

# Coral atolls of Lakshadweep, Arabian Sea, Indian Ocean

## Abstract

The Lakshadweep are least studied coral atoll group situated in the northern part of the Laccadive-Chagos ridge at a distance of 200-300km from the West Coast of India... The islands in the eastern side have lagoons which vary in size and are the habitat for a variety of plants and aquatic animals. They are also sites for harbor, aquaculture, recreation and tourism. The smaller lagoons are virtually filled with sediments The larger lagoons are comparatively deep with depth of about 10 to 16m. At low tide the reef is exposed and during high tide it is submerged. Eastern seaside part of the island has steep storm beach with deposits of shingles and boulders .and the lagoon side beach is sandy. The source of the sediments on the atolls is the coral reefs and the other biological communities. A substantial amount of the sediments in the reef front is lost in the deep sea because of morphology, waves and currents. The inner reef flat has thicker sediment cover, parts of which are transported to the lagoon.

The reef areas are the living places of various communities of corals belonging to different families of Acroporidae, Poritidae, Pocilloporidae, Faviidae, Fungiidae, Mussidae etc. Besides a large number of speices of Gastropods, Bivalves, Echinoids, Foraminifers, Ostracods and Bryozoans are also present. Halimeda is the most important constituent of the lagoon sands and play most important role in building up the reef. Survey in the lagoons and shallow offshore areas indicated the occurrence of 288 million tonnes of calcareous sands in the lagoons to a depth of about 1 meter below the lagoon floor. The sands have a low amount of silica, alumina and Fe<sub>2</sub>O<sub>3</sub>. They are suitable for a number of industries like cement, chemical, glass and paper. However, the geomorphic situation on the coral islands are delicate and precautions have to be taken while mining those sands The present calcareous sands occur in a loose form on the lagoon floor and will be easier to mine. We can expect a quick return from these deposits without disturbing the delicate balance .If limited quantity of sands are removed, there will not be appreciable change in the rate of production or derivation. Slight changes will be automatically adjusted the most important sediment-forming site is the reef area and it should not be disturbed as far as possible. The lagoon is the most important accumulation site and the lagoon will have the tendency to fill up automatically if the sands are taken out. However, a close environmental monitoring should be done. Once the system of exploitation is established in such an environment it can be widely used in other areas also. All programmes should be oriented according to the guidelines suggested by the Reef Monitoring Network and Management Plans.

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**Tapas Kumar Mallik**

Former Director, G.S.I, Marine Wing, India

**Correspondence:** Tapas Kumar Mallik, Former Director, G.S.I, Marine Wing, FD- 317, Sector-1ii, Salt Lake, Kolkata- 700106, India, Email tkmallik@rediffmail.com**Received:** September 27, 2016 | **Published:** April 20, 2017

## Introduction

The coral islands in the Arabian Sea constituting the smallest UT in India are known as Lakshadweep. This term is generally interpreted one hundred thousand isles. (Laksha—one hundred thousand; Dweep-island). These islands while lie directly along the trade route between Africa, Arabia and Malabar are also considered a landmark for navigators of sailing ships. Scientific information on Lakshadweep Coral atolls, is lacking, barring a few scattered notes in different publications and reports, and may not be accessible to scientific community. The present Article on Coral Atolls of Lakshadweep covers almost all the aspects including substantial information on geology. In view of this, this effort will be a source of information about a comprehensive picture on present status of the atolls on various aspects. According to the (2001 Census) Population: is 60,595 and the languages spoken are: Malayalam and Jeseri and Mahl The Lakshadweep are a group of the least studied coral atoll enclosing lagoons, submerged reefs and banks situated in the Arabian Sea at a distance of 200-300 km from the West Coast of India. (Figure 1) They

lie between latitude 8<sup>o</sup>-14<sup>o</sup>N and longitude 71<sup>o</sup>-74<sup>o</sup>E, covering an area of only 32Km<sup>2</sup> The Laccadive islands are situated on the northern part of the Laccadive-Chagos ridge in the western Indian Ocean extending over 2500 km. A considerable length of the crest of this ridge is composed of shoals, banks and coral reefs at depth less than 1500m. The ridge is divided into three main segments which are referred to the Laccadive Islands (Lakshadweep), the middle segment as the Maldive islands and southern segment as Chagos bank. Laccadive-Chagos ridge system was considered as a zone of transition between oceanic crust in the west and continental crust in the east due to block faulting along the west coast of India. The thickness of sediments is estimated be 2km between Kerala and Lakshadweep. Based on the borehole data the volcanic rocks lay below the seafloor on the Lakshadweep ridge. The atolls have formed on the Lakshadweep-Chagos ridge. There are 11 major islands and lagoons (Kavaratti, Kalpeni, Agatti, Chetlat, Bitra, Kiltan, Kadmat, Amini, Bangaram, Suheli, Minicoy) and 4 submerged reefs (Baliapani, Cheriapani, Perumalpar, Androth) and 5 banks (Bassas de Pedro, Sessostriis, Coradivh, Aminipitti, Elikalpeni) (Figure 2) Kavaratti is the capital city of these islands. The

Lakshadweep group of atolls is separated from the Minicoy by the 9<sup>th</sup> channel. Most of the atolls have low-lying islands on the east, a reef on the west and a lagoon in between. The largest island is Minicoy with a length of about 9 km, and an area of 4.37km<sup>2</sup>. The smaller inhabited island is Bitra with an area of 0.1km<sup>2</sup>. The islands have a lagoon 4,200km<sup>2</sup>, territorial waters of 20,000km<sup>2</sup> and 4,00,000km<sup>2</sup> of Exclusive Economic Zone



Figure1 Position of important Islands of Lakshadweep.

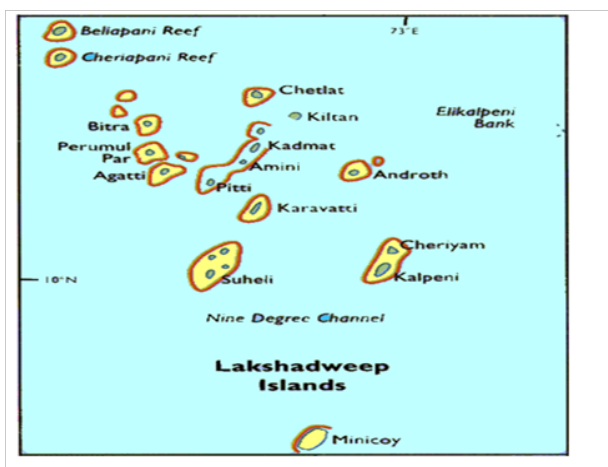


Figure 2 Lakshadweep Island and reefs in the Arabian Sea.

## Previous work

The earliest information on these islands dates back to the 19<sup>th</sup> Century when Agassiz (1903)<sup>1</sup> visited these islands on a Yale University Cruise. Later Gardinar (1903)<sup>2</sup> described the southerly atolls of Minicoy and Maldives. Sewell (1935) discussed about the topography and bottom deposits of Laccadive islands. Indian Bureau of Mines investigated the guano and limestone deposits<sup>3</sup> of these islands. Geological Survey of India carried out detailed sampling in the lagoons and offshore areas to assess the potentiality of calcareous sands for industrial use.<sup>4,5</sup> An area of 380sq.km was covered and 2490 samples were collected with 1190 line km echo sounding. Surveys indicated 288m. tones of calcareous sands in the lagoons up to a depth of 1m. Sediment movement studies were carried out by Venkatesh.<sup>6</sup>

Submerged terraces of Lakshadweep and ages of storm beaches were dealt by Siddiquie.<sup>7,8</sup> Grain size variation in the Kavaratti lagoon has been carried out by the present author.<sup>9</sup> Sedimentological and biological aspects of the Kavaratti and Kalpeni atolls and the effect of dredging of coral sands have been discussed by Mallik.<sup>10-13</sup> The DSDP borehole 219 on the ridge has brought out the sedimentation and tectonic history at the site (Whitmarsh et al.). Siddiquie et al. discussed the mineralogy of some of the units of this ridge. Mamgain et al. carried out detailed studies of benthonic foraminifera from the ridge site. While discussing the Deccan traps in relation to the drilled site and western continental shelf, some of the features like terraces and breaks in profiles were discussed to highlight the origin and formation of the atolls. (Mallik, 1995) Coral Reefs of the world has been compiled by Shepard et al.<sup>14</sup> and there is lot of information on the Lakshadweep in the Indian Ocean Volume. The Marine Wing of GSI had taken up a multidisciplinary scientific survey around Lakshadweep on board RV Samudra Manthan (News Letter, 1994). Work on morphology and carbonate potential has been discussed by Kalluryya.<sup>15,16</sup> Geomorphology of the atolls was used as clue to sealevel changes were depicted by.<sup>17</sup> Various aspects of the Coral Reefs and Exploration work in Lakshadweep and the Economic aspects has also been discussed in the book by Mallik et al. The science and Technology Department has set up a cell at Kavaratti for keeping a track of scientific investigations. CESS, Trivandrum is also engaged with few projects on various geological aspects of the islands.

## Some features of the atolls and reefs

There are various types of atolls which vary in shape from circular, sub circular to elliptical. Some enclose lagoons, some are with islands, some are without islands, and some are partially inundated. Reef usually vary in width from 200-400m. among the different islands. The wave cut platform extends from the reef margin to a distance of 50-100m towards the sea and the depth falls steeply within a short distance. A number of well defined submerged terraces exist on the sea ward side of the reef at 7-12m, 15m, 21-36m (prominent) and 43-47m depths. The first break usually represents a wave cut platform and the deeper terraces (>12m) appear to have been formed during periods of lowered sea level. Generally the topography of the lagoon towards the island margin is generally even but contains areas of ruggedness rugged due to outcropping corals at the reef margin. A number of surge channels oriented in NW-SE to NE-SW direction are also present in the outer reef. The radiocarbon data of the corals from the storm beaches range from modern to 2975±100 B.P and indicates clustering between 3000 to 2000 B.P. The sets of storm beaches are almost at the same level and are progressively younger towards the shore and beach on these parts of the island. They have grown by about 10m to 200m in 1000 years. The list of the atolls, submerged reefs and banks in Lakshadweep are given in Table 1.

## Origin of the name- Lakshadweep

The enchanting coral islands in the Arabian Sea the smallest UT in India were called as Laccadive, Minicoy and Amindevi Islands until recently, although they were popularly known as Laccadives or Lakshadweep. The earliest reference to the name Laccadives is in the Dutch Company records. The colloquial term Laccadives is derived from Lakshadweep. It is the least populous Union Territory of India. The first settlement on these islands was during the ruling period of Cheraman Perumal, the last King of Kerala. The Cheraman Perumal converted to Islam and left his capital for Mecca. His disappearance

triggered off search parties in sailing boats. One of the sailing boats of the Raja of Cannanore was caught in a storm and shipwrecked on Bangaram. This group reached Agatti where on improvement of weather they returned to the mainland. Another search party of sailors and soldiers discovered the island of Amini and small settlements gradually started in Kavaratti, Androth, Kadamat, Kiltan, Chetlat and Agatti. These islands form the smallest of the Union Territories of India, and are the country's only coral islands. The main islands are Kavaratti, Minicoy, and Amini. Kavaratti is the headquarters of these islands, while Bitra is the smallest of all, with a nominal population. About 93 percent of the people in Lakshadweep are the Shafi school Muslims of the Sunni sect

**Table 1** List of atolls, submerged reefs and banks in Lakshadweep

Atolls with Islands	Submerged reefs	Banks
Kavaratti	Cheriapani	Bassas de Pedro
Kalpeni	Beliapani	Sesostris
Agatti	Perumalpar	Coradivh
Bitra	Androth	Amini-Pitti
Kiltan		Elikalpeni
Chetlat		
Minicoy		
Amini		
Bangaram		
Suheli		
Kadmat		

### Population of the Islands

The population of the island is 60,595. Where the density of population has increased over the years to as high as 1894/sq.km. The literacy rate is 93.15% for males and 81.56% for females. Malayalam is the spoken language in all the islands and a specialized dialect known, as Jessri exists here. In Minicoy, the people speak Mahl, which is written in the Maldivian Dwehi script. The entire indigenous people of this Union Territory are classified as Scheduled Tribes (ST). The earliest references to the islands is made in Puranurus part of the ancient Tamil (Dravida) country, Tamilakam. Little else is known about the early history of the Lakshadweep islands. There are references to the control of the islands by the Cherasin the Sangam literature Pathitruppaththu. A Pallavain scription of 7th century AD refers to the islands as Dveepa Laksham and lists them as part of the Pallava domain. The oldest inhabited islands in the group are Amini, Androth, Kavaratti and Agatti. It was earlier believed that the Lakshadweep islanders were originally Hindus who later converted to Islam in the 14th century. However, recent archaeological evidence has established that Buddhist settlements had existed in the islands as early as the 6th or 7th century. According to popular tradition, Islam was brought to Lakshadweep by an Arab named Ubaidullain 41AH (661 AD). His grave is located in the island of Androth. Muslim grave stones dated to 139 AH (756 AD) have also been discovered here. During the 11th century, the islands came under the rule of the Late Cholas. In the 17th century, the islands came under the rule of Ali Rajahs/Arakkal Bheevi of Kannur, who received them as a gift from the Kolathiris. The Portuguese took control to exploit coir production until the islanders expelled the Portuguese. The islands are also mentioned in great detail in the stories of the Arab traveler Ibn Batuta. The Amindivi group of islands (Amini, Kadmat, Kiltan, Chetlat and Bitra) came under the

rule of Tipu Sultanin 1787. They passed to British control after the Third Anglo-Mysore War and were attached to South Canara. The rest of the islands came under the suzerainty of the Arakkal family of Cannanore in return for a payment of annual tribute. After a while, the British took over the administration of those islands for non-payment of arrears. These islands were attached to the Malabar district of the Madras Presidency. In 1956, despite the fact that most of the Islanders were Malayalis, the States Reorganization Act separated Minicoy from the mainland administrative units, forming a new union territory by combining all the islands.

### Geography and the people

Lakshadweep comprises twelve atolls, three reefs and five submerged banks, with a total of about thirty-six islands and islets. The reefs are in fact atolls, although mostly submerged, with only small unvegetated sand cays above the high water mark. The submerged banks are sunken atolls. Almost all the atolls have a northeast-southwest orientation with the islands lying on the eastern rim, and a mostly submerged reef on the western rim, enclosing a lagoon. The main islands are Kavaratti (which is the capital), Agatti, Minicoy, and Amini. Agatti has an airport where there are direct flights from Kochi, Kerala or Ernakulam (Cochin). Tourists need a permit to visit the islands; foreign nationals are not permitted to visit certain islands. Consumption of alcohol is not permitted in the islands except on Bangaram Island. Lakshadweep forms a single Indian district and is governed by an administrator appointed by the central government of India. The union territory comes under the jurisdiction of the Kerala High Court at Ernakulam. The territory elects one member to the Lok Sabha (lower house of the Parliament of India). There is no local government at the moment but the administration plans to introduce a two-tiered system based on the Panchayati raj. There will be ten island councils for the inhabited islands (with a total of 79 members). The people of all the northern islands speak dialect of Malayalam. According to local folk beliefs, they descended from traders who were washed up on the islands during a particularly heavy storm. However, the people of Minicoy, the southernmost atoll, speak Mahl, a variant of Divehi language spoken in the Maldives. The islanders are ethnically similar to coastal Kerala's Malayali people, and were influenced by Arab traders. Inhabitants of Minicoy, the southernmost and second largest island, are ethnically Dhivehi native to the Maldives. This group of Dhivehis form a subgroup of Dhivehis, sometimes referred by the name Mahls. Most of the indigenous population is Muslim. The locals of all the islands except Minicoy call themselves the Divior the Aminidivi ("from the mother island"). Lakshadweep's ethnic groups can be classified as 84.3% Malayali, and 15.7% Dhivehi.<sup>18</sup>

### Transportation services

The only airport in Lakshadweep, Aerodrome is situated on Agatti Island. Indian Airlines, the state-owned carrier, serves Agatti and flies to Kochi on the mainland. Also, from April 2007, a private carrier, Kingfisher Airlines, has commenced flights to and from Agatti. Kingfisher connects Kochi and Bangalore to Agatti. The other islands are linked by helicopter or boat service. Ships are the major means of transportation for the islanders. Ships are operated from either Kochi (Kerala) or Beypore (Calicut-Kerala). There are around 5 passenger ships, but generally only two at a time operate and advance bookings are required. There are cruises to all the other islands from Kochi as well as Agatti. There is a helicopter service as well to Bangaram from Agatti.



## Tourism and scuba diving in Lakshadweep

Lakshadweep is one place that still remains exactly the same way man found it. And the tourism department wishes to keep it unchanged. That is why out of the 36 islets, only 6 has been thrown open for tourism and only three to non-Indians. The number of tourists allowed on an island at a time is restricted. One can experience water sports in many parts of India, but it is the presence of coral reefs that sets Lakshadweep apart from the rest. Under the crystal blue water, lies a kingdom with the most enchanting color combinations possible. Scuba diving and snorkeling are the two most indulged in activities in Lakshadweep. Swimming alongside schools of fishes and amidst the living corals is an experience beyond words. Tourists also like to indulge in angling and surfing. Not many places in the world come close to the aura and charm possessed by the islands in Lakshadweep. No wonder they are considered among the best holiday destinations in the world. The empty white sand beaches and the silence of the nights embedded with the sound of dancing waves prove to be a perfect setting for a quite vacation. And the possibility of enjoying water sports for as long as one wishes to makes Lakshadweep an irresistible destination for family and adventure vacations.

## Livelihood

The main occupation of the islanders is fishing and agriculture. The main fishery is Tuna followed by Shark. Oceanic species of

tuna such as Skipjack (*Katsuwonus pelamis*) and Yellowfin Tuna (*Thunnus albacares*) constitute the major tuna resource exploited by the islanders by pole and line fishery with live baits. The per capita income out of fishing is Rs.1630 and annual income out of fishing is Rs.22 crores. About 2,598 hectares are under coconut cultivation and the productivity per hectare is 22,310. Coconuts cultivated in the Lakshadweep are also rich in coconut oil.

## Storms and cyclones

The islands are open to storms and cyclones. One of the earlier natural calamities recorded was in April 1847. During this cyclone the first island to hit was at Kapeni and finally moved to Androth and Kiltan. Many deaths were reported. In 1891 a violent storm burst upon Kavaratti causing great damages to the coconut plantation. Damages in Agatti and Amini were also reported. Kalepeni Island was once again hit by a severe cyclone in December 1922. The waves washed completely over the northern end but there was no loss of life. Another major storm was stuck in 1941. In 1963 and 1965 another major storm struck causing considerable damages to Anroth, Kalpeni, Agatti and Kiltan. The last cyclone occurred in 1977 and hit was in Kapeni and Androth with no loss of life. The recent cyclone that hit the islands was in May 2004 gently affecting Amini. Kiltan and Kavaratti were also affected by this storm but there was no loss of life. However, property damages were extensive. Details of the storms, loss of life and affected islands are shown in the Table 2.

**Table 2** Table showing the year, loss of life and affected Islands in Lakshadweep due to storm.

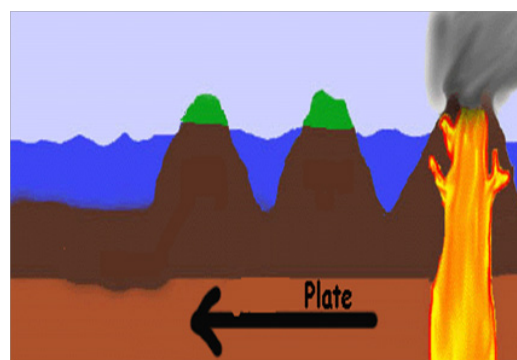
Disaster type	Year	Loss of life	Severely affected Islands	Other affected Islands
	1847	Kalpeni, 246 deaths	Kalpeni, Androth	Kiltan
	1891	No loss of life	Androth	Kavaratti, Agatti, Amini and Kalpeni
	1922	No loss of life	Kalpeni	
Storm	1963	No loss of life	Androth, Kalpeni	Agatti, Kiltan
	1965	No loss of life	Androth, Kalpeni	Androth, Kalpeni, Agatti, Kiltan
	1977	No loss of life	Kalpeni	Androth
	2004	No loss of life	Amini	Kiltan, Kavaratti

## Formation of the coral Islands

The conditions of coral growth requires clear and warm water at shallow depth.. Coral is a limestone formation formed in the sea by millions of tiny animals. Coral formations may look like branching trees, large domes, small irregular crusts, or tiny organ pipes. The Great Barrier Reef of Australia is the largest coral reef in the world (about 1800 km long). The formation of an island in the ocean is a first step towards the formation of coral island. The formation of oceanic island is shown in the sketches given below. When once island are sufficiently cooled and conditions are favorable the coral reefs will grow on top of the island. (Figure3).

## Type of reefs

There are three types of coral reefs:



**Figure 3** Formation of an Island in the ocean by volcanic eruption.

- (1) Fringing reefs.
- (2) Barrier reefs and
- (3) Atolls (Figure 4) Fringing reefs are submerged platforms of living coral animals that extend from the shore into the sea. *Barrier reefs* follow the shoreline, but are separated from it by water. They form a barrier between the water near the shore and the open sea. A barrier reef may consist of a long series of reefs separated by channels of open water. Such reefs usually surround volcanic islands of the South Pacific. An *Atoll* is a ring-shaped coral island in the open sea. It forms when coral.

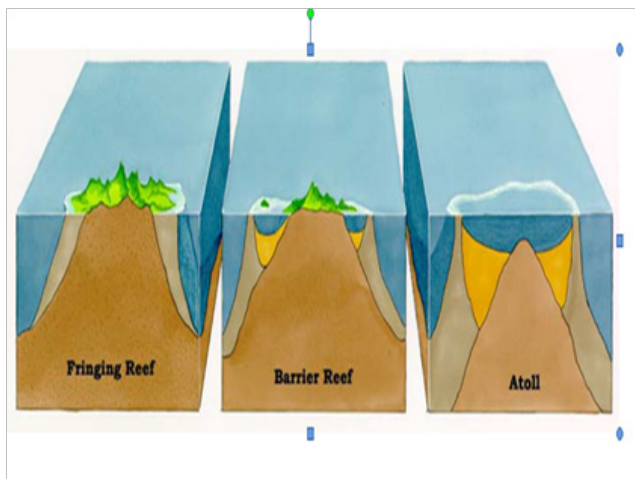


Figure 4 3 Types of Reef: (1) fringing reefs (2) barrier reefs, and (3) atolls.

### Geomorphic features

**Sand Dunes:** Sand dunes are the ridges of sand that often lie behind the active part of the beach. In the Lakshadweep islands there are shore parallel natural dunes and man made sand dunes in the interior part of the island. The anthropogenic-altered dunes are seen at Kavaratti. In general these sand dunes ranges from 3 to 6 m above the MSL (Figure 5).

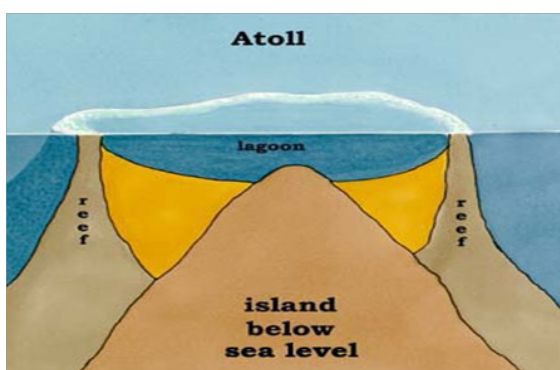


Figure 5 Enlarged view of an atoll.

**Beach:** Beaches are the important ecosystem of the islands. A beach may be defined as the unvegetated part of the shoreline formed of loose material usually a coralline, dead coral boulders, shingles, gravel that extends from the upper berm to the low water line. Beaches are the focal point for coastal recreation and tourism in the islands. They are also the first line of defense against storms and erosion. Birds,

reptiles and other animal's nest and breed on the berm and open beaches. Eastern part of the island has steep storm beach with deposits of shingles/boulders.

**Lagoon:** Lagoons are shallow water bodies parallel to the island coastline. They are often highly productive and habitat for variety of plants and aquatic animals, serve as nurseries for fishes and also sites for harbour, aquaculture, industry and recreation. In the Lakshadweep most of the inhabited islands have lagoons of varying sizes on the western part of the island except Androth. The lagoon varies from 1 to 100km<sup>2</sup> in size. The bottom topography and geomorphology of the lagoons also varies considerably. The smaller lagoon (Chetlet, Kiltan, Amini and Kadamat) is virtually filled with sediments. The water depths in these lagoons vary from 1 to 2.5 m and there are no significant topographic features. The larger lagoons (Bitra, Bangaram, Suheli and Minicoy) are comparatively deep with depth of about 10 to 16 m. The central part of the lagoons is usually deep. In the Kavaratti island the lagoon is about 4.5km long and 1.2km wide and has an average depth of 2m. At low tide the reef is exposed and during high tide it is submerged. View of the Lagoon with sands in the beach is shown in Figure 6.



Figure 6 View of a lagoon with sands in the shore.

### Resources of the ISLANDS

**Agriculture:** Agriculture is one of the major economic resource of the islands. About 81% of geographical area (2579 hectares) is under coconut and more than 1404 ha under fruits and vegetables. On an average a palm tree gives 81 nuts per tree. The coconut are grown with very high density of 242 trees/ha or even more. More value added products are being developed for the sustainable income generation to the people.

**Ground water resources:** Ground water is the most critical natural resource of the islands. The only source of potable water in the islands is rain, which seeps down the porous coral sandy soil and floats as lens above the saline water base. This water is drawn through wells. With consumption, the lens keeps on shrinking till it recharged with next rains. The sustainable yield of ground water in the islands is not sufficient to meet the demand. The per capita water requirement is 40 liters per day per person in the islands. Based on the requirement, Kavaratti, Minicoy, Agatti and Amini islands are classified as deficit. Chetlet and Kalpeni may become deficit in future. To meet the potable water in the island the Administration has started a trial plant of producing water from the sea using the thermal gradient in the sea.

**Non-living resources:** The seabed of the continental margins of India

contains variety of biogenous mineral deposits like relict oolitic and biogenic sands on shelf, coral and shelly sands in shallow areas of the lagoons of Lakshadweep islands. The estimated reserves of these sands in the lagoons down to 1-m depth are 288 million tons. These sands contain cent percent calcium carbonate useful for cement, lime, glass, paper and chemical industries. The estimated economic returns of 288 million tons reserve will be around 20 billion rupees. At present the land reserves is sufficient to meet the demand.

**Living resources:** Lakshadweep has immense potential for marine fisheries. The fishery resources are mainly characterized by a rich and diversified fish fauna. Estimation of the sustainable fishery resources of Lakshadweep islands is rather sketchy. Based on the results of experimental long line fishing carried out on fishable stock of tuna and allied species, is quantified as 50,000 tones, while the share of surface swimming skipjack is estimated as another 50,000 tones. The potential of pelagic sharks were estimated as 10,000 tones. At present the level of exploitation was estimated to be 12,000 tones (2001-2002), which forms only 10% of the estimated potential.

**Ornamental fisheries:** Recent survey on Lakshadweep shows the existence of exploitable quantities of ornamental fishes. More than 100 species of ornamental fishes belonging to 28 families could be exploited and marketed on a limited scale. Collection methods without tampering the reefs, packaging and transportation facilities need to be developed so as to tap these resources for export trade.

**Mariculture:** There is a good scope of Mariculture farming in the lagoon water of Lakshadweep. Bangaram offers an excellent site for pearl culture (Table 3).

**Table 3** Stages in the development of Lakshadweep atolls and growth of Islands

Stage	Sandy cays with shingle ridges	Vegetated sandy cays
Lagoons almost filled - a matured stage	Amini, Kiltan and Chetlat	Kadmat
Lagoons partly filled - an intermediate stage	Kavaratti and Kalpeni	Agatti
Deeper larger lagoons with small islands - an initial or nascent stage	Minicoy, Bitra, Beleapani, Suheli (Valiyakara) and Bingaram (Parli)	Suheli (Cheriyakara) and Bingaram
Atolls without islands		Beleapani, Bitra, Suheli, Kalpeni and Minicoy Chereapani and Perumal Par

### Uses of satellite in coral reef mapping

Satellite Remote Sensing is used for coral reef mapping. An atlas of the world's coral reefs has been brought out which carries maps of the entire world's reefs including the Indian reefs. The satellite images of coral reef depict extent of reefs and reef types. Baseline data for coral reefs of the entire Indian coast has been generated on 1:250,000 and 1:50,000 scales using Indian Remote Sensing Satellite data, Landsat, TM and SPOT data, wherein, extent, type of reefs and few broad geomorphologic zones were identified. The spectral signatures

are being used to classify the corals into live corals, dead reef, algal ridge, rocks and seagrass.

### Different type of corals in the Islands

The dominant live corals in the Lakshadweep islands are Porites, Favia, Acropora and Favites Seagrass and Algae in Lakshadweep–*Cymodocea* and *Thalassia* Seagrass beds are highly productive and valuable resources that occur in the shallow water lagoon of the islands. They enrich the sea and provide shelter and food for many aquatic animals. Two major plants constituting the sea grass are *Thalassia hemprichii* and *cymodocea*. *Thalassia* is found to be major food for the turtles and hence it is also called turtle grass. No commercial harvest of seaweeds is in practice in Lakshadweep. Algae occur in the lagoons and adjacent areas of the islands. They are economically important as a source of food and medicinal value.

### History of the Lakshadweep

#### Inference from breaks in profiles and terraces

The recent history of the atolls and the formation of the islands are reflected in the breaks in the profiles of the reef front and terraces. The breaks on profiles and terraces on these atolls represent the stages in the growth of the reefs on the atolls. These could be either due to strands in the rise of the sea level or even neotectonic events. The breaks in profiles and terraces seen on the reef front almost coincide with the minimum depths on the Bassas de Pedro (38 to 35m northern part and southern part 22 to 16m), Sesostris (20 and 22m) and Cora Divh (27m) banks. The maximum depths observed in the lagoon i.e. about 10-16m coincide with the breaks in profiles and terraces on the reef fronts of the atolls and on the Amini-Pitti (13m) Dingaram-Agatti (10m) and Elikalpeni (10m) banks. The two depth ranges i.e. 22-27m and 10-16m perhaps form important strands and the sea level at these depths would have been around 10,000 to 7,000 years before present. It would appear that the quaternary/holocene corals colonized at this level and the rims of atolls were also formed. With rising sea level, the coral growth kept pace with the rise and thus the stage was set for the formation of the islands.

### Formation of Islands

#### Sources, agency for generation and transport of sediments, erosion, accretion and depletion of sediments

The formation of islands on an atoll would require a source for sediments, an agency for generating and transporting the sediments to different physiographic regions on the atoll. The sources of sediments on an atoll are the luxuriant coral reefs and the associated communities on the reef front and reef flats of the atolls. The sediments are generated and transported on the atoll by waves, currents and cyclones. The currents in turn may be generated by waves or due to winds and tides. The continuous pounding of the reefs by waves breaks the corals and dislodges other organic communities from the substratum. The dominant direction of the waves in the area during the summer and monsoon (April- September) is from the W, WNW and WSW, though waves from the N, NNE and ENE are common during the winter (October- March). However, because of the greater height, the waves from the west are undoubtedly the more effective agent for generation of sediments and its eastward transport across the atoll. The eastern



reef on many of the atolls is narrower which also limits the capacity for carbonate production and sediment generation while the western reef and reef flat is much wider. The sediments thus generated are deposited on the reef front and subsequently the lagoon. The westerly waves also generate a circulation pattern favoring transport in the lagoon. The significant role played by the cyclones in the generation and transport of sediments is evident from the extent of storm beaches on many of the islands. The high waves generated during the cyclones break and transport not only the corals but also large sized colonies and blocks to some distance. The corals broken and deposited by cyclones on the eastern reefs perhaps effectively plugged the gaps in the reef and formed an effective barrier for trapping the sediments generated and transported from the western reef front. Undoubtedly in some other cases the cyclones have also played a destructive role by ripping the island and transporting the sediments and destroying the reef. The turbidity and sediments generated during such events might have even killed the corals. The cyclones though powerful are random events but a more sustained and perhaps a dominant role has been played by waves and currents to transport the sediments. A large volume of sediment is generated from the reef, however a substantial part of the sediment generated is perhaps lost from the atoll. The studies of carbonate production by reefs show that some of the reef (Kiltan, Chetlat and Kadmat) has produced far in excess of the sediment required for filling of the lagoons to the present depth. The growth of the reefs and filling of the lagoons started at about 15m below the present sea level at about 10,000 years BP and some of the lagoons by now have been filled up. The calculation shows that in some of the atolls with shallow lagoons the off reef transport may account for up to 95 per cent of the sediment annually produced. The shallow lagoons in these atolls cannot perhaps absorb any more sediments and most of the sediment is lost off the reef. Most of the sediment generated is lost through the gaps in the reefs especially their depth and location. These gaps act as funnels for sediments and its transport off the atoll. It is also suspected that a very large amount of sediment generated on atolls such as Bitra, Suheli, Minicoy and Agatti is lost from these wide gaps. It is felt that some of the islands i.e., Kiltan, Chetlat and Kadmat have reached an optimum size and would not grow larger because of the wide gaps in the reefs.

### Trends in the growth of the islands

Almost all the islands in the Lakshadweep are situated along the eastern leeward reef of the atolls. The islands have been broadly classified into two types i.e., sandy cays with shingle ridges and sandy cays vegetated or no vegetated. The vegetated sandy cays can be further divided into two types, those on the eastern leeward reefs of the atolls and those situated almost in the centre of the lagoon at the distal ends of the reef flat. The study of the atolls and the associated islands in the Lakshadweep shows various stages in their growth and islands to atoll ratios. It appears that the initial formation of the islands and their growth follows two different trends for the sandy cays with shingle ridges, vegetated sandy cays on the eastern reef and those at the distal ends of the reef flats.

### Sandy cays with shingle ridges

Chetlat, Kiltan and Minicoy best exhibit the pattern of development of these islands. The morphology of the atolls and the associated islands and the radiocarbon dates indicate that the rims of the holocene atolls were initially formed around 10,000 to 7,000 years

BP. The radiocarbon dates of the storm beaches show the oldest dates of 3000 to 2500 years BP from Minicoy, Kavaratti and Kiltan islands. This was the time when the eastern reefs of the atolls were hit by the earlier cyclones and the debris deposited on the reef. The cyclones continued to hit the islands periodically. However, the radiocarbon dates of the storm beaches show clustering between 3000 to 2000 BP and 500BP to present the former indicating the reef just reaching the sea and or stormier condition or both and the later stormier conditions only. The ages and pattern of storm beaches from both Chetlat and Kiltan atolls indicate that the first set of storm beaches were formed on the southeastern or the northeastern parts of atoll. These were followed subsequently by other sets of storm beaches, which led to the growth of the island to the east. The eastward rate of growth of the islands ranged from about 30m in the last 2760 years (Chetlat), 120m in 1620 years (Kiltan) and even 100m in 470 years (Minicoy). During this period parallel powerful westerly or south westerly waves were pounding the western reefs, during the monsoon and generating sediment which was transported eastwards extending the reef flat and shoaling the lagoon. The deposition of the coral debris in the first set of storm beach on the eastern reef provided an effective trap for sediments generated on the western reef and transported eastwards. The island thus started growing to the west, with the deposition of the second set of storm beach on the northeast or southeast, two separate sandy cays were formed westward behind these storm beaches. Subsequently the two were joined together by sediment deposited in between. Both in Kiltan and Chetlat, it is possible that with the growth of the sandy cays from the north and south and the barrier from the west, a water body could have been trapped in between the two sandy cays leading to the formation of a mangrove swamp.

### Vegetated sandy cays

The best examples of the vegetated sandy cays are Kadmat and Agatti. Kadmat is an elongate atoll while Agatti has an oval or oblong shape. The gaps in the reefs of the both the atolls are more or less similarly situated on the NE, W, NW, SW or SE. However, the opening at Agatti on the northwestern reef is much wider. It appears that in Kadmat, two sandy cays developed on the eastern reef first possibly on the north and subsequently in the south and these were later joined by sediment deposition between the two. In the case of Agatti, the sandy cay was formed first on the north and the island gradually started growing from this sandy cay further to the south. In both the atolls the growth has been more on the north because the predominant direction of sediment drift in all the atolls appears to be SE-NW, which favours greater transportation and deposition of sediments in this direction. The reef on both the atolls has opening on the southeast, which leads to off reef transport of sediments and consequently depletion of the sediments from the atoll.

### Vegetated sandy cays at the distal ends of reef flats

The vegetated sandy cays in Bingaram and Suheli atolls represent these. The reef on the west in these two atolls has large gaps with the result that most of the sediment generated during the monsoon because of the waves from this direction may be transported off the reef and may not find a way to the lagoon and contribute to the growth of reef flats and the formation of the islands. The southwestern reef in Suheli does not have large gaps and reef flats are extensive and perhaps sediment from the western reef is transported along the reef to the eastern reef also. In both these atolls extensive reef flats extend from

the eastern reef to the lagoon and at the distal end of these reef flats, the islands have been formed. The islands were probably developed at the farthest end to which the sediment could be transported by the waves and currents and represent the nodal points for wave refraction and deposition of the sediments.

### Hape of atolls in response to wind, waves and sediment drift patterns

It appears that even though different patterns in the growth of the atoll islands have been observed (sandy cays with shingle ridges, vegetated sandy cays on the leeward side and vegetated sandy cays at the distal ends of reef flats), however even in these, certain common factors controlling the growth are observed. It appears that in some of the islands the growth has been faster on the north (e.g. Agatti, Kavaratti and Kadmat) because of the predominant wind and wave and in turn the sediment transport from the west. Agatti and Kavaratti are both oval and oblong shaped atolls though the former has a wide gap on the western reef. In both the cases the islands have a bulge and have grown faster on the northern side, which appears to be due to the sediment transport in this direction. However, because of the gap in the south and off reef transport of the sediments the island in Agatti has not grown faster in the south. Both Kiltan (sandy cay with shingle ridges) and Kadmat (Vegetated sandy cay) are long linear atolls and both have an opening in the north and in the west in the centre. The opening if any in the reef in Kiltan on the southeast would have been probably plugged by the storms in early stages. The present sediment drift pattern in both these atolls appear more or less similar. The islands initially appear to have developed as sandy cays in the north and south separately and were joined latter by the sediment deposited in between. It would thus appear that growth of the islands has been controlled by the shape of the atoll and its deposition to the predominant wind and wave directions and gaps in the reef and in turn the predominant directions of sediment.

### Important features of coral reefs

Growth of coral will require clear shallow water with a particular temperature. Corals are formed by tiny lime secreting animal growing in millions in different shapes like branching trees, large domes, small irregular crusts, or tiny organ pipes. An Atoll is a ring-shaped coral island in the open sea. It forms when coral builds up on a submerged bank or on the rim of the crater of a sunken volcano. The atoll surrounds a body of water called a lagoon. One or more channels connect the lagoon to the open sea. Many coral islands of the South Pacific Ocean and Lakshadweep are atolls. The Laccadive islands are situated on the northern part of the Laccadive-Chagos ridge in the western Indian Ocean which extends over 2500km. A considerable length of the crest of this ridge is composed of shoals, banks and coral reefs at depth less than 1500m. The ridge is divided into three main segments and is referred as the Laccadive islands (Lakshadweep), the middle segment as Maldive islands and southern segment as Chagos bank. Laccadive-Chagos ridge system was considered as a zone of transition between oceanic crust in the west and continental crust in the east due to block faulting along the west coast of India. The thickness of sediments estimated between Kerala and Lakshadweep is about 2km. Based on the borehole data the volcanic rocks lay below the seafloor on the Lakshadweep ridge. The islands are open to storms and cyclones. One of the earlier natural calamities recorded was in April 1847. During this cyclone the first island to hit was at Kalpeni

and finally moved to Androth and Kiltan. Many deaths were reported. In 1891 a violent storm burst upon Kavaratti causing great damages to the coconut plantation. Damages in Agatti and Amini were also reported. Kalepeni Island was once again hit by a severe cyclone in December 1922. The waves washed completely over the northern end. There was no loss of life. Another major storm was stuck in 1941. In 1963 and 1965 also major storm struck causing considerable damages to Anroth, Kalpeni, Agatti and Kiltan. The last cyclone occurred in 1977 was in Kalpeni and Androth. There was no loss of life. The recent cyclone that hit the islands was in May 2004. Amini was greatly affected. Kiltan and Kavaratti were also affected. There was no loss of life. Property damages were extensive.<sup>19</sup>

### General setting

Islands in most of the atolls are situated on eastern leeward side of the reef. In the capital Island Kavaratti, the lagoon is 4.5km long, 800m wide and it is only few meters above sea level. The lagoon is situated to the west, enclosed by reef, elliptical in shape. Lagoon side beach is sandy; the eastern part is bouldery and formed by storms from east. Radiocarbon dates vary from 2975+- 100 year BP and indicate clustering between 3000 and 2000 year BP. The storm beaches are younger towards the shore and grown by about 10m/1000years to 200m/1000years.

**Beach:** Beaches are the important ecosystem of the islands. The beach consists of unvegetated part of the shoreline formed of loose material usually a coralline, dead coral boulders, shingles, gravel that extends from the upper berm to the low water line. Beaches are the focal point for coastal recreation and tourism in the islands. They are also the first line of defense against storms and erosion. Birds, reptiles and other animal's nest and breed on the berm and open beaches. Eastern part of the island has steep storm beach with deposits of shingles/boulders. Sand dunes are the ridges of sand that often lie behind the active part of the beach. In the Lakshadweep islands there are shore parallel natural dunes and manmade sand dunes in the interior part of the island. The anthropogenic-altered dunes are seen at Kavaratti. In general these sand dunes ranges from 3 to 6 m above the MSL.

**Lagoon:** Lagoons are shallow water bodies parallel to the island coastline. They are often highly productive and habitat for variety of plants and aquatic animals, serve as nurseries for fishes and also sites for harbour, aquaculture, industry and recreation. In the Lakshadweep most of the inhabited islands have lagoons of varying sizes on the western part of the island except Androth. The lagoon varies from 1 to 100km<sup>2</sup> in size. The bottom topography and geomorphology of the lagoons also varies considerably. The smaller lagoon (Chetlet, Kiltan, Amini and Kadamat) is virtually filled with sediments. The water depths in these lagoons vary from 1 to 2.5 m and there are no significant topographic features. The larger lagoons (Bitra, Bangaram, Suheli and Minicoy) are comparatively deep with depth of about 10 to 16 m. The central part of the lagoons is usually deep. In the Kavaratti island the lagoon is about 4.5 km long and 1.2km wide and has an average depth of 2m. At low tide the reef is exposed and during high tide it is submerged.

### Some observations on lagoons

The islands on most of the atolls are situated on the eastern leeward side of the reef. The general setting and bottom topography of these lagoons and offshore areas have been discussed in detail earlier/The



radiocarbon data<sup>8</sup> of the corals from the storm beaches range from modern to 2975±100 B.P. and indicates clustering between 3000 to 2000 B.P. The sets of storm beaches are almost at the same level and progressively younger towards shore and beach on these parts of the island. It is inferred that they have grown by about 10m/1000 to 200m/1000 years.

**Sediment and size distribution:** Sediment distribution in these atolls is related to the sources, morphology, and transport agencies. The source of the sediments on the atolls is the coral reefs and the other biological communities of the reef areas. A substantial amount of the sediments in the reef front is lost in the deep sea because of morphology, waves and currents. The inner reef flat has thicker sediment cover, parts of which are transported to the lagoon. The sediments in the lagoons consist of various types of sands and gravel size pieces resulted due to breaking of reefs. Outcropping corals break the pattern of distribution of the sediments in the lagoons. In some of the lagoons large areas are covered with seaweeds. Boring by the Harbour Engineering Department in the Kavaratti shows that the sands extend beyond 10m depths. Besides coral, Halimeda, shells of gastropods, foraminifera, ostracods and bryozoas are present. The sediments show a bimodal to polymodal character. Halimeda is the most important constituent of the lagoon sands in addition to corals. A good amount of fine debris is present in some samples.<sup>9</sup> Halimeda is the most prolific sediment contributor in the Funafute atoll as well as in most of the Pacific lagoons and Caribbean reef component (Milliman, 1974). In an average Halimeda constitute around 40% and corals 30% in the lagoons. The contribution of different communities on coral reefs and their influence on size distribution, has been discussed by the author earlier.<sup>9</sup> Examination of different size fractions indicate that the size more than 4mm (-2 phi) contains mostly fragments of rounded corals. Between 2mm to 4mm (-1 to 2 phi) also the coral fragments dominate with different shell fragments and very few pieces of halimeda. In the 1 to 2 mm size range (0-1 phi) although the coral fragments predominate, few distributions is controlled by the Halimeda group. Corals and halimeda are responsible for the modes in this group. In size range 0.51mm (1 to 0 phi) corals, halimeda and foraminifera occur almost in equal amounts. Foraminifer predominates in this range. In size range 0.25 to 0.15 (2 phi to 1 phi) corals and halimeda become important. In size range 0.25 (less than 2 phi) all constituents are mixed up due to mechanical and biological breakdown.

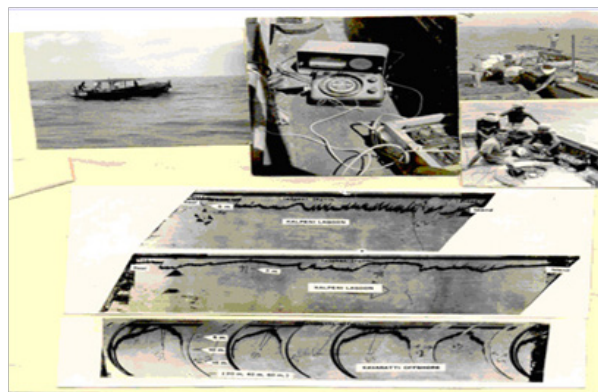
**Mineralogy:** Beach rocks contain mainly aragonite and traces of calcite with some doubtful Kaolinite. The lagoon sample contains calcite and aragonite as major constituent. The samples from the reef areas contain major calcite aragonite. The major source of aragonite is from corals, halimeda and mollusks. The lagoon sediments essentially consisting of halimeda and coral are mainly responsible for aragonite portions and the foraminifers contribute to the calcite portion. Diagenetic alteration causes changes in mineralogical composition.<sup>10</sup>

**Petrography:** The beach rock consist of moderately well sorted calcarenite composed of reef detritus of corals, coralline algae shells of gastropod, foraminifera, bivalves, bryozoas etc. coralline algae occur very frequently in the old reef rocks. Portions of algae often show micritisation and give a porous appearance. Recrystallization sometimes completely obliterates the cell walls. Fragments of intraclasts are present in some of these samples. In thin section corals show a feathery appearance and differential extraction of material results in a number of pore spaces depending on growth habits. Beach rocks at places show little or no cement indicating immaturity. The

spaces between the grains are generally filled up with micritic matrix showing slightly brownish colour. Some void spaces have been filled up by sparry calcite. Fluorescent microscopic studies indicated boundaries of Aragonite and Calcite clearly. The Aragonite shows brighter fluorescents. Presence of bright white yellow specks with much brighter fluorescent may be indicative of presence of Bitumen like material or resinous body showing effect of bacteria. Shells of foraminifers showing bright outer rims of higher fluorescence within the coralline algae may be indicative of development of similar type of material. These features are interesting for petroleum geologists as the coral reef areas are analogous to ancient reefs where valuable oil pools have been discovered.

### General characters of the atolls and banks

The general characters of the atolls and banks are described below with reference to the Survey was carried out in small Fishing Trawlers. The bottom topographic data were collected by Portable echo sounders Some of the Profile data is also shown Figure7. The lagoon shore is mainly sandy and the seaward northern eastern and southern shore is bouldery, pebbly and rocky. The boulders consist of corals while the inner side of the islands consists of black or old corals in a scattered form. The feature is clear on the eastern side. The beach exposures are recommended coral debris. In some parts of the lagoon shore considerable quantity of the seaweeds has been accumulated.



**Figure 7** View of a fishing trawler used for work, portable echosounder and some profile data.

**Bottom topography:** The depth in the lagoon in most of the cases is very shallow within a few meters. The topography of the lagoon towards Island margin is even. In the reef margin it is rugged. Reef varies in width from 200-400m. Wave cut platform extends from the reef margin to a distance of 50-100m towards the sea and the depth falls steeply within a short distance. Echo sounding indicated a number of well defined submerged terraces on the sea ward reef. The topography of the lagoon towards the island margin is considerably even but it is rugged due to outcropping corals at the reef margin. The bottom slope of the lagoon is steeper on the reef margin than at the island margin. The offshore areas show very rugged topography with steep slopes. The reef varies in width from 200 to few hundred meters and is widest in the southern part. Well defined wave cut terrace extends from the reef margin to a distance of 50-100m towards the sea in many islands The slope steepens within a very short distance in the sea ward side. A number of surge channels are also present in the outer reef oriented in NW-SE to NE-SW direction. Within short distance away from the shore the reef slope falls steeply beyond the range of the echo sounder. The surveys indicated a number of terraces on the

seaward reefs of the islands at 7-12m, 15m, 21-36m (prominent) and 43-47m depths. The first break usually represents a wave cut platform and the deeper terraces (>12m) appear to have been formed during periods of lowered sea level. The bottom sediments of the lagoon consist of various types of corals of sands and gravel size resulting from the breaking of the reefs by waves. The distribution patterns of sediments in the lagoon are broken at places by outcropping corals and coral rocks. Sediments are mainly localized towards the island and the central deeper part of the lagoon. They range from coarse coral gravel in the reef margin to coarse to medium sand in the Island margin. The sediments are more than 7m thick which is clear from the drilling data of the Lakshadweep harbour work near the Kavaratti jetty. The sediment in the reef is sparsely distributed and mainly occurs in pockets and channels. They are represented by coarse corals, sands and gravels.

### Biodiversity

The reef areas are the living places of various communities of corals belonging to different families of *Acroporidae*, *Poritidae*, *Pocilloporidae*, *Favidae*, *Fungiidae*, *Mussidae* etc. Besides a large number of species of *Gastropods*, *Bivalves*, *Echinoids*, *Foraminifers*, *Ostracods* and *Bryozoans* are also present. Important Coral varieties and other forms are shown in Figure 7. *Halimeda* is the most important constituent of the lagoon sands and played most important role in building up the reef. In the atolls besides corals and *Halimeda*, foraminifers, echinoderms, bryozoans, annelids, crustaceans etc. have also been noted and only a very short account is given here. These forms have played a vital role in producing sediments from the reef. During the survey between the Kalpeni and Cheriya reef in the low tide area it has been observed that the reef area is the dwelling place of a large number of different forms. The coral community is most dominant and occurs in colonies as well as in single individual species. Different types of growth forms such as branching, robust, massive, platy, foliated or flowerlike are quite common. The *Acropora* group is most dominant and a number of different varieties are present. The branching fragile types are common and widely distributed; the surface texture is irregular with thick roots. Usually they show a bright yellow colour. Sometimes a light-pink or light-blue colour is also seen which fades away after a few days following removal. The density of distribution varies. The root portion of the corals as well as in some cases the upper surface, is covered with encrusting algae. Former Director, G.S.I, Marine Wing is the next important group. They are usually more massive and rounded and can resist greater strength. *Pocillopora* also occurs in great abundance. *Pocillopora eydouxi* and *Pocillopora damicornis* are common. *Fungia* (*Pleuractis*) *scutaria* (young form) of Fungid group are also seen in reef areas. Some members of the *Montipora* group are also present. Amongst others, *Psammocora contigua* and *Lobophyllia hemprichii* belonging to *Thamnasteriidae* and *Mussidae* families respectively have been noticed occasionally. Most prolific growth of the corals occurs in the inner and outer side of the reef areas. Coralline algae occurring extensively in the reef areas and apparently more predominant in the seaward side have played a very important role in building up the reef. *Halimeda* is the most important coralline algae. Important coral groups from Kavaratti and Kalpeni atolls have been presented in Table 4.

**Table 4** Important coral groups from atolls of Lakshadweep

Phylum: Cnidaria	
Class: Anthozoa	
Order: Scleratinia	
Family: Acroporidae	<i>Acropora</i> sp.
Family: Poritidae	<i>Porites</i> sp
Family: Pocilloporidae	<i>Pocillopora eydouxi</i> Milne Edwards and Haime <i>Pocillopora damicornis</i> (Linn.)
Family: Faviidae	<i>Favia speciosa</i> (Dana) <i>Goniastrea pectinata</i> (Ehrenberg) <i>Montipora</i> sp.
Family: Fungiidae	<i>Fungia</i> sp. <i>Fungia</i> ( <i>Pleuractis</i> ) <i>scutaria</i> Lam. (young form)
Family: Thamnasteriidae	<i>Psammocora contigua</i>
Family: Mussidae	<i>Lobophyllia hemprichii</i>

### Other forms

Besides coral, a number of different types of forms are present in the reef areas, the opercula of *Turbo* sp. have often been noticed in the beach sands. The family *Cerithiidae* is represented by *Cerithium nodulosum* Brugier *Strombidae* are well represented by the commonly called spider shell or lambis and *Lambis* (*Harpago*) *chiragra chiragra* (Linnaeus). Some forms of the *Cymatiidae* family are represented by the very impressive and commonly called “trumpet shell” or *Charonia* (*Charonia*) *tritonis*, which attains very large sizes of upto 40cm. Another interesting and well-represented family is *Cypraea*. *Cypraea tigris tigris* Linnaeus was picked up from Kalpeni-Cheriyam dead reef area. Another conspicuous and quite abundantly occurring group is represented by the *Tridacnidae* mostly represented by *Tridacna maxima* which attains very large sizes. The living forms occur in the reef areas as well as in the lagoons. Dead shells of different sizes can be seen along with the boulders on the seaward side. They are the commonest species in most of the reef areas. Essentially they occur in the reef top and are very strongly attached to the reef surface. Living forms have a blue coloured mantle seen from a long distance. *Echinoneidae* are represented by *Tripneustes gratilla* of the *Toxopneustidae* in the lagoon waters near Pitti Tillakkam. A finely preserved form of the *Brissidae* family, *Brissus latecarinatus* (Leske) was recovered from the Pitti beach. *Hollothurians* are present all over the lagoon and reef areas. They are sausage-shaped, lumpy and brown to black in colour. The asteroid group includes the starfishes and the *Ophiroids* are represented by abundant brittle stars. *Foraminifers* are well represented in the lagoon sands as well as in the beach sands. *Amphistegina* is abundant in some of the samples from the lagoon. Other forms identified are *Triloculina*, *Quincoloculina*, *Calcarina*, *Eponids*, *Spiroloculina*, *Elphidium*, *Clavulina*, *Borilis*, *Asterigerina*, *Cibicides*, *Nonion*, *Caneris*, *Biogenerina*, *Lenticulina*, *Texularia*, *Discurbis* and some larger foraminifera. Mostly the forms are calcareous and haline, while the arenaceous forms are rare. A number

of boring organisms destroy part of the reef frame. Wherever the reef rock is broken the extent of boring can be examined. Many species of fishes, giant tortoise and turtles thrive in the lagoon and offshore areas but no detailed study has been done. There is still plenty of scope to study the varied fauna of this group of lagoons and reef areas.

### Resources of the Islands

**Ground water resources:** Ground water is the most critical natural resource of the islands. The only source of potable water in the islands is rain, which seeps down the porous coral sandy soil and floats as lens above the saline water base. This water is drawn through wells. With consumption, the lens keeps on shrinking till it recharged with next rains. The sustainable yield of ground water in the islands is not sufficient to meet the demand. A fresh water desalination plant has also been installed in Kavaratti to meet the local needs and the industries.

**Living resources:** Lakshadweep has immense potential for marine fisheries. The fishery resources are mainly characterized by a rich and diversified fish fauna of tuna and allied species.

**Non-living resources:** The seabed of the continental margins of India contains variety of biogenous mineral deposits like relict oolitic and biogenic sands on shelf, coral and shelly sands in shallow areas of the lagoons of Lakshadweep islands. The estimated reserves of these sands in the lagoons down to 1-m depth are 288 million tons. These sands contain high percent calcium carbonate useful for cement, lime, glass, paper and chemical industries. The estimated economic returns of 288 million tons reserve will be around 20 billion rupees. At present the land reserves is sufficient to meet the demand. Most important type of biogenous deposits of the Lakshadweep are derived from different varieties of corals as shown in Figure 8 which occur in the lagoons and reef areas of Lakshadweep in the Arabian sea. The Survey<sup>20</sup> in the lagoons and shallow offshore areas of the Lakshadweep indicated the occurrence of 288 million tonnes of calcareous sands in the lagoons to a depth of about 1 meter below the lagoon floor. The inferred reserves in some lagoons where no detailed surveys could be carried out are of the order of 423 million tonnes to a depth of 1 meter. The reserves at greater depth are expected to be many times more and the inferred reserves in the lagoons between 1-2 meter below the lagoon floor are about 712 million tonnes. The Reserves are shown in Table 5. These sands are of good quality with low silica, alumina and iron and MgO appears to be the only impurity. These calcareous sands have not been however used in spite of their great potential. The geomorphic situations in the islands are delicate.<sup>21</sup> We do not know the effect on these islands when large quantities of sands will be taken out. An analysis of problems related to dredging in a coral atoll has been discussed earlier<sup>11,22</sup> and it is expected that it is not difficult to achieve an optimum target of utilizing these sands without hampering the coral growth and ecological balance. "If limited quantity of sands removed", there will not be appreciable change in the rate of production or derivation. Slight changes will be automatically adjusted. It may be necessary to simultaneously monitor the various changes to allow us to establish the mode of operation in other areas with similar environment. There are several examples where the calcareous sands have been taken up in slightly different environment. In Johnson Island, Pacific a ship channel was cut into the shallow lagoon and subsequently enlarged without any adverse effect. In Suva, Fiji, commercial exploitation of coral sand (approximately 200,000 tonnes annually) was performed in the lagoon adjacent to Suva and no harmful effect was noticed. Offshore Apia (Samoa) sand/aggregate

dredging operations are conducted in a narrow lagoon behind barrier reef. The Seychelles airport was built up with sands dredged from back reef. At Kavaratti Harbour Engineering Department has already dredged 52,564 m<sup>3</sup> sands/rocks during 1971–1979 and there are no serious effect. The most important sediment-forming site is the reef area and it should not be disturbed as far as possible. The lagoon is the most important accumulation site and the lagoon will have the tendency to fill up automatically if the sands are taken out. As discussed by the author<sup>22</sup> the sediment production figures in the reef area should encourage the exploitation. Mining can even be started in any uninhabited island with simultaneous studies on bathymetric, organic community, shoreline changes etc., to understand the behavior and effect of mining. It may not be difficult to achieve the optimum target of exploitation without any harmful effect on the islands. The result of complete chemical Analyses of 36 samples is given in the Table 6. The sands have a low amount of silica, alumina and Fe<sub>2</sub>O<sub>3</sub>. They are suitable for a number of industries like cement, chemical, glass and paper. Since these deposits are in the form of loose sands it is advantageous for cement industries. However, the geomorphic situation on the coral islands are delicate and precautions have to be taken while mining those sands and the problem has been discussed in several publications by the author.<sup>10,11,22</sup> The present calcareous sands occur in a loose form on the lagoon floor and will be easier to mine. We can expect a quick return from these deposits without disturbing the delicate balance. Existence of very pure calcareous sands of the order of 288 million tones down to a depth of 1m below the lagoon floor aroused the interest of a few organizations to exploit these sands for the manufacture of cement, calcium carbide etc. Coral atolls represent a delicate equilibrium and not much is known about the behavior of these atolls if large quantities of sands are taken out for industrial purpose. Analysis of the present situation to predict the effect of dredging has been discussed here to throw some light on the key problem of the extent to which sediment can be removed from the lagoon without resulting in any unacceptable erosion of islet. For this purpose the observations made in a dredged channel maintained by the Lakshadweep Harbour Works as well as the adjacent beaches and reef areas have been summarized here including the data collected by the Lakshadweep Harbour Office. The results obtained from earlier work have also been critically analyzed to understand the dredging problems. The dredging operation started by the L.H.W. in 1971 and going on since then, is being done with the help of 1 CYD grab dredger ( mounted on Pontoon (draft 1m.). The dredged material is loaded in Hopper Barges (capacity 16m<sup>3</sup>) which are towed with the help of Pablo boat or tug to the dumping ground on the east and west side of the main entrance to the deep sea A huge quantity of sands has already been dredged till now and was dumped into the sea, which is lost forever as the profile is very steep outside the reef. o harmful effect was noticed due to dredging of the navigational channel by the Harbour Department. In the areas adjacent to the dredged channel accretion has been taking place instead of erosion.

**Area of sediment generation:** The corals are derived from the reef edge<sup>9</sup> and there is a clear relationship between coarser sands and the active margin. In contrast, coral heads in the lagoons are sparse and little coral debris can be added during transport. *Halimeda* live within the edge zone and also in the shallow lagoonal floors. A good portion of *Halimeda* occurs in the lagoon floor, within the lagoon itself. *Halimeda* is an important source of the finer mud, particularly and have high aragonite content.

**Sediment transport:** From the distribution of mean size it is clear



that the coarser sediments occur near the reef in general and finer sediments near the island. Agencies as currents, waves and tides have played a significant role in the grain size distribution. Sediment generated within edge zones is carried by wave action over the reef and into the lagoon area. Wave refraction will tend to transport it "onshore" irrespective of wind direction although there will be an alongshore component. The islands on the eastern margins of the atolls lie within the wave shadows of both the main wind directions and this is probably the reason for their formation in these positions. External currents are probably not relevant here. Currents within the lagoons may be important but in similar situations elsewhere it is expected to find a thin algal mat, which binds the sediment surface and prevents movement even during storms. Thus, the sediment arrives in suspension and having once settled moves infrequently. The irregular distribution of statistical parameters suggests that this may be the case.



**Figure 8** Some coral varieties and other forms.

**Table 5** Details of reserves in various lagoons

Lagoons surveyed	Area surveyed Km <sup>2</sup>	Reserves (MT Upto 1m)
1. Agatti	30.8	20.7
2. Kavaratti	14.2	4.39
3. Kalpeni	38.2	24.76
4. Chetlat	6.5	1.91
5. Kiltan	4.1	1.33
6. Bitra	66.6	57
7. Kadmat	17.7	16.74
8. Amini	5.4	1.25
9. Banagaram	53	35.06
10. Suheli	102.6	92.44
11. Minicoy		
Reconnaissance only	45.4	33.12
1. Belpani		
2. Cheriapani	50	62.5
3. Perumalpar	156	195
	63	78.6
4. Androth	70	87.5

**Table 6** Complete chemical analyses of Lakshadweep lagoon sands giving the ranges and average of different elements

Element	Range	Average	Element	Range	Average
SiO <sub>2</sub>	Traces to 0.12	0.082	Al <sub>2</sub> O <sub>3</sub>	0.09 to 2.22	0.88
Fe <sub>2</sub> O <sub>3</sub>	Traces to 0.39	0.12	TiO <sub>2</sub>	Traces to 0.43	0.034
P <sub>2</sub> O <sub>5</sub>	Traces to 0.14	0.056 (P=0.012)	CaO	49.01 to 51.90	50.16
MgO	0.24 to 3.0	1.63	Na <sub>2</sub> O	0.25 to 1.20	0.6
K <sub>2</sub> O	Traces to 0.30	0.05	SO <sub>3</sub>	0.17 to 1.17	0.67
L.O.I.	45.06 to 46.84	45.53			(S=0.26)

**Source areas of sediment:** The reef edge is the principal area of production of sediment. It is largely "rocky" in character and cannot be an area of accumulation. More than 10m of loose sand have been accumulated in the lagoon as observed from the borehole log from some lagoon. Though we do not know the extent to which sediment may move seawards through reef passes or deeper surge channels, the sediment, which may accumulate to seaward edges, is regarded as lost as depth increases rapidly.

**Examples of mining coral sand or dredging coral atolls from other areas:** Dredging of coral sands have been done in a few places. Commercial exploitation of coral sands (approximately 200,000 tonnes annually) is now performed in a lagoon adjacent to Suva in a larger framework. Presently the dredging is performed to a viable economic limit of approximately 10m water depth. The operation has been done successfully and has not affected the barrier reef and no effect has been noticed in the beaches and other dredging grounds or other subsistence fishing activity (personal communication R. Holmes, Suva, Fiji). Offshore Apia, sand/aggregate dredging operations are conducted in a narrow lagoon behind a barrier reef separated by 2km from the land. A ship channel was dredged in the Johnson Island (0.9 sq. km. Emery, 1956) Pacific into the shallow lagoon and it subsequently been enlarged. Sand and sediment from the channel was used to enlarge the island for its runway. There has been no difficulty till today. Few detailed investigations have been made of the effects of this kind of exploitation although it is not uncommon; the Seychelles airport was built with sands dredged from the back reef. Coral mining centered in the Gulf of Mannar on the reefs of Tuticorin group produced 100000 tonnes of lime till 1979 where 400 people were involved. In Indonesia, dead coral is taken from back reef for using as building materials. In Java, coral reefs for lime factories are being taken up. In Maldives coral rocks are also being used for housing and construction of buildings. In Sri Lanka, mining of Coral for lime is extensive. In all these cases though some adverse effects were observed still there was no appreciable damage.

**Human Impact and anthropogenic induced hazards:** Research on the reefs in the 1960's and 1970's led to the view that reefs were fragile ecosystem particularly vulnerable to human activity. Subsequent work led to contrasting ideas that reef communities are dynamic and unstable. Self-replacement and recovery from natural disturbance is normal and contributes to the maintenance of high diversity. The present consensus is being that the reefs are perhaps

not as fragile as was previously thought. The reef areas are constantly experiencing changes due to human impact which causes natural disturbances and the man made disturbances causes slowing in the recovery rates. The growth of the coral has been seriously hampered in these islands when boat channels are dredged or portions removed for mining or construction purposes. High population densities in some of the islands create more problems. Over exploitation, over fishing or pollutants released by ship oil etc. damage the reefs. The major coastal habitats of the island are coral reefs, sea grass beds, dunes, lagoons, and beaches etc. The major thrust areas are basically the major coastal habitats of the island ecosystem. The management of these habitats is based on well understood linkages among human activities and changes within natural system. The known uses of the coastal habitats are non extractive, extractive and transformative. Non extractive uses refer to recreation, research or education and do not involve removal of material from the habitats or do not have serious impacts. Extractive uses involve removal of renewable resources such as fish, ground water, mangrove wood etc. Transformative uses such as coral extraction, waste disposal without treatment result in negative changes in habitat characteristic and function. Sometimes there is a degree of overlap among the uses. All the extractive uses should be closely monitored and controlled for better preservation of reefs and atolls without causing any harmful effect. Fishing using dynamite fish poisons or intoxicants is widespread. These can be extremely damaging destroying the reef. Intensive recreational use by diving, boat anchoring and tourist generated pollution affects the coastal strips of many of these islands. Reefs are sometimes getting destroyed in countries with high population where tourism has been expanded rapidly. A variety of fish and reef invertebrates have been heavily overexploited where they are important to local people and are in demand by tourist. The ornamental coral trade in Philippines has led to significant localized reef damage. Mother of pearl species has been overexploited throughout much of the region. Giant clam have been seriously depleted particularly in Indonesia & Philippines. Ornamental shells are heavily exploited. All these factors results in destruction of the reefs rapidly.

**Remedial measures to be taken:** Scientists should be involved in preparation of detailed spatial plan of islands. Dwelling units including some of the infrastructural facilities can be mapped first using GPS. The conservation and preservation zones are the key components and should be mapped separately. Coral reef formation is extensive both inside and outside the lagoon waters. Reefs are present in depth exceeding 1-2m/in lagoon and also beyond breaker zone. In the outer reef areas it is present up to 30-40m depth. Live corals present in the range between 14 and 24%. Area bordering the above zone is a buffer zone. Rest of the area is classified as a non coral zone. The Centre for Earth Science Studies in Trivandrum considered the limited land area, fragile environment; limited resources and major environmental constraints faced by the islands and developed an integrated Island Management Plan for the Lakshadweep islands in accordance with the guide lines of the Island Protection zone Notification 2011 of the Ministry of Environment and Forest. Upgrading physical and social infrastructure in the island is an important issue. Some physical infrastructure required in the islands is primary health care facilities, high schools, primary schools, nursery schools etc. A general college, ITI with hostel facilities is possible in one of the larger islands. The emergency/cyclone shelters can be built in elevated area having double story building. The existing provisions can be upgraded in terms of land built space and facilities. Parks, play ground can be

upgraded. Potable water supply is generally short in most of the islands. Desalination plants fill up the gaps in Kavaratti, Agatti and Minicoy. Facility should be installed in all islands.<sup>23</sup> For sewage disposal two pit flush septic tanks are in place. Oxidation ponds, biotoilets offer alternatives according to soil condition. Solid waste disposal/management pose problem and alternative to sea dumping/inclination needs should be explored. Electricity is generated through Solar Panels and wind mills can act as alternative source. Corals have very specific requirement for light, temperature, water clarity, salinity and oxygen. Their lack of mobility makes them vulnerable to siltation through smoking and oxygen depletion. Coral growth tends to be slower where sediments are regularly disturbed and silted substrate inhibits larval settlement. Light penetration is decreased in turbid water reducing photosynthesis. In clearest seas reef building corals are restricted to depths <30m and are formed much shallower. Many strong corals have slow growth rates, which may be slowed further by adverse environmental conditions. Davies (1983) provides figures for reef growth in the range 0.38-12m/thousand years.

**Effect of Sea level changes:** Corals usually grow on hard bottom. A slow rise of sea level enables the island to sink and allow the reef to grow vertically and rapid rise of sea level will destroy the reefs. The Lakshadweep group of atolls is situated in the Lakshadweep Ridge and the history of these islands is related to the history of the ridge. The ridge is oriented N-S and extends for about 2200km between 10° S-12° N. There are various theories of origin of the Lakshadweep Ridge. Whitmarsh et al.<sup>24</sup> suggested a hot spot origin connected with the motion of the Indian Plate over a fixed spot. DSDP SITE-219 was drilled at a water depth of 1766m on Lakshadweep Ridge penetrated 411m and a sequence of upper paleocene to recent was recovered. Shallow water upper paleocene limestone, sandstone and siltstone succeeded by Eocene Chalk and ooze were noted. The sea bed began to sink to about 2000m in early Eocene times. The studies of the fauna also suggested that the ridge was connected to eastern shelf during late paleocene and the western shelf extended as far as Lakshadweep ridge. Details are available in Whitmarsh et al. (1974). Sedimentation history suggests that the site was once close to Indian landmass or perhaps a part of the main landmass. However, there is still a controversy about the origin of this ridge, and further geophysical studies are required to solve this problem. The corals started growing in the ridge depending on the hydrological and bathymetric character of the area. Fringing reefs formed in the western part as the waves supplying food were coming from the west. Active reef growth continued in the west to form acurete shapes. The various terraces noted represent the various stages in the growth of the atolls. These could be either due to strands in the rise of the sea level or by neo tectonic activity.<sup>25</sup> The two depth ranges 22-27 m and 10-16 m perhaps formed important strands. Sea level at this depth would have been around 10,000 to 7000 yr B.P. Perhaps the corals comprised at these level and the rims of the atolls were formed. The eastern reef on many atolls is narrower limiting the capacity of carbonate production. Sediments generated are deposited in the reef front and subsequently in the lagoon. A large volume of sediment is generated from the reef that is gradually deposited in the lagoon. Most of the sediments generated are lost through the gaps in the reefs. Very large amount of sediment is generated in the atolls. Sands and boulders piled up on the leeward side to form islands. Different coral communities thrived in these environments and various processes continued to act on the reef system giving rise to present configuration.

## Suggestions and recommendations

From the various observations it may be inferred that little sediment is generated within the lagoon. The sands originate and are transported irrespective of their final resting place. We can contrast this situation with some clastic environments where a sediment body within a transport system represents a balance between supply and erosion. However, we do not have a correct idea about the rate of sediment production. The removal of limited quantities of sediment from the lagoon without disturbing the reef will have no effect on the rates of production or of derivation. The generation of sediment is not disturbed. In a number of areas it has been shown that the bulk production of shallow water zones is in excess of that which actually accumulates there, the surplus being transported to deeper water. If such movement takes place here the non-arrival of sediment in deeper-water zones will not be noticed. This seems to open the way to sediment dredging as the lagoons are not sediment-generating areas to a great extent. Large scale dredging operations may affect the floral and faunal systems within and peripheral to lagoon. Wave and current activity within the lagoon and hence on lagoon shores of islands is also important and is dependent upon fetch, wind speed, duration and water depth. Any significant lowering of lagoon floors will be expected to have the effect of increasing wave amplitude on downwind shores. This will result in erosion, but if the interpretation of island origin is correct this should be limited to the establishment of a graded profile tuned to the new wave conditions. Dredging activity will undoubtedly draw much larger volumes of sediment into suspension than are normal. Certainly any channel will be a site of concentrated water flow during ebb tides. A new channel will probably promote active erosion in its head ward area at the lowest stage of the falling tide. The extent of this is not known. Data on tidal movements and information on the volume of water moving in and out of the lagoon with each tide would help in making a judgment here. There is obviously some doubt about the amount of sediment moving in the lagoon. Sediment is mainly generated from reef areas and so there may be no problem. If however, there is a continuous southeasterly movement the dredged channel will be filled up. Much would depend upon the area to be dredged. Disposal of calcareous sands in the open ocean by various Industrial Departments should be stopped immediately and the sand should be put to use or for reclaiming areas of the island. Dredging of sand for industrial purpose should not have harmful effect if limited quantities are removed from the lagoon. No great danger can be expected if 5 to 10m of calcareous sand is dredged from the lagoon. Islands with high population should not allow tourism to be expanded rapidly. Overexploitation of fish by local people should be avoided. There should be control on ornamental coral trade since all these factors results in destruction of the reefs rapidly. Human induced damage to corals reefs can be avoided by careful control. Sewage outfalls can be placed below the level of coral growth, thermal effluent can be discharged in deep water. There are new methods of dispersing oil and alternative methods may be applied to the local area available for construction. Upgrading physical and social infrastructure in the island is an important issue. Some physical infrastructure required in the islands is primary health care facilities, high schools, primary schools, nursery schools etc. A general college, ITI with hostel facilities is possible in one of the larger islands. The emergency/cyclone shelters can be built in elevated area having double story building. The existing provisions can be upgraded in

terms of land built space and facilities. Parks, play ground can be upgraded. Potable water supply is generally short in most of the islands. Desalination plants fill up the gaps in Kavaratti, Agatti and Minicoy. Facility should be installed in all islands or sewage disposal. Two pit flush septic tanks are in place. Oxidation ponds, biotoilets offer alternatives according to soil condition. Solid waste disposal/management pose problem and alternative to sea dumping/inclination needs are must be explored. Electricity is generated through Solar Panels and wind mills can act as alternative source. Coastal zone management and planning is particularly important. Reef management has to be considered in the context of the entire coastal zone. In spite of the fact that lot of work has been done on different aspects of the reef we still believe that the reefs are very fragile and vulnerable to human activity. The resources of the Lakshadweep atolls are enormous and it may be relevant to decide to what extent this fragile ecosystem can be used to gain maximum profit without causing any damage to the delicate balance. In Lakshadweep the lagoon is the most important sediment accumulating site. A large volume of sediment is being generated from the reef and deposited in the lagoon. So, if a limited amount of sand is taken out there is no danger at all. However, a close environmental monitoring should be done. Once the system of exploitation is established in such an environment it can be widely used in other areas also. There is still plenty of scope to work on a number of different aspects on the Lakshadweep group of atolls.<sup>26</sup>

## Indian coral reef monitoring network

The Ministry of Environment and Forest, Government of India has prepared a Management Action Plan and the various activities included the Survey and Inventorisation, monitoring and Vigilance and conservation and Protection measures (data source Google html version). The Eco-development Activities will reflect the sustainable livelihood options, education and awareness, community participation and Database Development. The Conservation and Management Thrust areas for Research will conduct the survey and inventory of corals and coral reef associates using Remote Sensing and GIS techniques studies on Systematics and Taxonomy of corals; Assess status of rare, threatened and endangered species of corals and evolve strategies for their in-situ and ex-situ conservation, Ecosystem Studies and socioeconomic studies, identification of threats and measures to mitigate, monitoring health of Coral Reef and their Resources/A number of Agencies supports the R and D activities on Corals like Ministry of Environment and Forest, DST, Department of Space, Ministry of Agriculture, UGC, State Dept. of Environment, Science and Technology, Agriculture, Fisheries, Tourism, A number of Institutions are involved in R and D activities on Coral Reefs like, ZSI, GSI, NIO, central Marine Fisheries, Central Agriculture Research and a number of Universities like Annamalai, Madurai etc. International Initiatives has also been taken up by UNDP, CORDIO PROJECT (NIO, GOA), GCRMN for Database Network and Training and Visit by Experts on Coral Reefs. Funding of Research on corals is provided by Ministry of Env and Forest, Conservation and Survey Div. Research and Extension Div. Biosphere survey Div. Wildlife Div. NNRMC, Coastal and Biodiversity Programme. The Programmes will also suggest the Livelihood Options, Information Data base Network, Political with Institutional Participation, Scuba Diving etc. Ultimately the Gaps in effective Implementation and the Policy for effective monitoring will be highlighted. A careful consideration of all the above suggestions should be thought critically during any future study.<sup>27</sup>



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The author is extremely thankful to DR AYLEN GREEN, Editorial Office of MEDCRAVE for kindly selecting and inviting me to contribute an article in the Inaugural Issue of the Journal MOJ Ecology and Environmental Science. The sands have a low amount of silica, alumina and  $Fe_2O_3$ . They are suitable for a number of industries like cement, chemical, glass and paper. Since these deposits are in the form of loose sands it is advantageous for cement industries. However, the geomorphic situation on the coral islands are delicate and precautions have to be taken while mining those sands and the problem has been discussed in several publications by the author.<sup>10,11,22</sup> The present calcareous sands occur in a loose form on the lagoon floor and will be easier to mine. We can expect a quick return from these deposits without disturbing the delicate balance Existence of very pure calcareous sands of the order of 288 million tones down to a depth of 1m. below the lagoon floor aroused the interest of a few organizations to exploit these sands for the manufacture of cement, calcium carbide etc. Coral atolls represent a delicate equilibrium and not much is known about the behavior of these atolls if large quantities of sands are taken out for industrial purpose. Analysis of the present situation to predict the effect of dredging has been discussed here to throw some light on the key problem of the extent to which sediment can be removed from the lagoon without resulting in any unacceptable erosion of islet. For this purpose the observations made in a dredged channel maintained by the Lakshadweep Harbour Works as well as the adjacent beaches and reef areas have been summarized here including the data collected by the Lakshadweep Harbour Office. The results obtained from earlier work have also been critically analyzed to understand the dredging problems. The dredging operation started by the L.H.W. in 1971 and going on since then, is being done with the help of 1 CYD grab dredger ( mounted on Pontoon (draft 1m.)). The dredged material is loaded in Hopper Barges (capacity 16m<sup>3</sup>) which are towed with the help of Pablo boat or tug to the dumping ground on the east and west side of the main entrance to the deep sea A huge quantity of sands has already been dredged till now and was dumped into the sea, which is lost forever as the profile is very steep outside the reef. No harmful effect was noticed due to dredging of the navigational channel by the Harbour Department. In the areas adjacent to the dredged channel accretion has been taking place instead of erosion.

## Conflict of interest

The author declares no conflict of interest.

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