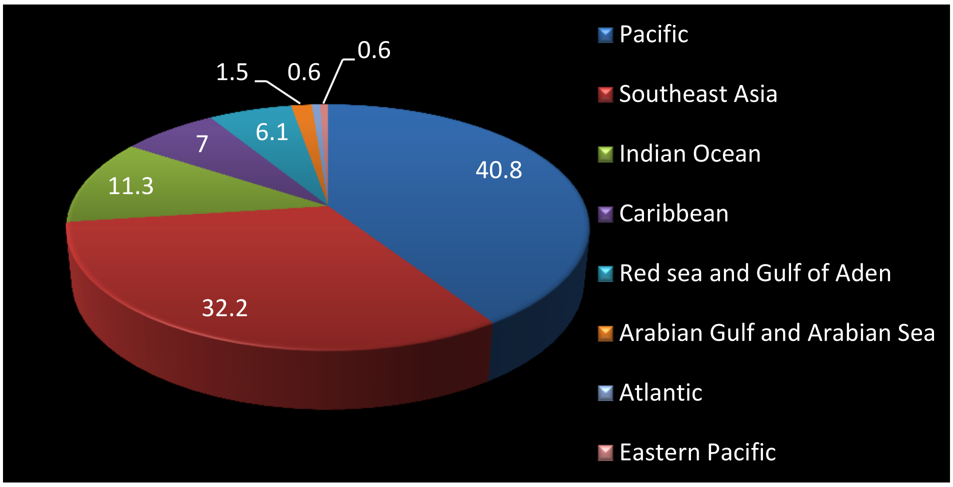

Figure 1.2 Global distribution of Coral reefs (%)

The species richness gradient of corals also follows the marine latitudinal diversity gradient which implies an increase in species richness with decreasing latitude from the equator to both Polar Regions (Briggs, 1974). Even on the same latitude the species richness and distribution are uneven *i.e.*, the Indo-Pacific region is roughly ten times diverse compared to that of western Atlantic. There are about 500-600 species representing Indo-Pacific coral community whereas it's approximately 50-60 at the western Atlantic. Scientists have found more coral species around a single island in Southeast Asia than have been identified for the entire Caribbean hence the region is called the epicentre of coral species. The high species richness in the circum-tropical belt is attributed to the desired seawater temperatures and maximum solar irradiation in the proximity of the equator. These two abiotic factors are supposed to be responsible for the relatively fast growth of shallow-water corals through their photo symbiotic relation with algae (zooxanthellae), which eventually may lead to the formation of reefs.

The Coral Triangle

The ranges of many tropical marine species overlap in a centre of maximum marine biodiversity, which is located in the Indo-Malayan region. This centre includes Malaysia, Philippines, Indonesia, Papua New Guinea (Figure 1.4) and has been named the East Indies Triangle. Due to its dependence on the presence of coral reefs, it has recently been referred to as the Coral Triangle. The species diversity of corals varies at different regions. The maximum coral species are found in South East Asia at a region known as the Coral Triangle (CT) where 76% (605 sp) of the world's coral species have been reported. The Coral Triangle is a geographical term referring to the tropical marine water of Indonesia, Malaysia, Papua

New Guinea, Philippines, Solomon Islands and Timor-Leste. Within this region, the highest coral diversity resides in the Bird's Head Peninsula of Indonesian Papua, which hosts 574 species (95% of CT total, and 72% of world's total), with individual reefs supporting up to 280 species per hectare. Within the Bird's Head Peninsula, Raja Ampat has the World's richest coral diversity area with 553 species.

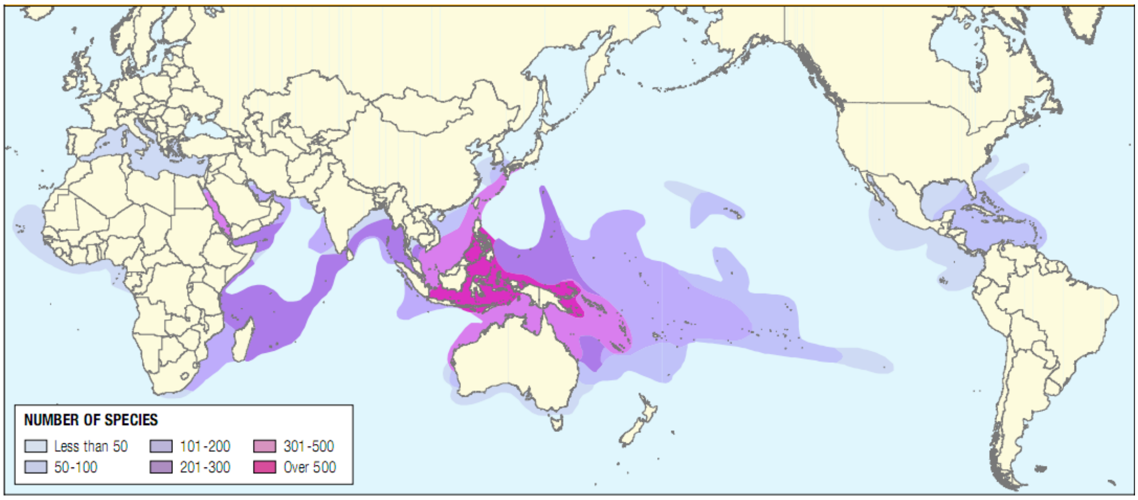

Figure 1. 3 Global scleractinian diversity; Source: J.E.N. Veron and Mary Stafford-Smith, Coral of the world Cape Ferguson, AIMS, 2000

Coral reefs of India

India is bestowed with four major coral reef formations namely, The Gulf of Kachchh in Gujarat state, Lakshadweep Islands, the Gulf of Mannar and Palk bay, in Tamil Nadu and Andaman and Nicobar group of Islands are the four major coral reefs of India. Except these, sites near Ratnagiri and Malvan of Maharashtra coast, Redi of Goa coast and Vishakhapatnam of the Andhra Pradesh coast also show the existence of coral reefs. During the 18th cruise of R V Gaveshani a submerged bank with living corals was discovered at Malpe. Recently, live corals have been recorded from Mumbai in Colaba area. Coral polyps were also collected in sediment - grab samples at the Bombay High Oilfield of the ONGC. In Indian Ocean, coral reefs formation is a function of a number of environmental factors like, the seasonal monsoons, equatorial calm, tropical cyclone and trade winds are the major factors regulating the reef distribution in the Indian Ocean regions. The impacts of Tidal ranges are prominently evident at reef areas (the Gulf of Kachchh) because reefs normally grow up to a certain tide level. Exposure to the atmosphere and desiccation controls the growth of corals, algae and other associated organisms in the reef zones (Bakus *et al.*, 1994). Reefs of Andaman and Nicobar contribute to 41% of the Indian reefs followed by Lakshdweep (35%), the Gulf of Kachchh (20%) and the Gulf of Mannar (4%) (Figure 1.5).

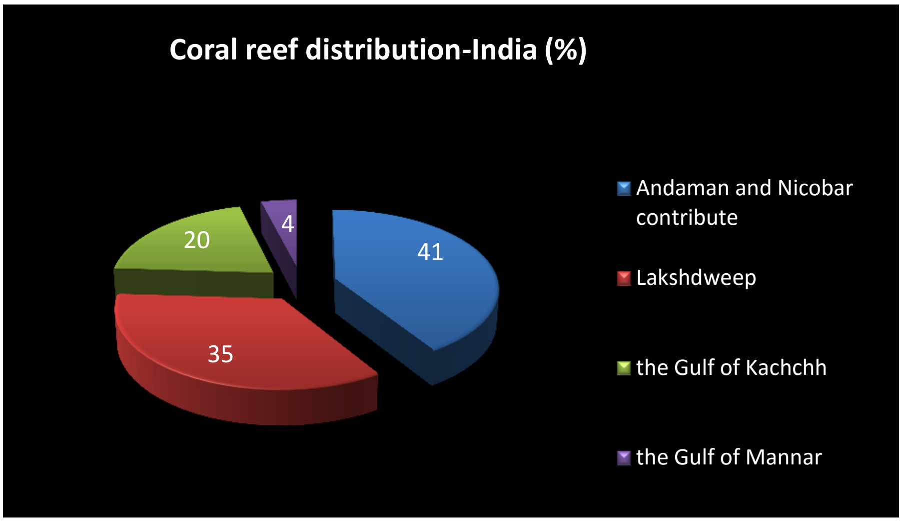

Figure1.4 Distribution of major coral reefs of India

1.3 Types of reef

Coral reefs are built by hermatypic corals that can grow in exclusively marine environment, warm temperature and well illuminated water. These requirements restrict the growth of reefs at shallow tropical coastlines. In a coral reef live part is limited to the thin veneer of live coral covering the hard rocky substratum or coral skeleton. The live tissue deposits calcium carbonate mineral Aragonite (a mineral form of crystalline calcium carbonate) beneath the live layer. With the course of time the underlying skeleton gets thickened getting the shape of a hard calcium carbonate platform. As per the complexity and morphology of the reef, they are classified in three major types, *i.e.*, fringing reef, barrier reefs and atolls.

Charles Darwin explained that corals first grew as fringing reef which is geographically in close association of sea shore compared to the rest two types and grows parallel to the coastline. The width of such reef depends upon the angle of the slope of continental shelf on which the reef is situated. If the continental shelf is steeply going downward towards the sea then the width will be shorter and vice versa. They are also known as shore reefs and this type of reef represents the simplest reef type. In most cases these types of reefs are young but with the passage of time and geographical changes it may progress into another kind of reef. Generally this type of reef does not contain any substantial lagoon and may merely form a narrow platform. The reef is not alike in the entire reef area but it differs significantly depending on the depth, faunal and floral community and structure of the reef. In this reef the coral growth is the most rapid and prolific due to shallow-well lit water which further allows the quick upward growth of calcium carbonate platform. Fringing reefs are found in the South Pacific - Hawaiian Islands and parts of the Caribbean. In India fringing reefs are found at Andaman and Nicobar islands (Venkataraman *et al*., 2003). Barrier reefs are also found parallel to the sea shore but far from the shore line and separated from the land by a shallow lagoon. They are believed to be older compared to the fringing reef. Sometimes the barrier reefs are formed from the fringing reef by the subsidence of the landmass they are growing on or the landmass gets flooded by the water due to eustatic transgression. The barrier reefs may get a variety of shape and size. Darwin added that sometimes the barrier reef covers the whole island and the distance between the reef and island may range from 1 mile to hundreds of miles. Generally the reef encloses a shallow lagoon like the atolls. Darwin also reported the barrier reefs as a stripe like or chains of reef in the mid ocean. As the seaward side of the reef experiences more violent waves, fragile corals grow more on the lagoon side of the barrier than on the open side of the reef. The barrier reefs may seriously obstruct shipping. The Great Barrier Reef of northern Australia in the Indo-Pacific region is the largest barrier reef in the world stretching more than 2,000 km (Venkataraman *et al.,* 2003). Florida, Cuba and elsewhere resemble many true barrier reefs in length, but are frequently not regarded as true barrier reefs because they are only separated from the mainland by a very shallow lagoon, or because they are not located on the edge of the continental shelf (Spalding *et. al.,* 2001). The barrier reefs are not recorded from Indian coast.

Atolls are characteristically formed in mid ocean far from the main land masses. They are unique reef formations with broadly circular shape, surrounded by oceans and surrounding a shallow lagoon inside the ring like structure. The physical characteristics of the water inside the lagoon show sharp contrast with the water outside. Darwin explained that the atolls initially are the island surrounded by a reef, which subside giving rise to a lagoon; an annular reef develops at or near the surface of the sea which is known as an atoll. Old underwater volcanoes may also act as a substratum for such reefs as they form rings of corals on the top of the volcanoes. There are some atolls which are not created by the sinking of an island but they have resulted from a rise in the sea level. Atolls are common in the Indian and South Pacific oceans. In India, atoll reefs are seen at Lakshadweep Archipelago Venkataraman *et al*., 2003).

1.4 Evolution

The origin of the reefs is as old as 3.5 billion years and evolution of these gigantic calcareous structures is closely connected with the faunal and floral diversity prevailing to its respective geological time period. Any sessile organism having sufficiently stable habit of producing carbonate is able to form a reef. During the origin of reef rather reef like structures, a number of faunal taxa are believed to be aggregated to form reefs when the ambient environmental conditions were quite different from the modern one. Such animals include many microbial communities, algae and skeletal metazoans (most now extinct- The oldest skeletal metazoans (~ 550–543 Ma), probably of diploblast grade, *i.e.*, stem- or crown-group cnidarians or basal stem-group bilaterians, sessile benthos, and found in shallow marine carbonate settings) since the early Archean, some 3.5 Giga years ago (Fagerstom, 1987).

During the Cambrian period about 540 Ma, the phenomenon of biogenic calcification is supposed to be evolved in order to detoxify the sudden rise in Ca^{2+} (Brennan *et al.*, 2004). With the course of time, the organisms evolved to utilize this $CaCO_3$ secretion in novel ways such as skeletal support, protection, extension into hydrodynamic regime, anchoring to substrate and competition for space. Various group of marine organisms take different benefits from calcification, hence the reduced calcification rate will affect all the organisms differently. Consequently the prediction of the animal fate with reference to calcification will vary accordingly.

Apart from the carbonate sedimentation, the reefs also play an important role as a significant organic carbon storehouses and regulator of atmospheric CO_2, this process further affects the climatic and eustatic changes (Opdyke and Walker, 1992) in addition to ecological variations. The Coral reefs play a significant role in carbon cycle by its metabolism which involves two types of biological pathways *i.e.*, organic carbon metabolism and inorganic carbon metabolism. The organic carbon metabolism involves photosynthetic fixation (by symbiotic zooxanthellae) and respiration whereas the inorganic carbon metabolism includes production and dissolution of calcium carbonate. With the production of one mole of $CaCO_3$ or organic matter by any of the aforementioned processes, a mole of total inorganic carbon gets decreased. A number of researchers have made experiments to measure the carbon fluxes in the coral reef which revealed, gross primary production (P) of the reef community is approximately 7 g C $m^{-2}d^{-1}$ and the community respiration (R) is, estimated to be equal to the same order of magnitude as primary production (P). Hence, the net productivity or the excess production tends to zero 0 ± 0.7 g C $m^{-2}d^{-1}$. The organic carbon metabolism contributes a little in net carbon fluxes of coral reefs and excess production is about 0.05 % of the net CO_2 fixation rate of the global ocean (Crossland *et al*., 1991).

1.5 Reef building and symbiosis

The reef building organisms are benefited by their photosymbiotic habit; in addition to nutritional requirement the symbiosis provide them with the rapid rates of calcification and thereby growth (Rowan, 1997). In the history of reef evolution the photosynthetic scleractinian came in existence about 210 mya but were lacking the reef building capacity.
Worldwide reef distribution is a function of a number of factors such as eustatic changes, geochemical variations, climatic fluctuations etc. Present day sea level is relatively low compared to that in much of the geological record such that the area of shallow water tropical seas is small, resulting not only in a reduced volume of shallow water carbonates being formed, but also in an absence of analogs for the very extensive shallow seas (known as epeiric or epicontinental seas) that were common when sea levels were high. The extensive carbonate platform reefs and atolls of today are also the product of an unusually prolonged period of stable sea level, which, together with relict topography, have exerted a strong influence over modern reef form and style of sedimentation. Present-day climate is also relatively cool, with well-developed polar ice caps (Rowan, 1997).

Biogeochemical processes

It is believed that tropical ocean waters are poor in nutrients, having low concentrations of dissolved nitrates, ammonia and phosphates still coral reef environment exhibit among the highest rates of photosynthetic carbon fixation, nitrogen fixation and limestone deposition of any ecosystem (Goreau *et al.*, 1979).
The major benthic calcifying organisms on coral reefs are corals, calcifying macroalgae, benthic foraminifera, molluscs, and echinoderms. As far as the tropical seas are concerned, scleractinian corals and calcareous algae are the important reef builders in addition to the cementation of the massive carbonate framework that forms the habitat for reef associates. The deep-sea corals build carbonate thickets or complex groves which provide habitat for many organisms at colder waters (50–1000m) in the continental shelves and offshore canyons.

Physiology of coral symbiosis

Scientists had made a series of elegant experiments at Great Barrier Reef and initiated the modern study to understand the physiology of coral symbiosis. He showed that symbiotic corals absorb phosphate and ammonia from the surrounding seawater by day and release them at night The increase of phosphate absorption in the light, suggests a relationship with the photosynthetic activity of the symbiotic algae-*zooxanthellae*. A correlation was found between phosphate uptake rates and the organic or inorganic feeding history of the corals; rates were indeed 4.6 times higher in 8-week starved than in fed corals and depended on the repletion status of phosphorus stocks within the symbionts (Goreau *et al.,* 1979).

The incorporation of radioactive carbon in reef corals showed that the carbon is readily utilized by the zooxanthlae for photosynthesis and the rate of photosynthesis is dependent on the light intensity. Some of these compounds are leaked to the host polyps. Some other workers found out in sequence of the study that the leaked compounds are nothing but glycerol, glucose and amino acids. The compounds may get any of the fate either they may be used up by the polyps for energy yielding metabolic pathways or they may be blocked in the manufacturing of proteins, fats and carbohydrates. The removal rate of the waste products controls the metabolic rate in the polyp. The removal rate again depends on the diffusion of the inorganic waste *i.e.,* carbon dioxide, phosphates, nitrates, sulphates and ammonia which is slower than the higher animals. However, the coral wastes are the very substances which the zooxanthelae need for its photosynthesis. Thus, the photosynthetic demand of the algae recycles the coral waste product in to new organic matter. The determination of the amount of C^{12} and C^{13} it was possible to estimate that about 2/3 of the carbon used in photosynthesis and calcification is recycled from the respiratory carbon dioxide of the coral polyp, and the rest is taken up from the sea water (Goreau *et al.,* 1979).

Organic substance from the zooxanthelae is one of the nutrition modes. They are efficient carnivores immobilizing animal planktons with the stinging cells of their tentacles or trapping them on the mucus filaments. The polyp can recognize its food by chemical stimulation which is reflected by extension of tentacles, opening of mouth and extruding mucus filament. Studies with radioactively labeled compounds revealed that corals can absorb the dissolved organic matter across their body wall (Goreau *et al.,* 1979).

Calcification in corals

The Coral polyp absorbs calcium ions from the sea water and transfers them by diffusion to the calcification site. The equation of calcification is as follows (Figure 1.6):

$$\boxed{Ca^{2+} + 2HCO^{-3} = CaCO_3 + CO_2 + H_2O}$$

Where $2HCO^{-3}$ is bicarbonate, $CaCO_3$ is calcium carbonate and CO_2 is carbon dioxide. It can be seen from the above equation that CO_2 is released as a byproduct of calcification (Rees *et al.*, 2005). The stoichiometry of the above equation holds true in freshwater such that 1 mol of CO_2 is released per mole of $CaCO_3$ deposited; however, in the marine environment 0.6 mol of CO_2 is released to the atmosphere per mole of $CaCO_3$ deposited because of the buffering effect of seawater (Wolast *et al.*, 1980; Ware *et al.*, 1991). In the marine environment, the remaining 0.4 mol of the CO_2 formed is recombined with carbonate ions and water to form bicarbonate, which remains in the water (Zeebe & Wolf-Gladrow, 2001). But the fate of the remaining 0.6 mol of CO_2 is under debate; however, the current consensus is that reefs are a source of CO_2 to the atmosphere (Barker *et al.*, 2003).

So far, the studies related to the impact of elevated pCO_2 have remained limited to a few species of coral and algae. Therefore, a research gap has been identified revealing the impact of pCO_2 on other calcifiers *i.e.*, benthic foraminifera, echinoderms, molluscs and deep-sea corals.

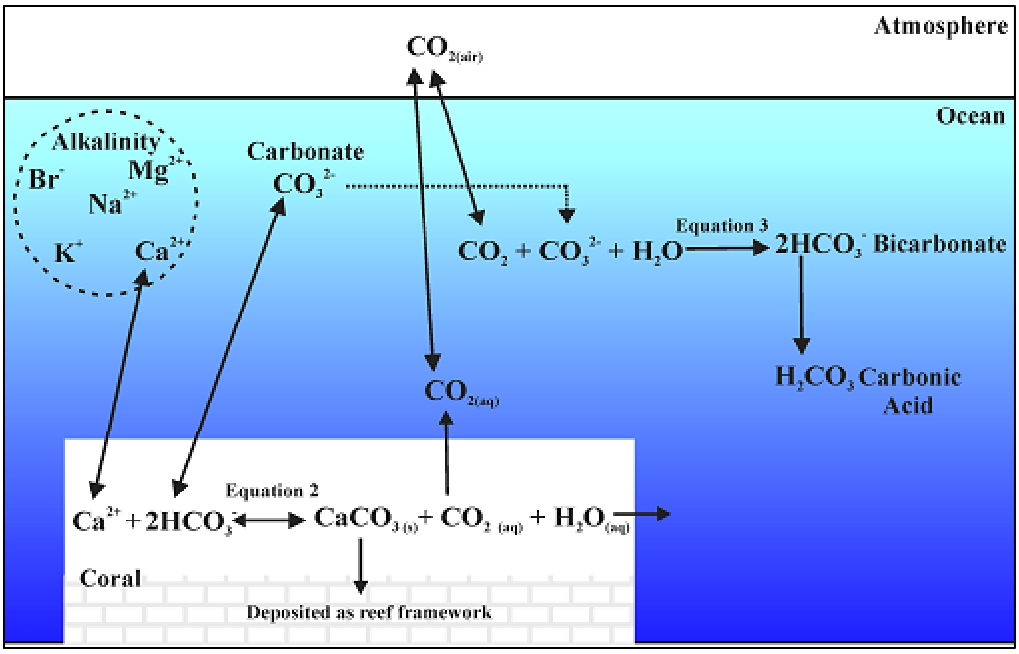

Figure 1.6 Role of coral reefs and CO_2 in the marine carbonate cycle (Rees,*et al.*, 2005)

1.6 Coral reef biodiversity

The diversity or variability of genes, species and community in space and time is defined as biodiversity (Heywood and Baste, 1995). The present section involves discussion over species diversity of coral reefs. The coral reefs are the underwater paradise teeming with incredible biodiversity. The dense and diverse biodiversity at coral reefs has puzzled scientist how coral reefs, manage to support so many species at a time *i.e.*, up to 650 coral and 1000 fish species within a single location (Bellwood *et al.,* 2006).

In addition to corals, various microbes, algae, invertebrates and certain vertebrates together construct the coral reef community. Although the name coral reef implies that corals should be the most abundant organisms there, algae population comprises over three times the biomass of corals (Verma and Agarwal, 2001). In terms of diversity, brown algae generally have the maximum number of species whereas, in terms of biomass, green algae are ahead in the coral reefs. Sea grasses grow in small clumps amongst coral reefs or in vast meadows in the adjacent areas (Allen & Steene, 1994).

Invertebrates

Invertebrates are the most diverse, numerous and colourful creatures of the coral reef ecosystem. They form the backbone of the coral reef building as well as integral part of almost every aspect of the ecology of coral reefs. Coral reefs are the most diverse of all marine ecosystems with estimates of reef species ranging from 6, 00,000 to more than 9 million species worldwide (Small *et al*., 1998). The marine invertebrate includes major groups *i.e.*, porifera, bryozoans, cnidarian (coelenterates), Platyhelminthes, mollusca, echinoderms and echiurans.

The porifera are represented by sponges, in the reef community as a colourful benthos, however only about half of the 2500-3000 species of sponges have been described (Gosliner *et al.*, 1996). The phylum contributes 74 species of sponges to the reef diversity of Gulf of Kachchh (Singh *et al*., 2004). However, during the survey of 2004, Venkataraman *et al.* reported about 25 species of the sponges.

The cnidarians form the backbone for coral reef ecosystem as the hard corals belong to this phylum. In addition to hard corals, soft corals, sea anemone and jelly fish are the important members of this phylum. They have a peculiar type of cells called *cnidoblasts*, nematocysts or stinging cells in the ectoderm, especially in the tentacles which is being utilized for either offensive or defensive purpose. This phylum is further divided into three classes *viz.*, Hydrozoa, Scyphozoa and Anthozoa. Some of the anthozoans secrete calcium carbonate skeleton.

Phylum Bryozoans also known as Ectoprocta (having the anus of the polyp outside the crown of tentacles) are aquatic, mostly marine, colonial animals, appearing like moss. They can colonize all type of hard substratum in aquatic habitat like sand grains, rocks, shells, wood or other algae. Apart from the hard substratum they may also be found on sediment. Most bryozoans inhabit much shallower water, while some species have been found at depths of 8200 meters. Bryzoans are generally sessile and immobile, but a few colonies are able to creep about, and a few species of non-colonial bryozoans live and move about in the spaces between sand grains (Buchsbaum *et al.,* 1987). Single species of this phylum has been recorded from GoK (Singh *et al*, 2004). E.g., Bugula

Annelids possess long, cylindrical and metamerically segmented Body. Among annelids, Polychaete worm form a dominant group in marine environment, which has reduced body segments, parapodia and setae (Gosliner *et al*., 1996). Polychaetes are segmented worms, generally less than 10 centimetres (3.9 in) in length, although ranging at the extremes from 1 millimetre (0.039 in) to 3 metres (9.8 ft). They are often brightly coloured, and may be iridescent or even luminescent.The polychaete worms are found around corals and live in the tube permanently; only the brightly coloured feeding tentacles remains outside the tube. The tentacles are highly sensitive to light and pressure and when disturbed they quickly withdraw them into the tube. e.g., Christmas tree worm, feather duster worm. Singh *et al.*, 2004 has recorded 4 spp of this group from GoK.

Echiura is a small group of animals closely related to annelids and sipunculans. The members of this group are also known as spoon worms and contain body divided into two distinct regions sausage shaped saccular, non-segmented trunk and a ribbon like probosis. The trunk may be thick or thin, smoothed or rough and vary in colours like gray, dark green, reddish brown or red. They use to inhabit ‘U’ shaped burrows with both the ends opened which are generally found at soft benthic substrata like, sand, mud or rubble. Echiurans are slow but not sedentary and animals without proboscis can swim. Peristalsis movement helps them to form burrows (www.jiffynotes.com). Singh *et al.* (2004) reported 2 spp of Echiurans and ZSI

(2004) reported the existence of 17 species of this phylum from the GoK. Dave and Mankodi studied the occurrence and distribution of *Acanthobonellia pirotanensis* on the Narara reef, gulf of Kachchh, Gujrat (Dave and Mankodi, 2008).

The phylum arthropoda is the largest in the animal kingdom comprising more than 75% of the animal species that have been identified. Hence it is almost impossible to generalize about the ecology and life history of arthropods (www. ucmp.berkeley.edu). It has been reported that arthropods were found to be marine at the initial stages of their evolution. This phylum comprises of six classes among which, only the animals belonging to Crustacea are found in aquatic habitat. The crustaceans' body has exoskeleton made up of a hard, impermeable substance called chitin. Their body is elongated and segmented, usually distinguished into regions like head, thorax and abdomen. Singh *et al.* (2004) had recorded 35 spp of crustacean from GoK and Venkataraman *et al*. (2005) had recorded 69 spp of crustacean.

The molluscans are the free living aquatic forms but some of them are amphibious. They are mainly found in either fresh water or in the marine environment. Their body is soft and unsegmented enclosed in a glandular mantle covered usually by a shell. Sea shells and their relatives comprise one of the largest divisions of the animal kingdom with a species total in excess of 100,000. It is not surprising that a group of this size exhibits amazing diversity. There seems very little in common between a microscopic, shelled gastropod and a 20m long squid, but both belong to the Phylum Mollusca. There are actually three major types (Classes) of molluscs occurring on coral reefs. It is difficult to formulate a simple definition of a group so large and diverse as molluscs. Most types possess a shell of calcium carbonate that is secreted throughout the life span. However, many molluscs, including snails, nudibranchs and some cephalopods have lost their shells entirely or they are much reduced. Another common feature is the radula, specialised horny teeth used for feeding and capturing prey. In the cone shells this structure is modified to form a single, harpoon-like tooth. A well-developed set of gills used for respiration is another characteristic of most marine molluscs. During the recently completed study by GEER Foundation, the mollusca contributed the major composition of invertebrates and had major share the coral reefs of Gulf of Kachchh (Singh *et al.*, 2004). They contribute 215 species during the present study. Earlier studies reported 207 species, but the recent taxonomical features restrict us to classify 215 species, which is further contributed by 145 gastropods, 58 bivalves, 5 cephalopods, 4 nudibranch and 3 amphineura.

The phylum Echinodermata includes animals which are free living, exclusively marine forms and largely bottom dwellers. The term *Echinodermata* literally means spiny or “prickly skinned” and refers to the conspicuous spines possessed by their test or skin. The very high power of regeneration is an important character of these animals. Adults show radially symmetrical body while larvae are bilaterally symmetrical. Their body is represented by a central disc which may bear extensions called arms. A unique ambulacral or water vascular system is present. Tube feet are present for locomotion and respiration. Tube feet are extended and retracted by variation in hydraulic pressure of the fluid in them and contraction of their muscles. Tube feet are for feeding as well.They bear complete digestive system. e.g., sea star, britle star, sea urchin. There are about 33 spp of echinoderms found at GoK (Singh *et al*., 2004)

Flat worms:

Flatworms belong to the phylum Platyhelminthes which involves the flattened worms. They are flattened and oval in shape and exhibit dazzling colour patterns. Their bright livery probably warns predators that they are toxic or distasteful. Otherwise these exposed slow moving creatures would easily become victims of worm feeding fishes. They are mostly less than 8cm in length. They can reproduce by fragmentation or may show sexual reproduction. Singh *et al.* 2004 has recorded 4 spp of this group from GoK.

Polychaete worms

The Polychaete worms belong to phylum annelid. They are also known as segmented worms as their body is divided into many ring like segments. The very well known terrestrial example of this phylum is earthworm and the Christmas tree worm and feather duster worm frequently found on reefs are the brothers of the earthworm. The polychaete worms are found around corals and live in the tube permanently; only the brightly coloured feeding tentacles remain outside the tube. The tentacles are highly sensitive to light and pressure and when disturbed they quickly withdraw them into the tube. e.g., Christmas tree worm, feather duster worm Singh *et al.*, 2004 has recorded 4 spp of this group from GoK.

Ribbon worm

The ribbon worms of the phylum Nemertea are very common on reef. As the name suggest they are flattened elongated creatures. They are not segmented as polychaete worms. They are generally 1-3cm in length but some reaches more than 5-7cm. They are mostly found at soft bottoms, under the dead corals or rocks. They generally feed on other invertebrates or their eggs.

Acorn worms

Acorn worms are inconspicuous creatures that live in sand or silt bottoms forming a 'U' shaped tube. Although the animals are directly not seen by the divers but the coils of sand above the burrow deposited by the animals are often observed.

Phylum: Chordates

Subphylum: Urochordata

Animals of this group possess a notochord which persists as an unsegmented bone for the lifetime. Animals included under this group possess long tail during their developmental stages hence known as Urochordata (tail chordate). They are also known as tunicates as they possess the sheath around their body. The animals found underwater, are saclike filter feeders with incurrent and excurrent siphons that is classified within the phylum Chordata. Most tunicates live on the ocean floor, others—such as salps, doliolids and pyrosomes—live above in the pelagic zone as adults. They were historically known as Ascidia, and are now commonly known as sea squirts and sea pork. Ascidian is a class under the subphylum urochordata. Ascidians are characterized by a tough outer "tunic" made of the *Polysaccharide tunicin*, as compared to other tunicates which are less rigid. Ascidians are found all over the world, usually in shallow water with salinities over 2.5%. There are 2,300 species of ascidians and three main types: Solitary ascidians, Social ascidians that form clumped communities by attaching at their bases, compound ascidians that consist of many small individuals (each individual is called a zooid) forming colonies up to several meters in diameter.

1.7 Climate change and coral reefs

Past Climate Change/ Historical Climate Change

Earth has undergone **periodic climatic shifts** in the past, including **five major ice ages**. These consisting of glacial periods where conditions were colder than normal, separated by warmer climate known as interglacial period.

Climate Change- *a consequence of Global Warming*

Climate change is a well-known phenomenon throughout Earth's history. But the accelerated change in climate is the most pressing issue in today's world which is the main outcome of the Global warming. The Global warming is a phenomenon of heating up of the earth and such heating of earth is caused by the Greenhouse gases that trap heat and light from the sun resulting into elevated temperature.

Swedish scientist named Svante Arrhenius (1859-1927) was the first to claim that fossil fuel combustion may eventually result in enhanced global warming (Weart, 2008). Since the end of the 19th century the earth's average surface temperature has increased by 0.3-0.6 °C.

Impacts of climate change on Corals and coral reefs

The climate change has got severe impacts on the oceans and as mentioned in the previous part of the chapter, corals are one of the major marine invertebrates which embrace incredible biological diversity of the oceans. Under the climate change scenario these fragile invertebrates are also experiencing unavoidable threats. Global climate change imposes interactive chronic and acute stresses, occurring at scales ranging from global to local, on coral reef ecosystems.

The major direct and indirect impacts include:

- Coral bleaching
- Impact on Reef Distribution
- Reduced Calcification Potential
- Sea level alteration
- El Niño- Southern Oscillation (ENSO)
- Ocean Circulation Changes
- Precipitation and Storm Patterns
- Impacts of climate change on socio-economy dependence on the reef ecosystem

Coral bleaching

Coral bleaching is the expulsion of dinoflagellate algae zooxanthellae from the coral tissue resulting in white or pale appearance of the coral colony. In fact the the living tissue of coral animals without algae is translucent, so the white calcium carbonate skeleton appears through, producing a bleached appearance. The phenomenon of Bleaching is a general stress response that can be induced by high or low temperatures, intense light, changes in salinity, or by other physo-chemical stresses. Hence, ecologists have expressed the coral bleaching as a biological reflection of environmental changes prevailing above corals' acclimatization capacity (Glynn, 1993). Bleaching is the extreme case of natural variations in algal population density that occurs in many corals (Fitt *et al.,* 2000, 2001).

A number of environmental factors have been identified to induce the dissociation of host and symbiont *i.e.*, extremes of temperature (heat shock and cold shock), high irradiance, prolonged darkness, heavy metals (especially copper and cadmium) and pathogenic micro-organisms (Hoegh-Guldberg, 1999; Brown, 2000). However, globally the elevated sea surface temperature is recognized as a major contributor to the considerable coral bleaching events (Stone *et al.,* 1999).

The coral bleaching can be evident as a localized or widespread event over large geographic scales based on the type and magnitude of the causative factors. It has been observed that localized bleaching events are often due to direct anthropogenic stressors (e.g., pollution or freshwater runoff), which can be mitigated by refined management practices and controlling the stress source (Salm *et al.,* 2001).

Three types of bleaching mechanisms are associated with high temperature and/or light: "animal stress bleaching," "algal-stress bleaching," and "physiological bleaching" (Fitt *et al.,* 2001). Though all the three are important to understand the climate-coral interactions, but two are particularly relevant to present concerns, they are: the algal-stress bleaching, an acute response to impairment of photosynthesis by high temperature coupled with high light levels; and the physiological bleaching, which reflects depleted reserves, reduced tissue biomass, and less capacity to house algae as a result of the added energy demands of sustained above-normal temperatures.

Impact on Reef Distribution

Globally, the distribution of reef-building corals is limited by annual minimum temperatures of ~18°C (64°F) (Veron, 1995; Kleypas *et al*., 1999). Although global warming might extend the range of corals into areas that are now too cold (Precht and Aronson, 2003), the new area made available by warming will be small, and the countervailing effects of other changes suggest that any geographic expansion of coral reefs will be very minor.

At present, coral reefs are limited to the tropics and occur only in waters where temperature remains warmer than 18°C (64°F). A 2°C (4°F) warming of the oceans will expand the range by few degrees of latitudes. Locations within this region that have suitable depth, substrate and other environmental conditions could potentially support new coral reefs at the higher temperatures. Only Southern China, Japan, Australia and Southern Africa present geographically realistic opportunities for reef expansion. Additionally, sea-surface temperature (SST) gradients are very steep in the vicinity of 18°C (the annual minimum temperature threshold for coral reef growth), and ocean model projections suggest that SST warming associated with doubled CO_2 will only move the 18°C contour by a few hundred kilometers, especially in the critical western boundary areas (Kleypas *et al.,* 2001). Whereas the west coasts of North and South America, Europe, Africa and southeastern United States and near the Amazon River, reef expansion along the coast is blocked due to the flow of cool water towards the equator and are thus “upstream” from potential sources, causing restricted distributions of coral reefs in the former while muddy coastal shelves, river deltas, and turbid water for the latter.

Reduced Calcification Potential

The oceans currently absorb about a third of the anthropogenic CO_2 inputs to the atmosphere, resulting in significant changes in seawater chemistry which in turn effects the calcification of the marine organism (Houghton *et al*., 2001).

Photosynthesis and respiration by marine organisms also affect seawater CO_2 concentration, but various studies have predicted a reduction in ocean pH and a lowering of the saturation state of seawater with respect to the calcium carbonate minerals such as calcite and/or aragonite as a consequence of the increased CO_2 concentrations in atmosphere (Caldeira and Wickett, 2003; Orr *et al*., 2005). Projected increases in atmospheric CO_2 may drive a reduction in ocean pH to levels not seen for millions of years (Caldeira and Wickett, 2003).

When CO_2 dissolves in water, it forms carbonic acid (H_2CO_3):

$$H_2O + CO_2 \rightarrow H_2CO_3$$

Carbonic acid is a weak acid that can lose hydrogen ion to form bicarbonate (HCO_3^-):

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

or

Further shed the remaining hydrogen ion to form carbonate (CO_3^{2-}):

$$HCO_3^- \leftrightarrow H^+ + CO_3^{2-}$$

Thus, carbon can occur simultaneously in several forms: CO_2 (dissolved CO_2 and carbonic acid), HCO_3^-, and CO_3^{2-}. Increasing atmospheric CO_2 drives more CO_2 into the ocean, lowering the pH (making the ocean more acidic) and changing the relative proportions of the three forms of carbon. This reduction in ocean pH has some direct effect on marine organisms (Seibel and Walsh, 2001).

In tropical water of normal salinity (35 Practical Salinity Units, or PSU), average temperature (25°C; 77°F), and preindustrial levels of CO_2 (280 ppmv), about 85 percent of the dissolved CO_2 in seawater exists as bicarbonate, and the remaining 15 percent exists as carbonate ion. Doubling the CO_2 concentration in seawater without changing the other conditions would increase bicarbonate ion concentration to 90 percent and decrease carbonate ion concentration to 10 percent. Calcifying organisms combine calcium and carbonate ions to build their skeletons ($Ca_2^+ + CO_3^{2-} \rightarrow CaCO_3$), so a reduction in carbonate ion concentration slows the calcification process and making it more difficult for calcifying marine organisms to form their shells and skeletons (Orr *et al.*, 2005).

The effect of reduction in the available carbonate ions has been most studied in coral, which form their skeletons from aragonite, a metastable form of calcium carbonate (Kleypas *et al.*, 1999; Hoegh-Guldberg, 2005).

Reef-building coral occurs where calcium carbonate precipitation exceeds its removal. The structural components of reefs (skeletons of corals and calcareous algae) are glued together and made more resistant to physical breakdown by calcium carbonate cements that precipitate within the reef framework, and by the overgrowth of thin layers of calcareous algae. A reduction in CaCO3 precipitation by either mortality of reef organisms, lowered calcification rates, or lowered cementation rates reduces a reef's ability to grow and to withstand erosion (Kleypas *et al*., 2001). Some slow-growing or weakly cemented reefs may stop accumulating or shrink as carbonate deposition declines and/or erosion increases. Such effects have been observed in the Galápagos and elsewhere (Eakin, 1996).

Future changes in seawater chemistry will not only lead to decreases in calcification rates, but also to increases in $CaCO_3$ dissolution. Field experiments by Halley and Yates (2000) indicated that the dissolution rate could equal the calcification rate once atmospheric CO_2 concentrations reach double the preindustrial levels. This indicates the slow-down or reversal of reef-building and the potential loss of reef structures in the future.

Sea level alteration

Sea level has remained fairly stable for the last few thousand years (Smith and Buddemeier, 1992), and many reefs have grown to the point where they are sea-level-limited, with restricted water circulation and little or no potential for upward growth. A minor rise in the sea-level would therefore be beneficial to such reefs. Though such a slight sea-level rise might "drown" the reefs that are near to their lower depth limits by decreasing the light availability, the projected rate and magnitude of sea-level rise are well within the ability of most reefs to keep up (Smith and Buddemeier, 1992). A more likely source of stress from sea-level rise would be sedimentation due to increased erosion of shorelines. Houghton *et al., (*2001) predicted that the rise of sea level due to the combined effects of thermal expansion of ocean water and the addition of water from melting icecaps and glaciers will be between 0.1 and 0.9 meter (4-36 inches) by the end of this century.

El Niño- Southern Oscillation (ENSO)

The El Niño-Southern Oscillation (ENSO) refers to a naturally occurring phenomenon observed at central and eastern equatorial Pacific. It involves fluctuating ocean temperatures in the equatorial Pacific. The warmer waters essentially oscillate, back and forth across the Pacific. For North America and much of the globe, the phenomenon is known as a dominant force causing variations in regional climate patterns. The pattern generally fluctuates between two states: warmer than normal central and eastern equatorial Pacific SSTs (El Niño) and cooler than normal central and eastern equatorial Pacific SSTs (La Niña). Such thermal fluctuation significantly affects the biodiversity prevailing over there. The mass coral bleaching events occurred in the past two decades has been clearly linked with El Niño (Hoegh-Guldberg, 1999). The widespread bleaching events took place during the El Niños of 1982-83, 1987-88, and 1997-98.

When the seasonal maximum water temperatures coincide with the warm water anomalies, coral bleaching event takes place. In the western Pacific, the Mean sea level decreases during an El Niño event, which can expose shallow reefs, and lead to mass mortalities (Eakin and Glynn, 1996). Coral bleaching also takes place in regions that tend to have warmer-than-normal SSTs during the La Niña *i.e.,* the cold phase of ENSO (e.g., South Pacific Convergence Zone; New Britain during 1998-99).

El Niño events have increased in frequency, severity, and duration since the 1970s (Mann *et al.,* 2000). The severity of bleaching events during El Niño years of the last two decades presents a "worst case scenario" in predicting the future of coral reef ecosystems, particularly when added to a background of warming sea-surface temperatures (Glynn *et al.*, 2001).

Ocean Circulation Changes

Global climate change may alter the ocean Circulation from local (wind-driven upwelling) to global (thermohaline) scales. Nearly all coral reefs of high latitudes inhabit where boundary currents deliver warm waters from tropical regions such as Bermuda near the Gulf Stream, Lord Howe Island in the East Australia Current, and the Ryukyus of Japan in the Kuroshio Current. Changes in the path or strength of these currents would inflict different temperature regimes on these reefs. There has been concern that ocean thermohaline circulation (THC) will shut down in the future due to changes in ocean temperature and freshwater runoff (Manabe and Stouffer, 1993). Recent modeling predicts a 0–40 percent slowing of THC within this century, but most models do not predict a complete shutdown (Gent, 2001). A slowing of THC would lead to significant changes in oceanic circulation and upwelling patterns that could potentially affect coral reef ecosystems (Vellinga and Wood, 2002), but how THC will be affected by global climate change remains uncertain (Broecker, 2003).

Precipitation and Storm Patterns

Tropical precipitation has increased over the past century by 0.2–0.3 percent per decade in the 10°S-10°N region, and the frequency of intense rainfall events is "very likely" to increase over most areas (Houghton *et al.,* 2001). Increased precipitation can lower the salinity and increase the sediment discharge and deposition near the river mouths, which may lead to mass mortalities on nearby coral reefs (Van Woesik *et al.*, 1991; Coles and Jokiel, 1992; Wolanski *et al.,* 2003). Studies shows that the frequency and intensity of the droughts are also expected to increase, which may result in the changes in vegetation cover and land use which may lead to erosion and sediment stress during the rains. Tropical cyclones such as hurricanes and typhoons commonly occur in many tropical regions, and although they may limit reef development in a few instances, healthy coral reefs recover from the infrequent damage caused by the cyclones (Macintyre and Adey, 1990). Various studies and comprehensive observations of last five or six decades of cyclone activity show few trends in cyclone frequency or intensity (Henderson-Sellers *et al.,* 1998). Hurricane models and calculations suggest that the maximum potential intensity of cyclones could increase 10-20 percent and surface winds could increase by about 3-10 percent (Knutson and Tuleya, 2001). There are little evidences that the frequency of cyclones or where they form is likely to change (Albritton *et al.*, 2001).

Impacts of climate change on socio-economic dependence on the reef ecosystem

Coral reefs directly provides economic benefits to the human society in many ways such as fishing; tourism etc. The economic values of such benefits can be calculated and estimated directly but other benefits such as protection, biodiversity, and aesthetic value cannot be estimated (Costanza *et al.*, 1997). Nearly 40 percent of the people on Earth live within 100 km of the coastline, and many local and regional economies are based on goods and services provided by coastal ecosystems.

Environmental degradation both on land (land clearing, agricultural and urban waste disposal) and in the ocean (unsustainable and destructive fishing practices) reduces the ability of reefs to support local economies. This economic loss can lead to even more destructive methods such as blast fishing, cyanide fishing to extract required amount of resources from the reef and adjacent environments (Cesar *et al*., 2003). The environmental degradation leads to change in the climate which in turn affects the reef ecosystem as mentioned in the previous sections of the present chapter. The consequences created by the climate change on the coral reef ecosystem will also affect the socio-economy of the country.

In the past, many coastal countries have paid heavily for the consequences created by the climate change. The mass coral bleaching events of 1997–98 evidenced from nearly all the reef areas stimulated a number of socioeconomic evaluations of coral reefs in nearly all the affected regions (Schuttenberg and Obura, 2001). In the Maldives, the mass coral bleaching of 1998–99 led to an estimated loss in tourism-related revenues of US$0.5–3.0 million (Westmacott *et al.,* 2001) whereas many reefs of Palau an island in western Micronesia suffered at least 50 percent coral mortality in the 1997–98 bleaching event, experienced a 5–10 per cent drop in tourism in the years following the event (Graham *et al.,* 2001).

1.8 Lacuna

A number of studies have been carried out on the corals and reef associates of the coral reefs of Gulf of Kachchh, Gujrat. C.S.G. Pillai and M. I. Patel (1988) provided the first detailed publication to the taxonomist regarding the distribution of various coral species in the GoK. It describes occurrence of 37 species of Scleractinians from different reefs of the Gulf of Kachchh (Pillai and Patel, 1988). Dave (2011) carried out the ecological assessment of Narara reef in the GoK with major focus on the coral community (Dave , 2011) Parasharya, 2012 studied the status of live corals along with opisthobranch fauna of the GoK (Parasharya, 2012). Pandey *et al.,* studied the recruitment and growth patterns of the corals in the GoK (Pandey *et al.,* 2010). Pandya (2014) studied the density and distribution patterns of Zoanthids at microhabitat level (Pandya, 2014). Bhattaji (2011) studied the major abiotic and biotic threats prevailing on the coral reefs of the GoK (Bhattaji, 2011).

Apart from these studies, the reef geology, geomorphology and sea level chronology has also been explored by the scientists including both GoK and Saurashtra coast. However, the impact of climate change on coral reefs and its carbon storage potential have not been explored yet. During the last decade, the changing climate has posed significant and prominent impacts on the coral reefs of the GoK, hence the present study will bring forth the research and provide significant outputs.

1.9 Aims and objectives

The present study emphasizes to explore the the calcification or calcium carbonate deposition rate of the coral reef. Calcification rate of corals is influenced by numerous environmental factors such as temperature, light, pH etc. Kleypas *et. al.*, (1999) estimated an average decline of reef calcification rates of 6–14 percent as atmospheric CO_2 concentration increased from preindustrial levels (280 ppmv) to present-day values (370 ppmv). This indicates that by estimating the amount of carbon deposited by the corals, we can derive the information of climate prevailing thousands of years before present. This hypothesis gave rise to study the 'carbon profile' of coral reefs to formulate the trend of carbonate deposition in past and consequently it will derive the future trends. To test this hypothesis present status of surface calcium carbonate and its contributors from the ecosystem needs to be assessed. Hence, the study aimed to evaluate the impacts of climate change on corals as well as the role of corals in carbon cycle. Addition to this, a prominent biological consequence of climate change reflected by the bio-indicators (corals) - coral bleaching- has also been covered in the present study. Hence, the major objectives to be achieved under this study are, as follows:

Objectives

1. To determine the Vertical Accretion Rate (VAR) of the reef.
2. To estimate carbon stored in coral reefs in the past.
3. To determine the future carbon storage of the reef.
4. To study the status of coral bleaching on the coral reefs.