ENVIS Publication Series : 4/2001

CORAL REEFS OF INDIA

State-of-the-art report

ENVIRONMENTAL INFORMATION SYSTEM CENTRE
Centre of Advanced Study in Marine Biology
Parangipettai - 608 502, Tamil Nadu, India

2001

Sponsored by
Ministry of Environment & Forests, Government of India, New Delhi

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FOREWORD

Coral reefs are familiar to us for their impressive biodiversity, productivity and scenic beauty. In India, coral reefs are distributed in six regions viz. Gulf of Kachchh, Lakshadweep, Gulf of Mannar, Palk Bay, Andaman and Nicobar Islands and the recently identified table reefs of Ratnagiri coast in Maharashtra State. Though research on the coral reef was initiated in India from late 18th century, our knowledge on coral reef ecosystem is still very limited. The works carried out so far in India on coral reefs by and large pertain to the qualitative assessment rather than quantitative estimation as compared to developed countries. In recent years, there has been a spirit among the world's research and conserving groups to conduct research on coral reefs for the sustainable utilization of their rich biological diversity. However, it should be noted that the available information on the coral habitats and species diversity is lying scattered necessitating an effort of this type which will be of immense use to policy makers.

This state-of-the-art report is the updated version (upto 2000) of our previous publication on Coral reef ecosystem of India, which includes the consolidation of research work done upto 1997. This compilation incorporates the research reports available in various parts of the country including those of the scientists in various institutes, actively engaged in this line of work since long. This report will be useful to the managers, conservators, policy makers, researchers and other user community to understand the present scenario of the coral reef ecosystems of the Indian subcontinent and to take policy decisions for effective management.

I congratulate all the staff of the ENVIS Centre for their painstaking efforts in bringing out this state-of-the-art report on the coral reef ecosystems of India. I also, express my sincere thanks to Dr. D. Bandyopadhyay, Director, Ministry of Environment and Forests, Government of India, New Delhi for his valuable guidance and advice in publishing this report and also his keen interest in the development of ENVIS Centre. My special thanks are also due to Prof. T. Kannupandi who initiated this work by bringing out the previous status report, and Prof. S. Ajmal Khan and Dr. N. Rajendran for critically going through the report and bringing this in a presentable form. My special thanks are also due to Prof. K. Krishnamurthy (Retd.), for his suggestions to improve the text. Further, I owe a lot to the scientists involved in coral reef research who have contributed much to the preparation of this status report through their valuable publications.

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Law and policy for Protection and Conservation of the coral reefs of India

1. INTRODUCTION

Coral reefs are diverse and vulnerable ecosystems characterized by a complex interdependence of plants and animals. The reef biocomposition is quite amazing and includes 180 species of benthic algae, 14 species of seaweeds, 12 species of seagrasses, 108 species of sponges, 4 species of lobsters, 103 species of echinoderms, 600 species of finfishes and also a good number of species of crabs, bivalves, gastropods and cephalopods each in Lakshadweep and Andaman and Nicobar islands (Devaraj, 1997). Coral reefs are massive limestone structures built up through the constructional cementing processes and depositional activities of the animals of the class Anthozoa (order: Scleractinia) and all the other calcium carbonate secreting animals and the calcifying algae. The value of coral reefs, both for the biosphere and human utilization is well known. Reefs are the centres of high biological productivity, sites of CO_2 sink, ecosystems of very rich biodiversity helping in shoreline protection, sources of huge deposits of $CaCO_3$ and centres of scientific research. Additionally, they are providing us with many natural raw materials for deriving pharmacological products especially the life saving drugs (Gopinadha Pillai, 1997).

Biodiversity of coral reefs is responsible for productivity in the sea and these coral reefs are built mainly by corals containing calcium carbonate skeleton. The reef building corals are the hermatypic corals harbouring zooxanthellae and the ahermatypic corals, without zooxanthellae. Coral reefs are found in the well lighted zone of waters upto a depth of 50-70 m having salinity of 32-35 ppt and temperatures above 20°C. In the coral habitat a variety of fascinating animal life such as giant clams, sea cucumbers, sea anemones, sea urchins, sea fans, crown-of-thorns star fish and a variety of coloured fishes abound. Each of these animals have a special niche in this system (Raghukumar, 1997).

Coral reefs are highly productive with annual production rates ranging from 2,000 to 5,000 g $C/m^2/yr$. Such a higher rate of productivity is due to the efficient retention and recycling of nutrients within the reef system. Such internal recycling of nutrients is greater than that of the other marine ecosystems which is responsible for the higher gross productivity of coral reefs. The potential fish yield from the world reefs is 6-9 million tonnes/yr, equivalent to 9-12 % of all marine fish catch. Indian reefs together with their shelves, lagoons and submerged banks covering an area of 1,800 km^2 have a potential fish yield of 0.2 million tonnes/yr, or about 10% of the annual marine fish production (Wafar, 1990).

Morphology and physiology of the corals are very interesting. The term "corallum" is the total coral bush and the "corallite" is the calcareous cup within which the coral polyps, the living parts are embedded. These polyps release mucus to entrap plankton and other food particles which are engulfed. The mesentrial filaments in the coelenteron digest the food materials and the absorption takes place through simple diffusion. The algal photosynthetic products are directly available to the hosts and the algae inturn receive nutrients and carbon-di-oxide from the coral polyps. Photosynthetic activity of zooxanthellae also helps altering the CO_2 concentration in the tissues of the coral organisms and increasing the innate ability of the organisms to extract more of calcium carbonate from seawater for production of lime.

The coral reefs of the central Indo-Pacific and the Caribbean hold the greatest diversity of marine life. The reefs of the Indian Ocean have been built up during the tertiary and quaternary periods. The Indian Ocean coral reefs include sea-level atolls, fringing and barrier reefs, elevated reefs and submerged reef platforms.

In the Indian subcontinent, the reefs are distributed along the east and west coasts at restricted places and all the major reef types are present. Fringing reefs are found in the Gulf of Mannar and Palk Bay. Platform reefs are seen along the Gulf of Kachchh. Patchy reefs are found near Ratnagiri and Malwan coasts. Atoll reefs are found in the Lakshadweep archipelago. Fringing and barrier reefs are found in Andaman and Nicobar islands. Due to the highest freshwater flow through a large number of rivers mixing with the Bay of Bengal, there are no significant coral reef formations on the east coast of India. Satellite imagery shows scattered patches of corals in the intertidal areas and occasionally at subtidal depths down to a few meters along the west coast of India, notably at Ratnagiri, Malwan, Rede Port and Vizhingam (Wafar, 1990). During the 18th cruise of RV Gaveshani in April 1977, which was devoted to geological work, a submerged bank with living corals was discovered at Malpe (Mangalore). The bank is about 300 m wide and located about 100 km away from the shore and the depth is around 35 m (the Indian Naval Hydrograph). As per satellite pictures, location of this bank is at Lat. 13°24' N and Long. 73°45' E. The coral species collected from this area are *Euphyllia fimbriata, Leptoseris papyracea, Stylocoeniella armata, Porites lichens* and *Cyphastrea serialia* (Nair and Qasim, 1978).

Variations in environmental factors in the Indian Ocean region clearly affect the formation of coral reefs. The seasonal monsoons, equatorial calm, tropical cyclone and trade winds are the major factors regulating the reef distribution. Tidal ranges are important in reef areas because reefs normally grow upto the neap tide level. Exposure to the atmosphere and desiccation are limiting the growth of corals, algae and other associated organisms in the reef zones. Most of our Indian Ocean tides are of semidiurnal or mixed type (mainly semidiurnal) (Stoddart, 1971).

A total of 155 hermatypic coral species belonging to 50 genera and 44 ahermatypic species belonging to 21 genera have been recorded from the Indian coral reef areas. Table 1 shows the checklist of coral distribution around Indian seas (Gopinadha Pillai, 1983) and Table 2 provides an overview of the coral reef distribution in India (Vineeta Hoon, 1997). Increasing human population and anthropogenic pressures have severely affected coral distribution and biodiversity. Natural calamities also cause considerable damage to the coral reef structures through direct and indirect means. Further, global warming leads to increase in volume of sea water due to melting of ice sheets. This is because global warming increases the sea surface temperature in addition to increasing UV radiation. It is alarming to note that sea surface temperature is raising by 0.1°C every year. The satellite measurements confirm the present sea level raise (SLR) at the rate of 2 mm/yr. Further, the concentration of green house gases increases in the atmosphere and the average earth surface temperature would rise between 2 and 5°C over the next 100 yrs. But it should be noted that the coral reefs are stenotypic requiring 'constant environmental conditions'. The raising sea level due to global warming would favour the vertical extension of the fast growing species, while slow growing species will die due to shading effect and also by the limited availability of resources. Increasing UV radiation is also harmful to a wide variety of corals and coral reef associated organisms (Wafar, 1990). Various activities such as fishing gear operations, anchoring of boats, collecting corals for ornamental purposes, algal collection, shell (molluscs) collection, illegal quarrying of corals for industries like cement industry and for use in house building, promotion of tourism and activities like mariculture would add to the complexity of management of coral reef ecosystems in India (Ramaiyan *et al.,* 1995). Relegating the responsibility of saving our valuable coral reefs solely to any single individual or institution will not serve the purpose of saving the reefs. The scientists, coastal people, islanders, industrialists and bureaucrats should be involved in the conservation and management measures. Further, ecosystem managers, organizers of rural development and press people should also be encouraged (see also Gopinadha Pillai, 1997) in such measures.

Table 1. Checklist of Scleractinian corals from the seas around India. The classification follows Wells (1956).

List of species	Lakshadweep	Gulf of Kachchh	Gulf of Mannar and Palk Bay	Andamans and Nicobars
ORDER : SCLERACTINIA				
SUBORDER : ASTROCOENIINA				
FAMILY: THAMNASTERIIDAE				
Genus *Psammocora* Dana				
P. contigua (Esper)	X	-	X	X
P. digitata Milne Edwards and Haime	X	X	-	-
P. haimeana Milne Edwards and Haime	X	-	-	-
P. profundacella Gardiner	X	-	-	X
FAMILY: POCILLOPORIDAE				
Genus *Stylophora* Schweigger				
S. pistillata (Esper)	X	-	-	X
Genus *Seriatopora* Lamarck				
S. crassa Quelch	-	-	-	X
S. hystrix Dana	-	-	-	X
S. stellata Quelch	-	-	-	X
Genus *Pocillopora* Lamarck				
P. brevicornis Lamarck	-	-	-	X
P. damicornis (Linn.)	X	-	X	X
P. ankeli Scheer and Pillai	-	-	-	X
P. ligulata Dana	X	-	-	-
P. meandrina var. *nobilis* Verrill	-	-	-	X
P. verrucosa (Ellis and Solander)	X	-	X	X
P. eydouxi Milne Edwards and Haime	X	-	X	X
Genus *Madracis* Milne Edwards and Haime				
Madracis sp.	-	-	X	X
FAMILY: ACROPORIDAE				
Genus *Acropora* Oken				
A. intermedia (Brook)	X	-	-	-
A. formosa (Dana)	X	-	X	X
A. valenciennesi Milne Edwards and Haime	-	-	X	-
A. abrotanoides (Lamarck)	X	-	-	-
A. gravida (Dana)	-	-	-	X
A. efflorescens (Dana)	X	-	-	X
A. conigera (Dana)	X	-	-	X
A. obscura (Brook)	-	-	X	-
A. teres Verrill	X	-	-	-
A. nasuta (Dana)	X	-	-	-
A. secale (Studer)	-	-	-	X
A. corymbosa (Lamarck)	X	-	X	-
A. hyacinthus (Dana)	X	-	X	X
A. indica (Brook)	X	-	X	-
A. millepora (Ehrenberg)	-	-	X	X
A. pinguis Wells	-	-	-	X
A. brevicollis (Brook)	-	-	X	-
A. palifera (Lamarck)	X	-	-	X
A. nobilis (Dana)	-	-	X	X
A. humilis (Dana)	X	X	X	X
A. diversa (Brook)	-	-	X	X
A. hebes (Dana) = *A. aspera*	X	-	-	-
A. variabilis (Klunzinger) = *A. vlida*	-	-	X	X
A. squarrosa (Ehrenberg)	X	X	-	-
A. hemprichi (Ehrenberg)	X	-	-	-
A. forskali (Ehrenberg)	X	-	-	-
A. rambleri (P. smith)	X	-	-	X
A. granulosa Milne Edwards and Haime	X	-	-	-

A. dumosa (Brook)	-	-	-	X
A. echinata (Dana)	X	-	-	-
A. multi-acuta Nemenzo	-	-	-	X
Genus *Astreopora* de Blainville				
A. myriophthalma (Lamarck)	X	-	X	-
A. listeri Bernard	-	-	-	X
Genus *Montipora* de Blainville				
M. subtilis Bernard	-	-	X	-
M. granulosa Bernard	-	-	X	-
M. explanata Brueggesman	-	X	X	-
M. exserta Quelch	-	-	X	-
M. digitata (Dana)	-	-	X	X
M. divaricata Brueggeman	-	-	X	X
M. cocosensis Vaughan	-	-	-	X
M. turgescens Bernard	-	X	X	X
M. manauliensis Pillai	-	-	X	-
M. monasteriata (Forskal)	-	X	X	-
M. venosa (Ehrenberg)	-	X	X	-
M. spumosa (Lamarck)	-	-	X	-
M. tuberculosa (Lamarck)	X	-	X	-
M. jonesi Pillai	-	-	X	-
M. verrucosa (Lamarck)	-	-	X	-
M. peltiformis Bernard	-	-	-	X
M. verrilli Vaughan	-	-	X	-
M. hispida (Dana)	-	X	X	-
M. foliosa (Pallas)	-	X	X	X
M. composita Crossland	-	-	-	X
SUBORDER : FUNGIINA				
SUPER FAMILY: AGARICIICAE				
FAMILY : AGARICIIDAE				
Genus *Pavona* Lamarck				
P. explanulata (Lamarck)	-	-	-	X
P. xarifae Scheer and Pillai	-	-	-	X
P. varians (Verrill)	X	-	X	X
P. decussata (Dana)	-	-	X	X
P. praetorta (Dana)	-	-	X	-
P. clavus (Dana)	-	-	-	X
P. maldivensis Gardiner	X	-	-	-
P. duerdeni Vaughan	X	-	X	X
P. divaricata (Lamarck)	-	-	X	-
Genus *Pachyseris* Milne Edwards and Haime				
P. rugosa (Lamarck)	-	-	X	X
P. speciosa (Dana)	-	-	-	X
Genus *Leptoseris* Milne Edwards and Haime				
L. papyracea (Dana)	-	-	-	X
L. fragilis Milne Edwards and Haime	-	-	-	X
Genus *Gardineroseris* Scheer and Pillai				
G. planulata (Dana)	X	-	-	X
Genus *Coeloseris* Vaughan				
C. mayeri Vaughan	-	-	-	X
FAMILY: SIDERASTREIDAE				
Genus *Siderastrea* de Blainville				
S. savignyana Milne Edwards and Haime	-	X	X	-
Genus *Pseudosiderastrea* Yabe and Sugiyama				
P. tayami Yabe and Sugiyama	-	X	X	X
Genus *Coscinaraea* Milne Edwards and Haime				
C. monile (Forskal)	-	X	X	-
SUPER FAMILY : FUNGIICAE				
FAMILY: FUNGIIDAE				
Genus *Cycloseris* Milne Edwards and Haime				

C. cyclolites (Lamarck)	-	-	X	-
C. sinensis Milne Edwards and Haime	-	-	-	X
C. distorta (Michelin)	-	-	-	X
C. hexagonalis Milne Edwards and Haime	-	-	-	X
C. costulata (Ortmann)	-	-	-	X
Genus *Fungia* Lamarck				
F. scutaria Lamarck	X	-	-	X
F. paumotensis Stutchberry	-	-	-	X
F. somervilli Gardiner	X	-	-	X
F. echinata (Pallas)	-	-	-	X
F. repanda Dana	-	-	-	X
F. danai Milne Edwards and Haime	X	-	-	X
F. horrida Dana	-	-	-	X
F. fungites (Linn.)	X	-	-	X
Genus *Fungiacyathus* Sars				
F. symmetrica (Pourtales)	-	-	-	X
Genus *Herpolitha* Eschscholtz				
H. limax (Esper)	-	-	-	X
Genus *Polyphyllia* Quoy and Gaimard				
P. talpina (Lamarck)	-	-	-	X
Genus *Podabacia* Milne Edwards and Haime				
P. crustacea (Pallas)	X	-	-	-
SUPER FAMILY: PORITICAE				
FAMILY: PROTIDAE				
Genus *Goniopora* de Blainville				
G. stokesi Milne Edwards and Haime	X	-	X	X
G. tenuidens (Quelch)	-	-	-	X
G. nigra Pillai	-	X	X	-
G. minor Crossland	X	X	-	-
G. planulata (Ehrenberg)	-	X	X	X
Genus *Porites* Link				
P. solida (Forskal)	X	-	X	X
P. lobata Milne Edwards and Haime	-	-	-	X
P. minicoiensis Pillai	X	-	-	-
P. lutea Milne Edwards and Haime	X	X	X	X
P. lichen Dana	X	X	X	-
P. exserta Pillai	-	-	X	-
P. andrewsi Vaughan	X	-	-	-
P. eridani Umbgrove (= *P. cylindrica*)	-	-	-	X
P. compressa Dana	-	X	X	-
P. mannarensis Pillai	-	-	X	-
Genus *Alveopora* de Blainville				
A. daedalea (Forskal)	-	-	-	X
SUBORDER : FAVINA				
FAMILY: FAVIIDAE				
SUB FAMILY: FAVIINAE				
Genus *Plesiastrea* Milne Edwards and Haime				
P. versipora (Lamarck)	X	X	-	X
Genus *Favia* Oken				
F. stelligera (Dana)	X	X	X	X
F. pallida (Dana)	X	-	X	X
F. speciosa (Dana)	X	X	X	X
F. favus (Forskal)	X	X	X	X
F. rotumana (Gardiner)	-	-	-	X
F. valenciennesi Milne Edwards and Haime	-	-	X	X
Genus *Favites* Link				
F. abdita (Ellis and Solander)	X	-	X	X
F. halicora (Ehrenberg)	X	-	X	X
F. complanata (Ehrenberg)	X	X	X	X
F. flexuosa (Dana)	-	-	-	X

F. pentagona (Esper)	X	-	X	-
F. melicerum (Ehrenberg)	X	X	X	-
Genus *Goniastrea* Milne Edwards and Haime				
G. retiformis (Lamarck)	X	-	X	X
G. pectinata (Ehrenberg)	X	X	X	X
Genus *Platygyra* Ehrenberg				
P. daedalea (Ellis and Solander)	X	-	X	X
P. sinensis (Milne Edwards and Haime)	X	X	X	X
Genus *Leptoria* Milne Edwards and Haime				
L. phrygia (Ellis and Solander)	X	-	X	X
Genus *Oulophyllia* Milne Edwards and Haime				
O. crispa (Lamarck)	-	-	-	X
Genus *Hydnophora* Fischer de Waldheim				
H. microconos (Lamarck)	X	-	X	X
H. exesa (Pallas)	-	X	X	X
H. laxa (Dana)	-	-	-	X
SUB FAMILY: MONIASTREINAE				
Genus *Diplostrea* Mattai				
D. heliopoa (Lamarck)	X	-	-	X
Genus *Oulastrea* Milne Edwards and Haime				
O. crispata (Lamarck)	-	-	-	X
Genus *Leptastrea* Milne Edwards and Haime				
L. bottae (Milne Edwards and Haime)	X	-	-	-
L. purpurea (Dana)	X	X	X	X
L. tarnsversa Klunzinger	X	-	X	-
Genus *Cyphastrea* Milne Edwards and Haime				
C. microphthalma (Lamarck)	-	-	X	X
C. serailia (Forskal)	-	X	X	-
Genus *Echinopora* Lamarck				
E. lamellosa (Esper)	-	-	X	X
E. horrida Dana	-	-	-	X
FAMILY: TRACHYPHYLLIIDAE				
Genus *Trachyphyllia* Milne Edwards and Haime				
T. geoffroyi (Audouin)	-	-	-	X
FAMILY: RHIZANGIIDAE				
Genus *Culicia* Dana				
C. rubeola (Quoy and Gaimard)	-	-	X	X
Genus *Cladangia* Milne Edwards and Haime				
C. exusta Luetken		West Coast of Kerala		
FAMILY : OCULINIDAE				
Genus *Galaxea* Oken				
G. fascicularis (Linn.)	X	-	X	X
G. clavus (Dana)	-	-	X	X
FAMILY : MERULINIDAE				
Genus *Merulina* Ehrenberg				
M. ampliata (Ellis and Solander)	X	-	-	X
Genus *Scacophyllia* Milne Edwards and Haime				
S. cylindrica Milne Edwards and Haime	-	-	-	X
FAMILY: MUSSIDAE				
Genus *Lobophyllia* de Blainville				
L. corymbosa (Forskal)	X	-	-	X
Genus *Acanthastrea* Milne Edwards and Haime				
A. simplex Crossland	-	X	-	-
A. echinata (Dana)	X	-	-	-
Genus *Symphyllia* Milne Edwards and Haime				
S. nobilis (Dana)	X	-	X	X
S. radians Milne Eswards and Haime	X	X	X	X
FAMILY: PECTINUDAE				
Genus *Mycedium* Oken				
M. elephantotus (Pallas)	-	X	X	X

Genus *Pectinia* Oken				
P. lactuca (Pallas)	-	-	-	X
SUBORDER : CARYOPHYLLIINA				
FAMILY: CARYOPHYLLIIDAE				
Genus *Caryophyllia* Lamarck				
C. clavus Scacchi	X	-	-	X
C. arcuata Milne Edwards and Haime	X	-	-	X
C. acanthocyathus grayi Milne Edwards and Haime	-	-	-	X
Genus *Deltocyathus* Milne Edwards and Haime				
D. andamanensis Alcock	-	-	-	X
Genus *Paracyathus* Milne Edwards and Haime				
P. indicus Duncan	-	-	-	X
P. profundus Duncan	-	-	X	-
P. stokesi Milne Edwards and Haime	-	X	-	-
Genus *Polycyathus* Duncan				
P. verrilli Duncan	-	X	X	X
P. andamanenis Alcock	-	-	-	X
Genus *Heterocyathus* Milne Edwards and Haime				
H. aequicostatus Milne Edwards and Haime	-	-	X	X
Genus *Stephanocyathus* Seguenza				
S. nobilis (Moseley)	X	-	-	-
Genus *Euphyllia* Dana				
E. glabrescens (Chamisso and Eysenhardt)	X	-	-	X
Genus *Plerogyra* Milne Edwards and Haime				
P. sinuosa (Dana)	-	-	-	X
Genus *Physogyra* Quelch				
P. lichtensteini Milne Edwards and Haime	-	-	-	X
FAMILY: FLABELLIDAE				
Genus *Flabellum* Lesson				
F. pavonium Alcock	X	-	-	-
Genus *Placotrochus* Milne Edwards and Haime				
P. laevis Milne Edwards and Haime	-	-	-	X
SUBORDER : DENDROPHYLLINA				
FAMILY: DENDROPHYLLIIDAE				
Genus *Balanophyllia* S. Wood				
B. imperialis Kent	-	-	-	X
B. scabra Alcock	-	-	-	X
B. affinis (Semper)	-	-	X	-
Genus *Endopsammia* Milne Edwards and Haime				
E. philippinensis Milne Edwards and Haime	-	-	X	-
Genus *Heteropsammia* Milne Edwards and Haime				
H. michelini Milne Edwards and Haime	-	-	X	X
Genus *Tubastrea* Lesson				
T. aurea (Quoy and Gaimard)	-	X	X	X
Genus *Dendropyllia* de Blainville				
D. coarctata Duncan	-	-	X	-
D. arbuscula V. der Horst	-	-	-	X
D. minuscula Bourne	-	X	-	X
D. micranthus (Ehrenberg)	-	-	-	X
D. indica Pillai	-	-	X	-
Genus *Enallopsammia* Micheloti				
E. amphelioides (Alcock)	-	-	-	X
E. marenzelleri Zibrowius	-	-	-	X
Genus *Turbinaria* Oken				
T. crater (Pallas)	-	X	X	X
T. undata Bernard	-	-	X	-
T. peltata (Esper)	-	X	X	X
T. mesenterina (Lamarck)	X	-	-	-
T. veluta Bernard	-	-	-	X

X = recorded - = Not yet recorded

Source: Gopinadha Pillai, (1983)

Table 2. Distribution of coral reefs in India

Category	Extent of Coral Reef (Km^2)			
	Gujarat	Tamil Nadu	Lakshadweep Islands	A&N Islands
Reef flat	148.4	64.9	136.5	795.7
Sand over reef	11.8	12.0	7.3	73.3
Mud over reef	117.1	-	-	8.4
Coraline shelf	-	-	230.9	45.0
Coral heads	-	-	6.8	17.5
Live coral platform	-	-	43.3	-
Algae	53.8	0.4	0.4	-
Seaweeds	-	-	0.7	-
Seagrass	-	-	10.9	-
Reef vegetation	112.1	13.3	-	8.9
Vegetation over sand	17.0	3.6	0.4	10.5
Lagoon	-	0.1	322.8	-
Sandy substrate	-	-	(67.4)	-
Reef patch	-	-	(13.4)	-
Deep	-	-	(98.5)	-
Uncertain	-	-	(143.5)	-
Total	460.2	94.3	816.1	959.3

Source: DOD & SAC (1997)

2. CORAL REEF ECOSYSTEM OF KERALA COAST

A well preserved, submerged assemblage of Scleractinian corals and marine molluscs was observed from a well dug to a depth of 8 m from the present mean sea level (MSL) and about 8 km inland, at Vazhakala near Cochin (Kerala). Based on the determination of age of a sample of *Goniastrea retiformis* – a reef coral, it was suggested that the deposit is of Pleistocene Era. The sea level circa 40000 y B.P. at this region was about 7-8 m than the present and the coastline extended up to 8 km eastward than the current. The Pleistocene coral and molluscan faunae reported herein do not display much variation from the present faunal elements known from the seas around India. Table 3 lists the coral fauna in the Pleistocene deposits (Gopinadha Pillai *et al.,* 1999).

Table 3. List of reef corals from Vazhakala Pleistocene deposit

Family	Name of Species
Pocilloporidae	*Pocillopora damicornis*
	P. verrucosa
Acroporidae	*Acropora formosa*
	Montipora tuberculosa
Poritidae	*Porites* sp. (indeterminable)
Favidae	*Favia palliada*
	Goniastrea retiformis
	Leptastrea transersa
	Platygyra lamellina
	Leptoria phrygia
Oculidae	*Galaxea astreata*
Caryophylliidae	*Heterocyanthus aequicostatus*

Source: Gopinadha Pillai *et al.,* (1999) Fourty four species of marine molluscs belonging to 34 genera were also recorded (Table 4). The present record is the first of its kind from the west of Kerala and provides a fairly comprehensive faunal assemblage of corals and marine molluscs from the Pleistocene era of Kerala coast. The largest coral colony was of a *Goniastrea retiformis* with greater diameter of nearly 0.5 m. The *in situ* nature of the corals could not be ascertained. Besides corals and molluscs, an excellently preserved young one of the marine turtle, *Chelonia mydas,* remnants of sponges, crustaceans and calcareous algae were also found (Gopinadha Pillai *et al.,* 1999).

Table 4. Pleistocene marine mollusc from Vazhakala deposit

Family	Name
Nuculanidae	*Nuculana* sp.
Arcidae	*Arca fusca*
	Arca sp.
Pectinidae	*Chlamys lacteus*
	C. leopardus
	C. gloriosus
Chamidae	*Chama* sp.
Carditidae	*Cardita bicolor*
	Venericardia sp.
Cardidae	*Cardium* sp.
Veneridae	*Venus* sp.
Mactridae	*Mactra* sp.
Donacidae	*Donax scortun*
	Donax sp.
Tellinidae	*Tellinia* sp.
Solenidae	*Solen* sp.
	Siliqua sp.
Dentaliidae	*Dentalium rectum*
Trochidae	*Calliostoma* sp.
Turbinidae	*Turbo intercostalis*
Turritellidae	*Turritella acutangula*
Strombidae	*Strombus marginatus*
	Strombus spp. (2 species)
Naticidae	*Natica* sp.
	Polynices sp.
Cypreaidae	*Cyprea coellata*
	C. tigris
	Cyprea sp.
Cassidae	*Phalium glaucum*
Cymatiidae	*Cymatium pileare*
Muricidae	*Thais rugosa*
	Murex sp.
Bullidae	*Bullia* sp.
Nasariidae	*Nasarius* sp.
Olividae	*Olivia* spp. (2 species)
Mitridae	*Mitra* sp.
Vasidae	*Xancus pyrum*
Marginellidae	*Marginella* sp.
Turridae	*Brachitoma crenularis*
	Cochlespira sp.
Conidae	*Conus figulinus*
	Conus sp.

Source: Gopinadha Pillai, *et al.* (1999)

Pillai and Jasmin (1995) reported patchy growths of hard corals along the coast of erstwhile Travancore at the southwest coast of India belonging to the genus *Pocillopora* and represented by five species. Massive genera like *Porites, Favia, Favites, Goniastrea* and *Platygyra* as well as *Leptastrea* are non-conspicuous in this area and a total of 29 species belonging to 17 genera of scleractinians is reported. Out of these, 13 species divided among 6 genera are hermatypes and the rest, 16 species coming under 11 genera are ahermatypes. The coral fauna in structure and composition is more related to that of the Gulf of Mannar than Lakshadweep.

Boring sponges cause destruction of calcium carbonate skeleton of corals, molluscs etc. For chemical defence, sponges develop a variety of antibiotic substances, pigments, toxins, antiinflamatory and antiarthritic compounds and many of such compounds have great pharmaceutical potential (Thomas, 1996).

3. CORAL REEF ECOSYSTEM OF GOA COAST

Sedimentological studies on conventional and side wall cores from thin limestone bands of B-172-2, 4 and 6 revealed a very significant fact of the presence of small carbonate buildups in the southeast of Bassein field. These organic buildups were found developed in an otherwise finer clastic dominant sequence towards Oligocene strata (Alibag Formation). Different lithofacies along with depositional environments identified in the limestones are coral boundstone (reef environment), algal wackestone/mudstone (micrite mound), mixed skeletal wackestone to packstone (reef flank/reef floatstone facies), and large benthonic foraminiferal-algal packstone (near reef/ inter-reef facies). The limestone bodies show periodic breaks in reefal growth and the primary porosity of the coral boundstone facies has vastly improved owing to selective solution activity due to vadose diagenesis under subaerial condition. These organic buildups, by virtue of their genetics, are likely to occur in many more places and assume importance from the hydrocarbon point of view because oil has already been struck in B-172-2 (Das, 1999).

Recent detailed studies of a thin limestone band, sporadically developed in the area southeast of Bassein field within the clastic sequence, revealed a rich assemblage of larger foraminifera including *Miogyosinoides formosensis*, *M. complanatus, Spiroclypeus ranganae, Planolindrina* spp. and *Heterostegian* spp., correlated with Late Oligocene Zone. Occurrence of this limestone is geologically significant as it is positioned close to the Oligocene-Miocene unconformity and in one of the wells south of Bassein field its oil bearing Litho and microfacies analysis of the limestone suggests small organic buildup features in the form of coral patch reefs and algal micrite mounds and their associated facies (Das and Narayanan, 1996).

Three species of reef building corals : *Porites (Porites) lutea, Favites pentagona* and *Turbinaria mesenterina* were recorded near Grandi island, off Marmagoa (Goa). This is the first report of hermatypic corals along the Goa coast. A non-reef building solitary coral of the Atlantic region *Astrangia* sp. was also recorded and could have been introduced in Indian waters due to maritime activities (Rodrigues *et al.,* 1998).

4. CORAL REEF ECOSYSEM OF THE GULF OF *KACHCHH

The Gulf of Kachchh covers an area of 7,350 sq. km. and is located between Lat. 22° 15' – 23° 40' N and Long. 68° 20' – 70° 40'E (Fig. 1). The present day coral growth in this area is of patchy type seen either on intertidal sand stones or on the surface of wave cut and eroded shallow banks. Most of the reefs are narrow and the live corals found at the edges of the seaward slope of the reef (Anjali Bahuguna *et al.,* 1992). They are also consisting of dead coral blocks and pebbles. The first report on corals of this area was published by Gideon *et al.* (1957), but his classification and findings of the corals are not clear. Patel (1976 & 1978), Gopinadha Pillai and Rajagopalan (1979), Scheer (1985) and Wafar (1986) made many studies on the distribution and diversity of coral fauna of this region.

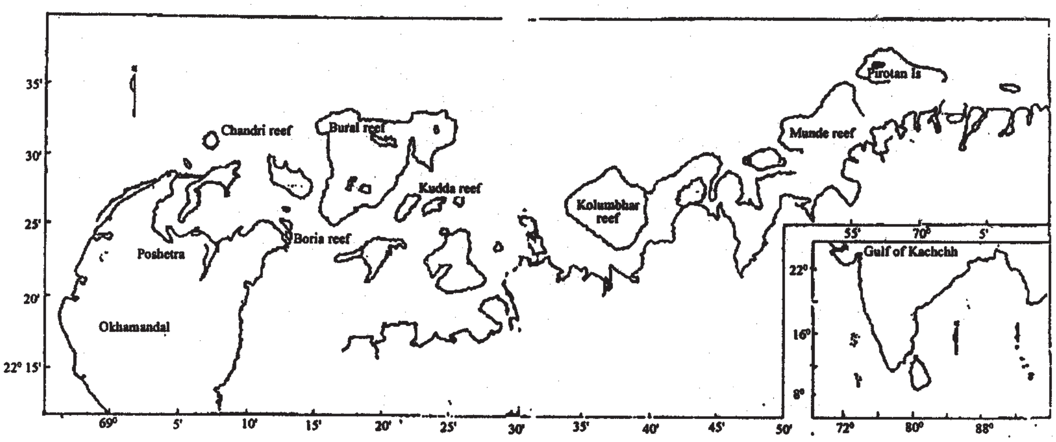

Fig. 1. Gulf of Kachchh showing the areas of coral formations (adapted from Gopinadha Pillai and Patel, 1988).

*The term 'Kutch' of the pre-1947 British India has been pronounced or spelt variously by various workers like many author place names in Independent India for the sake of consistancy, we adhere to the Atlas - Orient Longman School Atlas 1997 - for easy reference.

Physico – Chemical Parameters

The Gulf of Kachchh region is lying in semi-arid zone with a maximum depth of 60 m. The tidal range varies from 3.06 to 5.89 m with an average of 4 m. There could have been a relative change in the levels of land and sea in the past as evidenced by the presence of raised coral reef at Okha which is still intact near the railway station (Gopinadha Pillai and Rajagopalan, 1979).

Coral Distribution

The coral fauna of the Gulf of Kachchh includes 26 species coming under 20 genera. The scleractinian coral fauna present in this area is very less when compared to those of other Indo-Pacific coral reef areas. Coral fauna of the Red sea embraces 64 genera, of which 56 genera are present in the Gulf of Aquaba. But the Gulf of Kachchh lying further south is possessing only 24 genera while the Maldives which is still further south is reported to have 75 genera. This would indicate that the latitudinal difference does not influence the distribution of corals but geographic isolation may be the factor for reduced distribution of coral species in the Gulf of Kachchh (Gopinadha Pillai and Rajagopalan, 1979).

Generic diversity of scleractinian corals around Poshetra point of Gulf of Kachchh was described by Patel (1978). He classified the intertidal reefs into 3 types viz. rock pool facies, eulittoral and submerged reefs. Rock pool reefs were found in small temporary pools located on the top of the knife-edged barren rocks, sprinkled at hightide, with small scattered colonies of encrusting coral species such as *Favia* and *Montipora*. Eulittoral region was found to have a rugged topography with very small pools which receive sea water from current flow and tidal stirrings. The eulittoral pools had discontinuously distributed coral species such as *Turbinaria, Montipora, Favia, Leptoria, Porites, Leptastrea, Goniopora* and *Goniastrea*. The submerged reefs of this area can be classified into four zones such as Shoreward reef, Back reef, Surface reef and Oceanic reef. Coral composition of the submerged reefs was made of *Turbinaria, Montipora, Porites, Symphyllia, Favia, Favites, Goniopora, Goniastrea, Leptoria, Podabacia, Pavona, Hydnophora* and *Leptastrea*. *Acropora* species and other branching corals (ramose) were not present in this area. Huge quantities of the dead horns of *Acropora* sp. found in this area suggested that there could have been a luxuriant growth of branched corals in the past (Patel, 1978 ; Gopinadha Pillai and Rajagopalan, 1979).

The stable isotopic analyses ^{18}O and ^{13}C of coral *Favia speciosa* spanning forty two years (1948-89 A.D.), collected from the Pirotan Island in the Gulf of

Kachchh were carried out to assess its potential for retrieving past environmental changes in this region. It was seen that the summer (minima) ^{18}O variations in the coral $CaCO_3$ were negatively correlated with seasonal (summer) monsoon rainfall in the adjoining region of Kachchh and Saurashtra (Chakraborty and Ramesh, 1998).

The predatory starfish, *Acanthaster planci*, grazing on coral polyps was also noticed in these reefs. Silt deposition appeared to be the major cause of coral mortality in the interdial regions of the Gulf of Kachchh. Death of corals appeared to have been caused by settlement of the fine sediment on the coral colonies, smothering the polyps to death. The thickness of the sediment on the colony ranged from a few millimeters to several centimeters (Ravindran *et al.,* 1999).

Biodiversity

The Gulf of Kachchh is rich in algal diversity (120 species) dominated by the species of *Sargassum, Ulva, Enteromorpha* and *Cladophora* (Anjali Bahuguna *et al.,* 1992). Sipunculans and Echinurans are the common inhabitants of the coral and beach rock communities throughout the Gulf of Kachchh. The representative Sipuncula in this area are *Aspidosiphon maculata, Cloeosiphon aspergillum, Sipunculus robustus, Siphonosoma cumanense* and *Themiste signifer*. The representatives of Echinura are *Achaetobonellia maculata, A. vulgaris, Anelassorhynchus sabinum, Ochetostoma zanzibarense, Ikedella misakiensis* and *Ikedosoma pirotansis* (Singhal, 1988). Available data revealed this area to have about 70 species of sponges, 200 species of fishes, 27 species of prawns, 30 species of crabs and few species of lobsters and barnacles, 200 species of molluscs, 3 species of turtles and 3 species of marine mammals.

The current classification of scleractinian corals based upon gross morphological features has been found unsatisfactory due to additional information from skeletal microarchitecture and microstructure. It is necessary to investigate microstructural details and limits in morphologic variations within and between different coral clades before a revised classification is constructed. The microarchitecture and distribution of characters observed in the Kachchh Dimorpharaea require a re-evaluation of familial-specific concepts and suggest that the population belongs to a single species, *Dimorpharaea stellans* Gregory, 1900, rather than four nominal species (*D. stellans, D. distincta, D. continua* and *D. orbica*) as has been assumed (Pandey *et al.,* 1999).

The live corals – both soft and stony are abundantly present in the sub-tidal regions of the reefs at various stages of growth. The genera of stony corals found were : *Favia, Favites, Goniopora, Montipora, Sinularia, Tubastrea, Turbinaria* and broken branches of *Acropora.* The soft coral genera were *Dendronephthya* and *Nephthya*. Stony corals dominate the Pirotan reef while soft corals dominate the other reefs. A total of 12 species of stony corals, 7 species of soft corals, 28 species of benthic marine algae and 23 species of benthic fauna were recorded during the underwater survey (Table 5). The abundance of live corals decreased from the inner to the outer reefs, from75 to 80 per cent at Pirotan and Karumbhar to around 50 per cent at Boria and Beyt Shankhodar. Siltation varied from moderate to fairly high from the inner to the outer reefs. Underwater tidal currents were stronger at the inner reefs (Deshmukhe *et al.,* 2000).

Table 5. Subtidal coral biodiversity along the Gulf of Kachchh.

Station	Stony corals	Soft corals	Associated fauna	Associated flora
Pirotan*	*Favia favus, Favites melicerum, Goniopora nigra, G. planulata, Montipora* sp., *Platigyra sinensis, P. compressa, Tubastrea aurea*	Gorgonians	Perch fish, puffer fish, *Sabella* sp., sea anemone, Sponges, *Acanthaster planci*, bryozoans, gastropod, *Bonelia* sp., crabs, *Panulirus polyphagus* (spiny lobster), *Lytocarpus* colony	*Caulerpa, Codium, Ulva,* coralline algae, *Enteromorpha, Gracilaria, Hypnea, Padina, Sargassum, Soliera*
Karumbhar*	*Cymfavia radians, Favia favus, F. specicosa, Favites melicarum, Goniastrea pectinata, G. planulata, Platigyra sinensis, Porites* sp., *P. compressa, Tubastrea aurea, Turbinaria peltata*	*Astromuriacea stelligera,* gorgonians, *Dendronephthya dendrophyta, Lophogorgya lutkeni, Nephthya* sp.	Perch fish, *Pomacanthus annularis, Sabella* sp., sea anemone, *Antedon,* sponges, sea lily, brittle star, bryozoan, hydrozoans, gastropods, polychaete , *Triphyllozooan* sp., crabs	*Caulerpa, Ulva,* coralline algae, *Enteromorpha, Halimeda, Hypnea, Sargassum, Soliera*
Boria Reef*	*Montipora* sp., *Porites* sp., *Turbinaria peltata*	*Dendronephthya dendrophyta, D. brevirama,* gorgonians, *Nephthya* sp.	Sea lily, bryozoans, gastropods, crabs, sponges	*Caulerpa, Codium* coraline algae, *Gracilaria, Halimenia, Hypnea, Kjellimania, Sargassum, Soliera*
Beyt Shankhodar*	*Goniopora nigra, Turbinaria peltata*	*Dendronephthya dendrophyta, D. brevirama,* gorgonians, *Lobophytum panciglorum, Nephthya* sp., *Sclerophytum polydactylum, Sinularia* sp.	Sea anemone, *Discosoma* sp., sponges, sea lily, bryozoans, gastropods	*Caulerpa, Halimenia, Kjellimania, Sargassum, Soliera*
Mungra reef	Young polyps-colony of *Tubastrea* sp., *Porites* sp.	Gorgonians	Bryozoans, gastropods, crabs, polychaetes, sponges, sea urchins	*Ulva,* coralline algae
Mundrn	Young polyps-colony of *Tubastrea* sp., dead *Acropora* pieces.	Gorgonians, *Dendronephthya* sp.	*Holothuria* sp., brittle star, *Antedon,* sea urchins, gastropods, *Membranopora*	Coralline algae
Mandvi	Young polyps-colony of *Tubastrea* sp.	-	Sponges, bryozoans, *Membranopora,* barnacle, gastropods, oyster spats	*Dictyota bartreysiana*

* All the coral forms and associated fauna were identified by Mafatial I. Patel, Commissionerate of Fisheries, Government of Gujarat, Gandhinagar.

Source: Deshmukhe *et al.* (2000)

Recent findings of a profusion of live sub-tidal corals along the islands at the south, and the existence of live coral patches along the hitherto discounted northern shores have added to the problem of conservation. Even a small oil spill in the Gulf will be adequate for near-extinction of the coral reefs and close-to-shore mangrove vegetation, whose very existence has been protecting the Saurashtra Coast from damage thereby encouraging industrial development in the pristine Gulf of Kachchh and oil import using super tankers (Sen Gupta and Geetanjali Deshmukhe, 2000).

Rohan Arthur (2000) reported the Gulf of Kachchh reefs to show an average of 11% bleached coral with no apparent bleaching-related mortality. The Gulf of Kachchh is characterized by sparse, patchy coral cover of around 11.7% and old dead coral covered with turf with mud dominating the substrate. Several species of macroalgae, including *Ulva, Sargassum, Caulerpa*, and *Padina*, were found common in the Kachchh reefs. Coral genera are limited in the Kachchh. This study recorded 11 genera of coral, restricted to massive and encrusting forms, dominated by *Favites, Porites,* and *Platygyra* (Table 6). The reefs of the Gulf of Kachchh in contrast, seemed to be less severely affected than the other reef areas. No obvious bleaching-related death was observed in the seven reefs surveyed, and only 1.92% of the coral was bleached severely.

Table 6. Percentage composition of coral genera in the Gulf of Kachchh

Genus	Lakshadweep	Gulf of Mannar	Gulf of Kachchh
Branching *Acropora*	12.41	6.82	-
Tabular *Acropora*	0.90	22.02	-
Astreopora	1.15	-	1.77
Cyphastrea	2.71	0.31	2.04
Favia	-	5.03	4.74
Favites	1.45	0.91	24.59
Fungia	0.24	-	-
Galaxea	0.46	-	-
Gardinerorseris	0.76	-	-
Goniastrea	0.41	0.42	-
Goniopora	0.15	-	12.77
Hydnophora	-	0.84	1.23
Leptastrea	0.71	-	-
Millepora	1.48	-	-
Montipora	4.31	35.77	2.64
Mycedium	0.08	-	-
Pavona	10.94	-	-
Platigyra	0.46	-	18.03
Pocillopora	1.44	3.55	-
Porites	57.95	14.51	23.91
Stylophora	1.99	-	-
Symphyllia	-	0.33	5.27
Turbinaria	-	9.47	3.02

Source: Rohan Arthur (2000)

Current Status

The preventive, protective and conservation measures taken in the National Marine Park of Gulf of Kachchh have resulted in the restoration of the reef significantly. The 'living' coral area has increased to 20-30% (Vineeta Hoon, 1997).

However, mud deposits over the reef raise alarm and would clearly indicate the degradation of the reefs in this area. The rate of degradation of the coral reefs would depend on the degree of dredging, filling, mining and weapon testing by the armed forces and cutting of mangroves and the rate of degradation of the coral reef has been around 2.5% during 1975 and 1985 (Anjali Bahuguna *et al.,* 1992). There is very little influx of freshwater and the fluctuations of physical parameters in the coral reef area are also minimum except for the high degree of sedimentation, the sediments being derived from terrestrial environment. Absence of *Acropora* sp. in the Gulf of Kachchh is mainly due to the high degree of siltation. A major part of the South East Goos reef and Pirotan reef is being eroded and destroyed due to over siltation (Pandeya Anjali *et al.,* 1989). Extreme physical conditions such as prolonged exposure to open air limit the degree of colonization of corals and associated animals. The destruction of coastal vegetation for use as fodder to cattle and camels is a major problem which enhances coastal erosion. The sediments deposited on the substratum restrict the settlement of planulae (Gopinadha Pillai and Rajagopalan, 1979). The coral reefs located closer to shores were found extensively damaged/destroyed due to industrial installation like chemical factories, fertilizer factories and salt pans (Anon., 1997).

5. CORAL REEF ECOSYSTEM OF THE LAKSHADWEEP ISLANDS

Lakshadweep islands in the Arabian sea are situated between the Lat. 8° 12'N and Long. 71° 40'E consisting of 36 islands, 12 atolls, 3 reefs and 5 submerged coral banks. All islands are geometrically similar in shape, relatively wider at north and narrowing down towards south except Androth. All the islands are small in size ranging from 0.1 to 4.4 km^2 in area, and are encircled by fringing reefs with the formation of lagoon on the western side. The total land area of Lakshadweep is 32 km^2 and the total extent of lagoon is about 420 km^2 (Chandramohan *et al.,*1993). The earliest records of flora and fauna of the Lakshadweep islands are those of Gardiner (1905) and Ellis (1924).

Physico-Chemical Parameters

At Kavaratti, the maximum tidal range is about 1.7 m. The average current velocity in the lagoon is around 10 cm/sec (5 cm/sec at the southwest corner; 20.4 cm/sec near the entrance) during November. At low tide, the reef is exposed and at high tide, the reef is submerged (Qasim and Sankaranarayanan, 1970). The tides at the Lakshadweep islands region are of semi-diurnal type, with the spring tidal range of about 1.2 m and the neap tidal range of about 0.3 m. Owing to the presence of wide reefs on the open sea side, wave induced longshore currents along the open beaches are relatively weak i.e. within 0.1 m/sec. at all islands. But on Androth island, because of its east-west orientation, long shore currents along the southern coast are faster with a velocity ranging between 0.1 and 0.2 m/sec. (during February). As the wave action is intensive during the southwest monsoon, the morphological changes on the lagoon beach are significant. It is observed that all the inhabited islands are subjected to erosion problem (Chandramohan *et al.,* 1993). Wave diffraction plays a significant role in the distribution of wave energy along the coasts of the islands and thus affects the stability of the coast. The maximum wave height ranges from 5 to 8.95 m (Ramachandran and Ajayakumar Varma, 1997). During the monsoon, the surface currents in the open ocean flow eastwards and clockwise in direction due to the coastal configuration. It flows northeastwards along the Arabian coast and southwards along the Indian coast as wind driven ocean current. This clockwise circulation strengthens with the progress of south-west monsoon. This coastal current is a continuation of the Somali current flowing along the East African Coast (Nair *et al.,*1986).

Rainfall is slightly more in south than north showing an average of about 1,640 mm for Minicoy and 1,504 mm for Amini while the temperature ranges from 35° to 17° C (Jones, 1986). The physico-chemical parameters of the lagoon water and the sea of the Lakshadweep are shown in Table 7 (Sankaranarayanan, 1973).

Diurnal changes in different environmental parameters are shown in Fig. 2. Changes in pH, $PO_4 - P$ and $NO_3 - N$ values are almost similar at sea (outside the coral reef) and the lagoon. Fluctuations in $SiO_3 - Si$ values are more at sea rather than the lagoon. The range of pH is 7.4 - 8 with higher and lower values in the day and night samples respectively (Goswami, 1979). Monthly mean values for the physico-chemical parameters viz. temperature, salinity, phosphate, pH, nitrate, nitrite, and calcium are shown in Fig. 3. Temperature varied between 27.5° C and 31.6°C (Fig. 3A). No significant variations were noted in pH, salinity and phosphate (Fig. 3B-D). Nitrite varied between 0.02 and 1.62 μg at.1^{-1}, with exceptionally high values during February-May and October-December (Fig. 3E). The variations in nitrate and calcium were not found to be significant with the exception of high value of nitrate during August 1988 (Fig. 3F,G). Current velocity ranged from 3.5 to 14.9 cm. $sec.^{-1}$ (Fig. 4A), with the highest seasonal average value during monsoon (11.9±2.2 cm.$sec.^{-1}$). The premonsoon and postmonsoon values were 4.5±0.9 and 5.6±1.6 cm.$sec.^{-1}$ respectively. However, the actual velocities could be still high as the measurements were made during low water and the velocity depended on prevailing wind and tide. The amount of suspended matter in water (Fig. 4B) varied between 1.9 and 17.8 mg.1^{-1}. The monthly rate of sedimentation ranged from 2.3 to 124.5 mg.cm^{-2}.d^{-1} (Fig. 4C), with the highest seasonal average value of 85.7±24.7 mg.cm^{-}

^{2}.d^{-1} during monsoon. The premonsoon and postmonsoon averages were 4.4±1.8 and 10.7±6.7 mg.cm^{-2}.d^{-1} respectively. The data on monthly rainfall are depicted in Fig. 4D. Monthly zooplankton count (no.m^{-3}) ranged between 64 and 1041 (Fig. 4E). Environmental conditions with the exception of the amount of sediments in water, seemed conducive to the growth of *Acropora formosa* (Suresh and Mathew, 1993).

Table 7. Physicochemical parameters of the lagoon waters and the open sea of the Lakshadweep

Open Sea										
Station No.	Depth m	Temp. °C	Salinity %0	pH	Alkalinity meq/litre	Oxygen ml/litre	Inorganic phosphorus µg at/litre	Total phosphorus µg at/litre	Chlorophyll a µg/litre	Particulate organic carbon µg/litre
1	Surface	30.1	34.38	8.1	2.300	4.78	0.325	2.87	0.224	115
	10	29.1	34.35	7.9	2.226	6.50	0.350	2.46	-	-
2	Surface	31.0	34.35	8.0	2.226	5.75	0.350	2.87	0.106	204
	10	30.8	34.35	7.9	2.189	6.12	0.325	7.38	-	-
3	Surface	31.0	34.11	8.2	2.189	5.53	0.275	3.49	0.067	168
	10	30.80	34.30	8.0	2.151	6.72	0.350	4.31	-	-
4	Surface	31.0	34.32	8.2	2.226	5.53	0.375	3.85	0.123	186
	10	30.60	34.32	8.1	2.189	6.42	0.400	3.28	-	-
5	Surface	31.0	34.44	8.2	2.151	7.91	0.350	3.85	0.163	144
	-	-	-	-	-	-	-	-	-	-

Lagoon Waters											
Station No.	Depth M	Temp. °C	Salinity ‰	pH	Alkalinity meq/litre	Oxygen ml/litre	Inorganic phosphorus µg at/litre	Total phosphorus µg at/litre	Chlorophyll 'a' µg/litre	Particulate organic carbon µg/litre	Total phosphorus in sediments µg/g
6	S	30.60	34.40	8.00	2.289	7.84	0.200	2.25	0.172	180	264.7
	B (1 m)	30.20	34.34	7.90	2.314	7.39	0.200	8.30	-	-	-
7	S	30.60	34.40	8.10	2.482	4.48	0.266	4.10	0.073	96	211.4
	B (1 m)	30.80	34.35	8.10	2.374	5.08	0.266	3.94	-	-	-
8	S	31.60	34.48	8.20	2.410	5.08	0.200	6.40	0.028	162	225.7
	B (1.5 m)	31.20	34.48	8.00	2.386	5.23	0.300	4.99	-	-	-
9	S	31.20	34.45	8.10	2.386	5.08	0.170	3.07	0.073	192	189.7
	B (2 m)	30.60	34.41	8.10	2.386	5.38	0.230	1.15	-	-	-
10	S	31.60	34.41	8.20	2.290	7.39	0.200	1.02	0.0448	96	179.8
	B (2.5 m)	31.00	34.42	8.10	2.290	5.53	0.300	1.79	-	-	-
11	S	31.20	34.42	8.00	2.280	6.97	0.433	1.28	0.079	234	182.9
	B (2 m)	31.20	34.46	8.20	2.280	8.16	0.266	1.54	-	-	-
12	S	-	-	-	-	-	-	-	-	-	176.1
	B (2 m)	-	-	-	-	-	-	-	-	-	-
13	S	30.80	34.36	8.10	2.240	7.42	0.300	1.024	-	-	223.8
	B (2 m)	30.80	34.42	8.00	2.240	6.82	0.233	0.768	-	-	-
14	S	31.20	34.34	8.10	2.240	6.23	0.266	0.768	0.107	168	226.9
	B (2.5 m)	31.20	34.35	8.10	2.240	6.08	0.300	1.408	-	-	-
15	S	31.00	34.38	8.20	2.240	7.42	0.099	1.024	0.072	246	217.6
	B (1.8 m)	31.00	34.41	8.10	2.240	7.27	0.233	1.024	-	-	-
16	S	-	-	-	-	-	-	-	-	-	-
	B (3 m)	-	-	-	-	-	-	-	-	-	205.2
17	S	32.00	34.34	8.20	2.260	9.05	0.099	1.280	-	-	-
	B (3 m)	31.60	34.45	8.20	2.280	7.86	0.266	1.164	-	-	189.7
18	S	31.40	34.45	8.20	2.240	9.20	0.066	1.152	0.0448	258	200.3
	B (2.5 m)	31.20	34.40	8.20	2.140	7.12	0.066	1.280	-	-	-
19	S	-	-	-	-	-	-	-	-	-	-
	B (1 m)	-	-		-	-	-	-	-	-	234.2
20	S	32.40	34.45	8.20	2.160	10.24	0.133	0.768	0.112	210	220.7
	B (2 m)	32.40	34.45	8.20	2.160	9.49	0.133	0.768	-	-	-
21	S	-	-	-	-	-	-	-	-	-	-
	B (1 m)	-	-		-	-	-	-	-	-	174.5
22	S	-	-	-	-	-	-	-	-	-	-
	B (2 m)	-	-		-	-	-	-	-	-	189.7

S=Surface; B=Bottom

Source: Sankaranarayanan (1973)

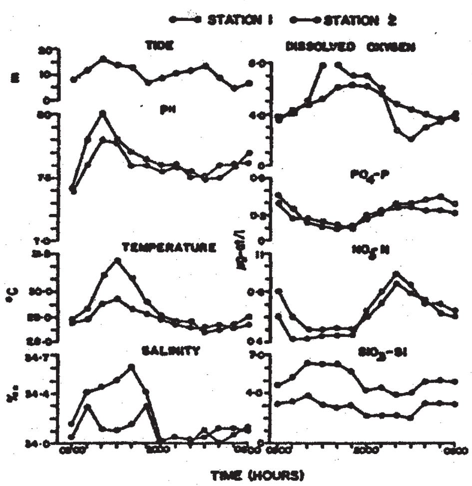

Fig. 2. Diurnal variations in environmental parameters at 2 stations at Kavaratti atoll (adapted from Goswami, 1979).

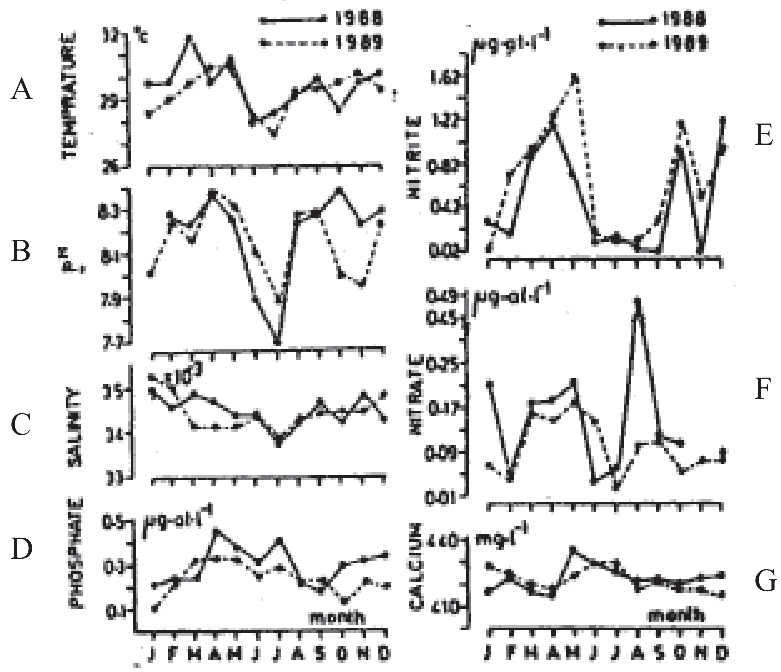

Fig. 3. Monthly mean values of temperature (A), pH (B), salinity (C), Phosphate (D), Nitrite (E), Nitrate (F) and Calcium (G) in the study area (adapted from Suresh and Mathew, 1993).

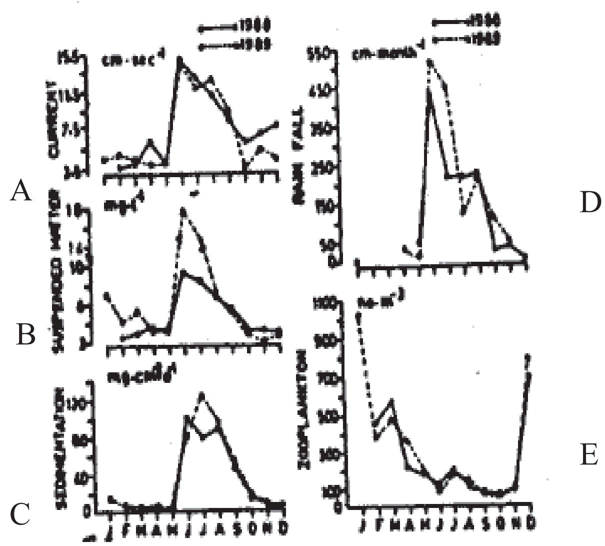

Fig. 4. Monthly mean values of current velocity (A), suspended matter (B), sedimentation (C), rainfall (D) and zooplankton (E) in the study area (adapted from Suresh and Mathew, 1993).

The mineral resources of the islands consist of low grade phosphates (derived from bird droppings, deposited continuously even before the islands were colonized by man) and calcium carbonate sands (Jones, 1986). Strontium content in the Minicoy reef lagoon varied from 3,960 to 7,000 ppm (av. 5630 ppm). Distribution of strontium indicated an inverse relation with magnesium ($r = 0.37$) and the ratios on the reef and lagoon ranged from 4.9 to 8.7; being higher in the lagoon and lower in the reef (Marcarenhar *et al.,* 1980). The Rare Earth Elements (REE) concentration (ppm) in various seasonal bands of *Porites* sp. of Kalpeni atoll is shown in Table 8 (Naqvi *et al.,* 1996). The concentration of petroleum hydrocarbons was found higher at Minicoy compared to Kavaratti and Androth (Ramachandran and Ajaykumar Varma, 1997). Cobalt concentrations in growth bands of a reef building coral (*Porites* sp.) collected from Kalpeni Atoll of the Lakshadweep group of islands (Arabian Sea), revealed cobalt concentrations and Co/Ca ratios to exhibit similar trend. Study indicated that most of the cobalt is located in non-lattice phases. Positive relations were found among cobalt concentrations, Co/Ca ratios and rainfall in the monsoonal bands (Naqvi and Nath, 1998).

Table 8. REE concentration (ppm) in various seasonal bands of *Porites* sp. of Kalpeni Atoll sample

Year		La	Ce	Sm	Eu	Gd	Dy	Er	Yb	Lu	ΣREE
1985	HD	1.45	0.13	0.22	0.04	0.20	0.04	0.06	0.03	0.03	2.2
1985	LD	0.87	0.15	0.20	0.03	0.13	0.05	0.06	0.04	0.02	1.62
1984	HD	1.39	0.20	0.24	0.02	0.20	0.03	0.04	0.03	0.02	2.17
1984	LD	0.78	0.10	0.20	0.02	0.18	0.03	0.04	0.08	0.03	1.46
1983	HD	0.89	0.14	0.20	0.03	0.10	0.04	0.04	0.11	0.05	1.60
1983	LD	1.51	0.17	0.15	0.02	0.07	0.07	0.03	0.07	0.04	2.13
1982	HD	1.84	0.33	0.21	0.03	0.19	0.03	0.03	0.13	0.05	2.84
1982	LD	0.69	0.17	0.18	0.03	0.30	0.05	0.02	0.09	0.02	1.55
1981	HD	0.55	0.19	0.21	0.01	0.15	0.07	0.01	0.10	0.03	1.32
1981	LD	0.50	0.12	0.10	0.02	0.09	0.03	0.02	0.13	0.06	1.07
1980	HD	0.56	0.16	0.15	0.01	0.11	0.03	0.06	0.07	0.01	1.16
1980	LD	0.52	0.14	0.17	0.02	0.30	0.04	0.03	0.09	0.03	1.34
1979	HD	0.99	0.22	0.30	0.05	0.19	0.02	0.02	0.01	0.04	1.84
1979	LD	0.44	0.13	0.17	0.04	0.17	0.03	0.02	0.01	0.04	1.05
1978	HD	1.29	0.22	0.08	0.02	0.13	0.01	0.01	0.03	0.04	1.83
1978	LD	0.89	0.15	0.16	0.04	0.21	0.03	0.03	0.04	0.05	1.60

HD = High Density (Monsoonal Band)
LD = Low Density (Non-monsoonal Band)
Source: Naqvi *et al.* (1996)

Coral Distribution

A total of 104 scleractinian corals belonging to 37 genera was reported from this region (Gopinadha Pillai and Jasmine, 1990). A comparative study of the coral fauna of southeast coast of India and the Minicoy showed *Acropora* as the common genus at both the places, but the species occurring at the sites are markedly different. Minicoy shows a closer affinity to those of the Maldives but the southeast coast of India shows a close affinity with Malaysian region (Gopinadha Pillai, 1971). The genus *Acropora* is the commonest as is the case with all the Indian Ocean reefs and forms about 25% of the total species known from Minicoy. A notable feature of the coral fauna of Lakshadweep is the absence of foliaceous forms such as *Montipora foliosa* and *Echinopora lamellosa*. The massive coral species such as *Porites solida, P. lutea* and *Diploastrea* sp. are very common in Minicoy (Gopinadha Pillai, 1986).

A coral reef survey was conducted in the Minicoy lagoon and the result of study showed that the coral reefs of Minicoy are characterized by low species diversity and live coral cover except for a few monospecific species in the deeper zones. The study of ecological characteristics of the environment showed that the variation in temperature, salinity, dissolved oxygen and nutrients in the lagoon and reefs were within the limit of lethal levels. The sedimentation rate and the variations in velocity of currents were normal. The major faunal groups that caused erosion of calcareous substrate included fishes, echinoids, sponges, polychaetes, sipunculids, bivalves and cirripeds. Blasting of the reef flat and the lagoon shoals and dredging of the lagoon bottom, hand picking of live corals, removal of coral rocks and coral stingles for construction purposes were found to have detrimental effects on coral growth in Minicoy Atoll (Navas and Mathew, 1995).

Growth study for 2 years, in respect of skeletal extension, was conducted *in situ* at Kavaratti atoll. Average annual rate of extension of branches was 7.9 ± 2 cm for first year and 8.2 ± 1.8 cm for second year. Growth of individual branches exhibited intra colony variations. Monthly rate of growth was found to be slower during monsoon (June-September) when compared to premonsoon (February-May) and postmonsoon (October-January) seasons (Suresh and Mathew, 1993).

Biodiversity and Productivity

The production of particulate organic carbon (POC) by the reef community is about 20% of its gross production, which is equivalent to about 95% of coral respiration as determined from the flow studies at night (respiration – 0.100 gC/m^2/hr). The relative concentration of particulate organic carbon in the surrounding sea and at different sites of Lakshadweep is shown in Fig. 5 (Qasim and Sankaranarayanan, 1970).

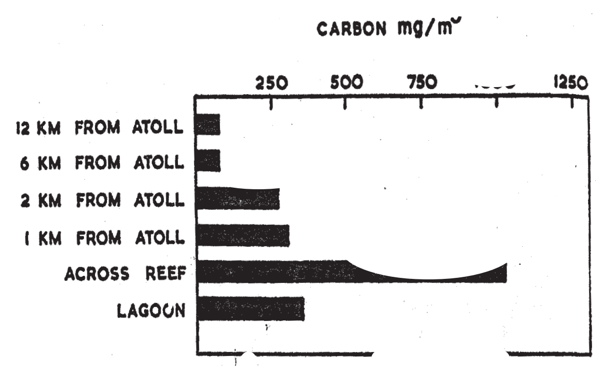

Fig. 5. Relative concentrations of partic"late organic carbon in the surrounding sea and at different sites of Lakshadweep (each value is a mean of 4-5 measurements) (adapted from Qasim and Sankaranarayanan, 1970).

The unit volume of production in this area varied from 8 to 34 mg C/m^3/day, with a maximum rate at Minicoy (Nair *et al.,* 1986). Minicoy reefs are autotrophic with annual net production from the lagoon (from a reef) is 3000 g C/m^2 day (Nair and Gopinadha Pillai, 1969). The calcium / chlorinity ratio of the samples collected from the two lagoons of Kavaratti and Minicoy were 0.02145 (± 0.000036) and 0.02142 (± 0.000046) respectively. These values are comparatively lower than the open sea values. The calcium / chlorinity ratio for the open ocean samples was found to be 0.02168±0.000015 with an average calcium concentration of 424.9 mg.kg^{-1} (Naqvi and Reddy, 1979). The zooxanthellae derive a major portion of the N requirement from coral excretion (Wafar *et al.,* 1993). The biological characteristics of the Lakshadweep sea during different years are shown in Table 9. Lakshadweep sea has been described earlier as an oligotrophic environment. But later it has been proved that only certain areas of the region can be termed oligotrophic that too during October only (Bhattathiri and Devassy, 1979).

Due to the shallowness of the lagoon, it is supporting rich growth of macrophytes. The benthic algae present in the lagoon are playing a significant role in the biogeochemical processes of these waters. The magnitude of the photosynthetic activity of algae and phytoplankton population can be seen from the diurnal changes in the oxygen, which varied from 1.73 to 8.83 ml l^{-1}. The higher photosynthetic activity of algae in the waters would have a good bearing on the precipitation of carbonates. The lagoon sediments are derived from coral rocks and debris and show low retention of phosphorus as compared to other types of bottom sediments (Sankaranarayanan, 1973).

In situ primary productivity measurements were carried out with different macrophyte species (belonging to four groups) dominating the benthic commmunities in the coral reef lagoon of the Kadmat Island of the Lakshadweep Archipelago. The photosynthetic productivity and respiratory requirements in nine macrophytes were determined. The highest net productivity was recorded in *Laurencia papillosa* while the lowest was in *Dictyota bartayresiana*. More than 75% of the macrophytes studied had net photosynthetic productivity higher than 15 mg C (g^{-1} dry wt) d^{-1} and only one macrophyte, *Boergesenia forbesii* had net production and respiration ratio higher than 10. The macrophyte species investigated were most productive and both macroalgae and seagrasses contributed equally to the carbon production of the coral reef lagoon of the Kadmat Island (Dhargalkar and Shaikh, 2000).

Totally, 69 marine algae belonging to 52 genera were collected from various islands of Lakshadweep. Table 10 lists the marine algae and seagrasses of the Lakshadweep islands and Fig. 6 shows the shore profiles of algae, seagrasses and coral distribution (Jagtap, 1987).

Table 9. Biological characteristics of the Lakshadweep sea during October - December, 1976 and March - April, 1978

Sl.No.	Surface *pp mgC/m³/day	Surface Chl a mg/m³	Surface Phaeo pigments mg/m³	Surface POC mg/m³ October	Column *pp mgC/m³/day	Column Chl a mg/m³	Column Phaeo pigments mg/m³	Column POC mg/m³
(October - December 1976)								
129	13.29	0.08	0.04	205	358.8	12.00	10.89	33.21
134	14.67	0.12	0.05	709	190.3	8.86	4.24	35.80
137	6.01	0.12	0.05	142	175.9	4.41	8.45	17.30
138A	2.48	0.07	0.05	173	23.0	0.89	0.26	2.04
139	14.03	-	-	142	202.1	-	-	13.50
140	7.91	0.07	0.03	205	92.0	6.61	1.54	18.32
141	5.85	0.13	0.05	79	95.9	7.20	3.79	11.18
143	2.72	0.16	0.05	551	135.3	8.67	3.93	21.91
147	3.54	0.10	0.03	-	177.9	4.09	1.86	-
150	0.53	0.08	0.05	142	21.8	5.39	1.15	13.68
151	0.79	0.02	0.03	173	53.2	3.85	2.70	24.26
153	0.33	0.05	0.03	79	29.5	6.54	6.40	9.39
154	1.94	0.03	0.05	110	98.7	7.23	7.74	19.63
157	1.93	0.05	0.04	173	222.5	7.85	7.22	17.20
Av.	5.43	0.08	0.04	222	134	6.44	4.63	18.26
SD	5.14	0.04	0.01	188	94.7	2.8	3.25	9.2
March - April 1978								
212	1.65	0.04	0.03	213	85.0	4.40	3.04	14.30
214	2.96	0.09	0.03	100	110.9	3.84	5.29	6.16
215	3.61	0.15	0.03	246	164.4	16.72	6.75	8.23
217	3.23	0.10	0.01	75	190.2	12.90	6.37	2.00
219A	8.17	0.22	0.04	125	635.6	11.91	4.83	14.75
220	32.89	0.58	0.20	94	578.7	18.86	7.45	11.68
222	28.32	0.17	0.06	150	676.1	16.89	11.49	10.75
225	2.30	0.10	0.03	63	199.9	7.75	15.98	3.62
227	2.96	0.15	0.04	175	115.5	3.98	1.35	8.82
228	42.23	0.33	0.09	50	1166.6	16.55	7.48	3.25
230	3.84	0.10	0.32	50	170.7	9.38	11.35	10.07
233	0.67	0.08	0.06	88	263.9	3.87	7.76	2.63
235	3.55	0.10	0.05	75	44.6	7.08	4.38	1.97
236	4.65	0.11	0.06	50	608.8	7.19	9.49	2.50
Av.	10.07	0.17	0.08	111	357.9	10.60	7.36	7.20
SD	13.62	0.14	0.08	63	324.7	5.0	3.80	4.6

(March - April 1978)

St. No.	*pp mgC/m³/day	Chl 'a' mg/m³	Phaeopigments mg/m³	Nannoplankton Chl 'a' mg/m³	Nannoplankton Phaeo pigments mg/m³	POC mg/m³	*pp mgC/m³/day	Chl 'a' mg/m³	Phaeo pigments mg/m³	Nannoplankton Chl 'a' mg/m³	Nannoplankton Phaeo pigments mg/m³	POC mg/m³	Attenuation coeff.
854	2.80	0.13	0.05	-	-	52	829.5	9.05	6.24	-	-	2.81	0.074
856	5.02	0.09	0.06	-	-	20	532.2	15.40	17.22	-	-	5.05	0.085
858	4.00	0.05	0.02	0.01	0.05	44	461.2	7.51	6.36	1.63	3.47	2.46	0.081
859	6.50	0.01	0.01	0.01	0.03	32	330.8	8.05	7.07	5.48	2.95	2.58	0.081
861	4.36	0.02	0.02	-	-	20	264.9	1.61	1.58	1.09	1.77	1.95	-
862	2.37	0.01	0.04	0.01	0.02	41	269.7	2.06	6.71	1.47	3.86	4.15	-
864	2.98	0.10	0.01	0.04	0.01	81	293.5	7.26	4.13	2.74	2.65	4.75	0.074
866	4.40	0	0	-	-	78	456.3	1.43	1.16	-	-	-	-
868	1.44	0.04	0	0.04	0.01	76	423.7	3.88	2.39	3.88	1.02	5.33	0.077
870	3.91	0.15	0.06	-	-	80	270.5	1.65	1.41	-	-	5.36	0.061
872	7.48	-	-	-	-	109	388.2	3.73	1.64	-	-	6.16	-
873	4.89	0.04	0.01	0.02	0.02	98	259.7	2.35	2.34	1.99	2.98	4.50	0.065
874	5.05	0.06	0.05	0.03	0.02	100	257.3	3.27	5.73	1.07	2.66	2.77	0.077
878	30.23	0.08	0.03	0.04	0.14	50	367.0	2.88	2.86	2.44	1.95	1.66	0.094
879	4.62	0.20	0.04	0.08	0.02	62	285.8	5.37	4.01	3.84	1.37	3.03	0.113
880	8.73	0.15	0.04	0.06	0.04	19	253.6	2.23	2.42	2.23	2.95	1.55	0.100
Av.	6.2	0.08	0.03	0.03	0.04	60	371.5	4.86	4.58	2.53	2.51	3.61	0.082
SD	6.7	0.06	0.02	0.02	0.04	30	150.6	3.8	4	1.4	0.88	1.5	-

*PP=Primary Production

Source: Bhattathiri and Devassy (1979)

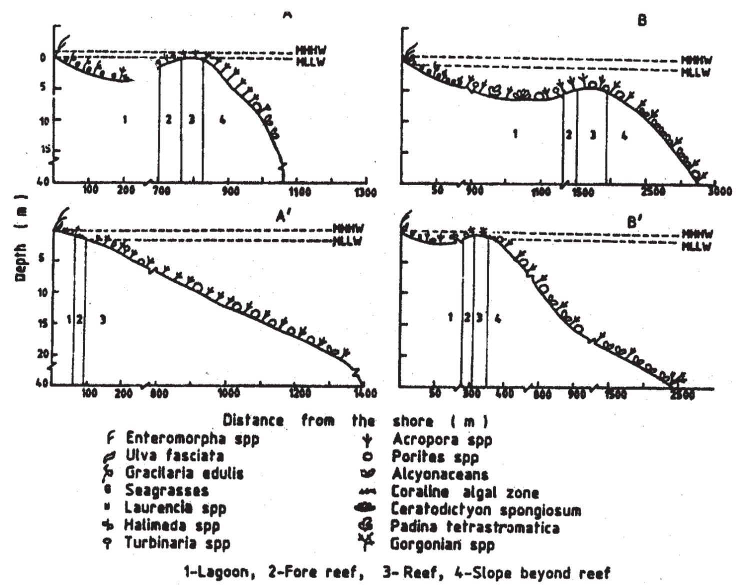

Fig. 6. Shore profiles showing distribution of algae, seagrasses and corals (A, A'– along west and east coasts of Kavaratti, respectively; B, B' – along west and east coasts of Agatti, respectively)(adapted from Jagtap, 1987).

The distribution, abundance and standing stock of macrophytes on the intertidal reef flat at Agatti atoll were recorded. The reef flat at Agatti can be divided into three zones partly correlated with physical factors. The upper zone is characterized by *Thalassia hemprichii, Boergesenia forbesii, Gracilaria edulis* and *Valoniopsis pachynema,* the middle zone by *Gelidiella acerosa, Laurencia papillosa* and *Ceramium* sp., and the lower zone by *Ulva lactuca, Turbinaria ornata* and *Codium arabicum*. *Halimeda gracilis* is dominant in both the middle and lower zones. Algal abundance was reduced to one third in April mainly because of periodicity governed by the monsoon. Macrophytes wet weight standing stock of Agatti reef flat was estimated to be 835 ± 59 t. in October 1993 and 686 ± 77 t. in April 1994 (Rodrigues *et al.,* 1997).

The productivity of the coral reef alga *Halimeda gracilis* was estimated. The percentage cover of *H. gracilis* was 32.6% on the reef, 10.9% on the shore reef and 17.3% on the seagrass beds. The length of *H. gracilis* varied between 4.6 cm at the reef and 8.5 cm in seagrass beds but the weight showed only slight variation. Length-weight relationship of *H. gracilis* indicated least variable morphology at reef and lagoon. Plants collected from seagrass beds in the lagoon showed the highest productivity of 0.64 gC/ m^2/day while the lowest production of 0.08 gC/m^2/day was recorded from the shore reef. Environmental parameters such as temperature, salinity, dissolved oxygen and nutrients were monitored at three stations (Haneefakoya *et al.,* 1999).

Table 10. Marine algae and seagrasses of Lakshadweep islands.

	1	2	3	4
Seagrasses				
Hydrocharitaceae				
Thalassia hemprichii	+	+	+	-
(Ehrenberg) Aschers.				
Halophila ovalis (R. Brown)				
Hook.f	-	+	+	+
Potamogetonaceae				
Cymodocea rotundata	+	-	+	-
Ehrenberg et Hemprich				
Halodule uninervis (Forssk.)				
Aschers	+	-	+	-
Syringodium isoetifolium	+	-	+	-
(Aschers) Dandy				
Marine Algae				
Cyanophyta				
**Aphanocapsa* spp.	+	-	-	-
Oscillatoria spp.	+	-	-	-
**Phormidium* spp.	+	-	-	-
Lyngbya majuscula	+	+	+	+
Harv.ex.Gomont				
**Gardnerula tenuissima*	+	-	-	-
Tseng et. Hua				
Chlorophyta				
**Ulva fasciata* Dellile	+	-	+	-
Enteromorpha tubulosa	+	-	-	-
Kuetz				
E. linza (L) J. Ag.	-	+	-	-
**Rhizoclonium hookerii*	+	+	-	-
Kuetz				
Chaetomorpha linum	+	-	+	+
(Muell) Kuetz				
Cladophora fascicularis	+	-	-	-
(Mertens.) Kuetz				
Cladophoropsis zollingeri	+	-	-	+
(Kuetz) Boerg				
Bryopsis plumosa	+	-	-	+
(Hud.) Ag.				
**B. hypnoides* Lamour	+	-	-	-
**Caulerpa sertularioides*	+	-	+	+
(Gmel.) Howe				
C. serrulata (Forssk.)	+	-	-	-
J. Ag. Emend Boerg				
**C. racemosa* var. *clavifera*	+	-	-	-
(Turner) V. Bosse				
C. racemosa (Forssk.) V. Bosse	+	-	+	-
C. cupressoides (Vahl) A.g	+	+	-	+
**C. fastigata* (Mont)	+	-	+	-
**Codium adhaerens* (Anderson)	-	-	+	-
Halimeda gracilis Harv.et.J.Ag.	-	-	+	-
H. opuntia Lamour	+	-	+	+
H. tuna (Ell et. Sol)	+	-	-	-
Boodlea composita	-	-	+	-
(Harv et. Hook F. Brand)				

	1	2	3	4
Dictyosphaeria cavernosa	+	+	+	-
(Forssk.) Boerg				
Boergesenia forbesii (Harv.)	+	+	+	+
Feldm.				
Struvea anastomosans	+	+	-	+
(Harv. Picon)				
Phaeophyta				
Hydroclathrus clathratus (C.Ag.)	-	-	+	-
Dictyopteris deliculata Lamour	+	-	+	-
**D. australis* (Sonder)	-	-	+	-
Dictyota dichotoma (Huds.) Lamour	+	-	+	+
Padina tetrastromatica Hauck	+	-	+	+
Pocockiella variegata (Lamour) Papen.				
Sargassum duplicatum Ag.	-	+	-	-
Turbinaria ornata J. Ag.	+	+	+	+
T. conoides, Kuetz.	+	-	+	-
Rhodophyta				
**Acrochaetium* sp.	+	-	-	-
Galaxaura sp.	+	-	-	-
**Asparagopsis taxiformis* (Delile)	+	-	+	-
Coll et. Harv.				
**Gelidium pusillum* (Stackh.) Le Jolis	+	-	+	-
Gelidiella acerosa (Forssk. Et. Feld)	+	-	+	-
Jania adhaerens Lamour	+	+	+	+
**Melobesia* sp.	+	-	-	-
Halymenia venusta Boerg.	+	-	-	-
Hypnea valentiae (Turn.) Mont.	+	+	+	+
Gracilaria crassa Harv.	+	-	+	-
G. edulis (Gme.) Silva	+	-	+	+
Gelidiopsis intricata (Ag.) Vickers	-	-	+	+
**Ceratodictyon spongiosum* Zanard.	-	-	+	-
Champia parvula	-	-	+	-
Callithamnion sp.	+	-	-	-
Centroceras clavulatum (Ag.) Mont	+	+	+	+
Ceramium moryae Veb V. Bosse	+	+	+	-
**C. tenuissimum* J. Ag. (?)	+	-	-	-
Spyridia aculeata J. Ag.	+	-	-	-
Wrangelia sp.	+	-	-	-
Chondria dasyphylla ag.	+	-	-	+
Laurencia obtusa (Huds.) Lamour.	-	-	-	+
**L. pedicularioides*, Boerg	+	-	-	-
L. cruciata Harv.	+	-	-	-
L. papillosa (Forssk.) Gravel	+	-	+	+
Herposiphonia sp.	+	-	-	-
Acanthophora muscoides (L) Boerg	-	+	-	-
A. spicifera (Vahl.) Boerg.	+	+	-	-
Tolipocladia glomerulata (C. Ag.)	+	-	-	-
Web. V. Boss				
Chondrococcus hornemanii Mart.	+	-	-	-
Leveillea jungermannioides	+	-	+	-
(Mart et Hering) Harv.				
Dictyurus purpurescens Boerg.	+	-	+	-

*+ connotes presence of species, - connotes absence of species, * new records*
(1 = Kavaratti; 2 = Suheli; 3 = Agatti; 4 = Bangaram)

Source: Jagtap (1987)

The lagoon areas of the islands showed seagrass beds dominated by *Thalassia hemprichii* (James *et al.,* 1987). Major seagrass meadows from three coral atolls of the Lakshadweep group (Arabian Sea) were studied for their floral components. Seagrass beds were heterogeneous, comprising mainly of *Thalassia hemprichii* and *Cymodocea rotundata*, in Agatti and Kavaratti and it was observed to be monospecific (*T. hemprichii*) in the Kalpeni lagoon. Maximum (0.34 km^2) and minimum (0.005 km^2) extent of seagrass beds were observed in Kavaratti and Agatti lagoons, respectively. Seagrass weight (dry) of 43.97, 30.88 and 0.74 t were estimated from Kavaratti, Kalpeni, and Agatti, respectively. Maximum biomass occurred from 0 to 2 m depth, mainly contributed by the above ground shoots, and was found to be negatively correlated with depth ($r = 0.71$, $p < 0.05$). Sediments were devoid of seed reserves indicating seagrass growth mainly by vegetative propagation; Epiphytes, on an average, contributed 7.5% of the seagrass biomass and were dominated by algae such as *Melobesia* spp., *Microcoleus lyngbyaceus* and *Ceramium* spp. Epiphytic biomass, too, decreased with increasing depth. Associated marine algae were represented by 66 species, dominated by rhodophytes (Jagtap, 1998).

The biomass distribution of algae on the seaward side of the reef at Minicoy island varied from 620.2 g wet wt./ m^2 in September to a maximum of 2800.6 g wet wt./ m^2 in August. Reef flat had a minimum in July (251 g wet wt./m^2) and a maximum in December (2074.9 g wet wt./m^2). Significant seasonal differences were noticed in the three regions with maximum biomass during monsoon on the seaward side and in the postmonson at reef flat and lagoon side of the reef. *Laurencia ceylanica* formed a continuous mat on the seaward side and *Halimeda gracilis* (56.0%) and *Turbinaria ornata* (32.0%) were major algae of the reef flat and lagoon side of the reef. Minor algae observed on the reef were *Gelidiella acerosa, Boergesenia forbesii, Sargassum duplicatum* and *Cladophoropsis zollingeri.* Monthly average of total biomass is shown in Table 11. The seasonal variations of hydrographical parameters such as water temperature, salinity, nutrients, rainfall are shown in Table 12 (Mohammed *et al.,* 2000).

Table 11. Monthly average biomass (g wet wt./m^2) of algae at the three sites.

Months	Seaward side	Reef flat	Lagoon side
January	830.2	811.3	900.3
February	880.7	601.7	873.5
March	683.2	604.3	882.4
April	711.5	608.6	1071.3
May	645.3	1143.2	790.7
June	1013.3	901.4	552.4
July	1928.6	251.0	805.6
August	2800.6	304.3	1204.2
September	620.2	601.3	624.7
October	1303.9	1480.4	1935.6
November	1213.2	1671.7	2161.3
December	953.1	2074.9	2316.8

Source: Mohammed *et al.* (2000)

Table 12. Seasonal variations in hydrographical parameters in the study area during 1998.

Parameter	Premonsoon	Monsoon	Postmonsoon
Water temperature (°C)	29.0±0.79	29.4±1.02	28.6±0.43
Salinity (ppt)	33.8±0.35	33.7±1.06	34.3±0.43
Phosphate (µ at/l)	0.60±0.14	0.66±0.14	0.35±0.25
Nitrate (µ at/l)	0.39±0.06	0.58±0.15	0.39±0.24
Water movement (m/s)	0.29±0.14	0.35±0.19	0.35±0.09
Rainfall (mm)	22.4±36.80	111.12±48.84	91.75±66.17
Hours of exposure	43.8±49.6	121.30±113.5	165.0±269.8

Source: Mohammed *et al.* (2000)

The thraustochytrid fungus (*Corallochytrium limacisporum*) was found in great numbers in the waters of the coral reef lagoon of Lakshadweep. The possible contribution of this thraustochytrid to the total microbial biomass of these lagoons was based on the estimates of ATP and organic carbon (OC). The thraustochytrid contributed 2.88 to 213.57% ATP and 1.15 to 84.43% OC which was higher than that of total viable bacteria which contributed 0.024 to 3.09% ATP and 0.002 to 1.24% OC to the total microbial biomass (Raghukumar *et al.,* 1987; Raghukumar and Balasubramanian, 1991). Coral mucus is utilized by various micro organisms and the mucus (floating) attached detritus species are *Corallochytrium limacisporum, Thraustochytrium motivum, Labyrinthuloider minuta, L. yorkensis* and *Ulkenia visurgensis.*

Productivty contribution of phytoplankton in Kavaratti atoll revealed that gross production (mg C/m^3/hr) varied between 0.62±0.01 and 6.0±2.5 and net production between 0.2±0.13 and 1.46±0.85. Gross production showed seasonal variations with a fall during monsoon months (June to September). Productivity appeared highly variable and limited by salinity as well as light conditions (Suresh and Mathew, 1999).

The coral zooplankters satisfy the nutrient requirements of the corals. Table 13 shows the energy available to the reef each night from zooplankton. The most striking feature in the distribution of zooplankton in Lakshadweep waters is the higher abundance of zooplankton in the adjoining sea as compared to the lagoon. Table 14 shows the taxonomic composition of zooplankton from the oceanic and lagoonal waters of Lakshadweep (Tranter and Jacob George, 1969). The diel cycle of planktonic distribution present in the day light samples is shown in Fig. 7. Copepods constitute an important component in the demersal zooplanton which hide in the coral sediments or crevices during day time but emerge at night for feeding (Goswami and Usha Goswami, 1990). Zooplankton community structure was found more diverse in the surrounding sea than in the lagoon (Goswami, 1983). A comparison of the mean zooplankton biomass showed that the sea outside Kalpeni and Agatti atolls is 3 to 10 times richer (1.3 and 3.3 ml $(100m^3)^{-1}$) than their respective lagoons (0.13 and 1.03 ml $(100m^3)^{-1}$) (Achuthankutty *et al.,* 1989). The environmental parameters such as water temperature, salinity, cloud cover, wind force, rainfall and tide influence the distribution and abundance of zooplankton, copepods, amphipods and decapod larvae were the dominant groups in the zooplankton (Nasser *et al.,* 1998). The tides also influence the zooplankton abundance and biomass which are higher during the flood tide. Copepods were poorly represented in the planktonic samples collected from inside of the reef flats than outside. The percentage occurrences of calanoid, harpacticoid and cyclopoid copepods in the outer reef flats were 86.73, 2.28 and 10.99 whereas they were 27.85, 42.45 and 20.70 respectively in the inner reef flat. The hyperiid amphipods occurred in greater numbers at station outside the reef while the gammarid amphipods were abundant in the lagoon. Fish eggs and fish larvae were also quite common in the plankton samples. The fish larvae belonging to the families Gobiidae, Myctophidae and Holocentridae occurred frequently in the plankton samples. The mean numerical abundance of zooplankton in the lagoon was about 26% (Goswami, 1979).

Table 13. Potential energy available to the reef in the form of zooplankton carbon.

Current velocity (cm/sec)	Seaward zooplankton biomass (Mg/m^3, wet weight)				
	50	100	200	400	800
10	0.06	0.12	0.24	0.48	0.96
20	0.12	0.24	0.48	0.96*	1.52
40	0.24	0.48	0.96	1.92	3.84
80	0.48	0.96	1.92	3.84	7.68
100	0.96	1.92	3.84	7.68	15.36

Source: Tranter and Jacob George (1969)

Table 14. Taxonomic composition of zooplankton from the ocean station compared with that of lagoon station of Lakshadweep.

Taxon	Density (No/m^3)		Percentage	
	Ocean	Lagoon	Ocean	Lagoon
Calanoid + Cyclopoid copepods	917	2	75	0.4
Pelagic tunicates	48	0	4	0
Chaetognaths	28	0	2	0
Pelagic polychaetes	7	0	0.6	0
Siphonophores	4	0	0.3	0
Harpacticoid copepods	2	366	0.1	65
Decapod larvae	3	53	0.3	9
Mysids	0	11	0	2
Gammarids	0	2	0	0.4
Ostracods	149	123	12	22
Miscellaneous	69	8	5.6	1.4
Total	1227	565	99.9	100.2

Source: Tranter and Jacob George (1969)

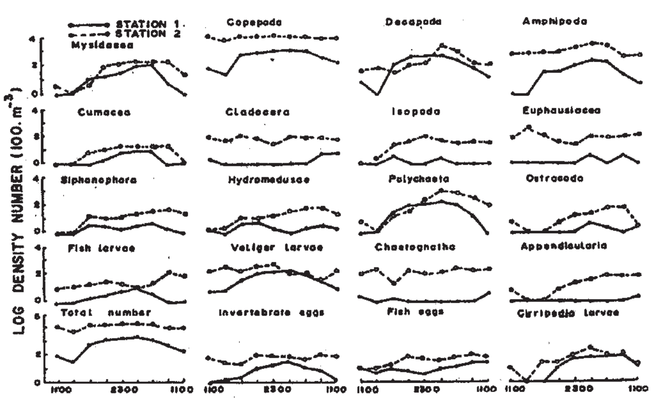

Fig. 7 Occurrence of common groups of plankton over the diel cycle at 2 stations in Lakshadweep (adapted from Goswami and Usha Goswami, 1990).

Secondary production values for the surface zooplankton samples were low during the day time in the lagoon due to the higher incident illumination and temperature which forced the plankton to hide in the thick growth of seagrasses, *Thalassia hemprichii* and *Cymodocea isoetifolia*. Low zooplankton biomass values obtained for the lagoon samples were due to consumption of zooplankton by the corals and associated animals. Zooplankton collected from the surrounding sea showed higher diversity of faunal composition. Most of the oceanic groups such as Foraminifera, Siphonophora, Hydromedusae, Appendicularia and Thaliacea were found not to occur in the lagoon (Goswami, 1983).

Macrofauna comprising of 9 groups was dominated by polychaete worms, while meiofauna, comprising of 10 groups was dominated by nematodes. Densities of both macro and meiofauna were higher near the shore were biomass of *Thalassia hemprichii* was maximum (Ansari, 1984).

Alcock (1898 & 1899), Borradaile (1903) and Sankarankutty (1961) have recorded 36 species of crabs from Lakshadweep. Appukuttan (1973) has listed 48 species of gastropods and 12 species of bivalves. Thomas (1973 & 1979) reported 41 species of sponges from Minicoy, including typical coral and shell boring species viz. *Spirastrella cuspidifera*, *S. inconstance* and *Cliona* sp. The total percentage of boring sponge species present in each Lakshadweep atoll was 46.4% (Kavaratti), 36.1% (Kalpeni), 48.3% (Suheli), 66.6% (Androth), 50% (Minicoy), 38.4% (Amini), 20% (Kiltan) and 58.3% (Kadmat). Availability of the coral skeleton in large quantities is the major limiting (affecting) factor for the occurrence of boring sponges (Thomas, 1997). Bhaskar (1984) reported four species of turtles viz. *Eretmochelys imbricata* (Hawksbills), *Lepidochelys olivacea* (Olive ridley), *Chelonia mydas* (Green turtle) and *Dermochelys coriacea* (Leather back). Cheap to very expensive ornamental fishes were also found available in huge quantities. Varieties of ornamental fishes such as the species of *Abudelduf, Amphiprion, Apogon, Coris, Balistes, Platax* and several other beautiful coral fishes were recorded as common in Lakshadweep (George *et al.,* 1986).

The book “Fishes of the Laccadive Archipelago” by Jones and Kumaran (1980) gives detailed information on 603 species of reef fishes including many bathypelagic forms. Annual fishery potential of the Lakshadweep sea was estimated as 90,000 tonnes but the yield as per 1984 statistics was only about 5,000 tonnes/year (Jones, 1986). Distribution and community organisation of reef fish, food and feeding habits and reproduction of some important and common species and fishing methods were described (Anand and Pillai, 1995). *Chromis caeruleus* and *Dacyllus aruanus* were reported as the predominant fishes among the resident coral fishes which coexisted with ramose corals. Both these fishes are diurnal and feed on plankton resting in the interspaces of branches and branchlets of corals or swimming around the corals during the day time. The fish population of *C. caeruleus* and *D. aruanus* on a coral showed five to seven size ranges. These included newly settled post larvae of 7 mm T.L. (Total Length) to adults of 40 mm T.L., though the fishes are capable of growing upto 80 mm. The surface area of the samples of corals ranged from 380.3 to 934.25 cm^2 and the average fish biomass weight ranged from 22.42 to 38.87 g (Gopinadha Pillai *et al.,* 1985). *Acanthurus triostegus triostegus* was the commonest acanthurid found on shallow intertidal reef flats of Minicoy atoll and other Lakshadweep Islands. It is a typical herbivore and feeds on filamentous and segmented algae commonly found on live and dead coral boulders (Gopinadha Pillai *et al.,* 1983).

Coral reef fish community organisation on Kavaratti atoll showed Labridae as a generalist family found on all sub-habitats except on live coral zone. Subsequent positions were occupied by other families characteristic of particular sub-habitats, reflecting primarily the feeding mode, site-attachment and other habits. With an exception of sand flats where only Labridae and Acanthuridae were dominant, 3 to 5 families from a collective list consisting of Acanthuridae, Balistidae, Chaetodontidae, Labridae, Mullidae, Pomacanthidae, Pomacentridae and Scaridae were dominant on each sub-habitat (Anand and Pillai, 1995).

Current Status

The Nationwide project on the Coastal Ocean Monitoring And Prediction System (COMAPS) provides data on the water quality and productivity of this region which revealed the water temperature to be rather uniform and the concentration of the suspended solids higher at Kavaratti. Other hydrographical features are: high pH in Minicoy, low dissolved oxygen concentration in Kavaratti and Androth, almost uniform nutrient concentrations in all the regions and high biological oxygen demand in Kavaratti and Androth. Low dissolved oxygen concentration and high BOD values indicate environmental stress in these regions. The concentration of petroleum hydrocarbons is higher at Minicoy in comparison to Kavaratti and Androth (Ramachandran and Ajayakumar Varma, 1997).

These has been more than a 200% raise in the human population over an area of 1615 km^2 with consequent and dramatic increase in the density of houses and passenger and cargo traffic. The lagoons of Lakshadweep are rich in seaweeds which have good potential for industrial products. However, the indiscriminate seaweeds harvest would adversely affect their stock (James *et al.,* 1986a). All islands in the archipelago are subjected to cyclones which may do mechanical damage to coral growth (Gopinadha Pillai, 1986). The rate of siltation in the lagoon of Minicoy and other islands has increased due to sea erosion and increased human activity in the lagoon. Quarrying corals from the shore and reefs, pitting the ground and removal of surface soil are the major human impacts on the Lakshadweep coral reefs (Gopinadha Pillai, 1986; Navas and Mathew, 1995). At present, the coastline is facing erosion in Kalpeni, Kavaratti, Minicoy, Agatti, Kadmat and Androth islands. Erosion can primarily be attributed to four causes viz. removal of reef materials, dredging, construction of harbour and current circulation pattern in the lagoon. Increase in the construction activity using coral blocks due to lack of alternative source of construction materials is the major cause for the removal of reef boulders. This in turn destroys the natural barrier which protects the islands from the direct influences of waves. In order to provide the inter island navigational facility, entrance channels are being dredged at all the islands by blasting the coral beds (Chandramohan *et al.,* 1993). This would also lead to the destruction of coral beds in different islands. On the evening of 26th September 1974, an American oil tanker, TRANSHURON owned by Hudson Waterways Corporation (U.S. Navy), ran aground in Kiltan, one of the islands in the Lakshadweep archipelago which led to oil spill in the surrounding sea. The hermatypic corals which are the builders and producers of the atoll were extensively and intensively damaged by the oil pollution. The total damage caused by the oil spill and its ecological implications were difficult to assess (Qasim *et al.,* 1974).

Mortality of corals due to sponge attack has been calculated as 80% for an area of 25m^2/yr (Thomas, 1997). Occurrence of *Acanthaster planci* (Crown-of-thorn Starfish), a well known predator of coral polyps, was observed in Kavaratti lagoon as well as reef slopes of Kadmat islands (Ravindran *et al.,* 1999) and found feeding on live *Acropora* sp. and causing death of corals in Kavaratti and Minicoy islands (Sivadas, 1977 and Murty *et al.,* 1980). However, it is heartening to note that the Crown-of-thorn Starfish has not occurred from 1981 probably due to many ecological reasons.

As per the latest figures, annual fisheries yield of Lakshadweep is around 9,000 tonnes, of which tunas alone constitute 7,000 tonnes (Rodrigues, 1997). Steady increase in landings and decrease in mean length of the yellow fin tuna are matters of great concern over the dwindling tuna populations of this area (James *et al.,* 1986b). Results of growth studies conducted in *Acropora* spp. from a shallow water site in Kavaratti atoll showed the mean annual extension of *A. aspera* to range between 3.8 cm (1998) and 4.9 cm (1989) and for *A. formosa* as 8.0 cm (Suresh and Mathew, 1993, 1995).

Coral bleaching was common in Lakshadweep reef, although the incidence was low during our survey from April 96 to Feb. 98. Fully – and partially – bleached colonies were frequently noticed. Bleached colonies under the water are easily identifiable by their white skeleton which is devoid of pigments. Colonies showing bleaching were observed to secrete excess mucus. While the fully-bleached colonies appeared totally white, partially bleached ones showed moderate loss of their original colour and were also observed to secrete excess mucus (Ravindran *et al.,* 1999). Bleached coral comprised of 82% of the coral cover and bleaching related mortality was high at 26% in lagoons reef of Lakshadweep. In contrast, the lagoon reefs of the Lakshadweep had a much higher coral cover and nearly 15% coralline algal cover. Eighteen genera of coral were recorded in Kavaratti and Kadmat lagoons, *Porites,* branching *Acropora,* and *Pavona* being the most abundant (extent of stressed and dead corals recorded in Lakshadweep were 26% pale, 30.09% bleached, 25.71% dead and 81.80% totally affected). The Lakshadweep reefs were most severely affected by the bleaching-more than 80% of the coral cover (Rohan Arthur, 2000). Disease, predation and stress were the major factors of coral mortality. Death caused by diseases – the Black Band Disease (BBD), the White Band Disease (WBD) – necrotic lesions, and bleaching was observed in Kavaratti and Kadmat islands of Lakshadweep. Necrotic lesions were observed very frequently in *Porites lutea* which is common in the lagoons of Kavaratti and Kadmat islands. Encrusting fleshy red algae were found on a few occasions on *Porites lutea* in Kavaratti lagoon, causing death of the underlying polyps (Ravindran *et al.,* 1999).

The White Band Disease was found on several massive corals in the reef slope of Kavaratti Island. In this case a white band was present around a necrotic patch on the coral colony. The dead portion was devoid of polyps and appeared white. Older patches were colonized by algae. The BBD was noticed occasionally on *Porites* sp. in Kavaratti atoll. This was characterized by a necrotic patch surrounded by a black line or band (Ravindran *et al.,* 1999). The major faunal groups that caused erosion of calcareous substrate included fishes echinoides, sponges, polycheates, sipunculids, bivalves and cirripeds. The diademid sea urchin *Echinothrix diadema* was the most abundant coralline algae grazing echinoid on the reefs while on the lagoon, the rock boring *Echinometra mathei* was the most common echinoid species (Navas and Mathew, 1995).

The available information on coral reef fishes of India shows that Lakshadweep received considerable attention. Similar attention was not paid to coral reef fishes inhabiting the reef of Andamans and Gulf of Mannar. Gulf of Kachchh received the least ichthyological activity. However intensification of efforts in the Gulf of Kachchh region is not likely to yield good collections due to an almost dead environment (Anand and Pillai, 1995).

6. CORAL REEF ECOSYSTEM OF THE GULF OF MANNAR

The Gulf of Mannar along the Indian coast is situated between Lat. 8° 47’ - 9° 15’ N and Long.78° 12’ - 79° 14’ E. Coral reefs are distributed on the shelfs of 21 islands, lying between Rameswaram and Kanyakumari. The Gulf of Mannar is one of the Marine Biosphere Reserves (GOMMBRE) covering an area of 10,500 sq. km. The Gulf of Mannar is one of the biologically richest and important habitats for sea algae, seagrass, coral reef, pearl banks, sacred chank bed, fin and shell fish resources, mangroves so also endemic and endangered species. Nearly 3,600 species of flora and fauna are represented here. The 21 islands and Gulf of Mannar were declared as Marine National Park in 1986 for the purpose of protecting marine wild life and its environment by Government of India and state of Tamil Nadu (Upreti and Shanmugaraj, 1997). Early studies on corals and coral reefs of this area are available in plenty (Foote, 1888; Brook, 1893; Thurston, 1895, 1897, 1905; Matthai, 1924; Gravely, 1927a,b; Sewell, 1932, 1935). Various islands of the Gulf of Mannar are shown in Fig. 8. The area of the islands is ranging between 0.50 ha (Poovarasanpatti island) and 130 ha (Musal island) (Krishnamurthy, 1987).

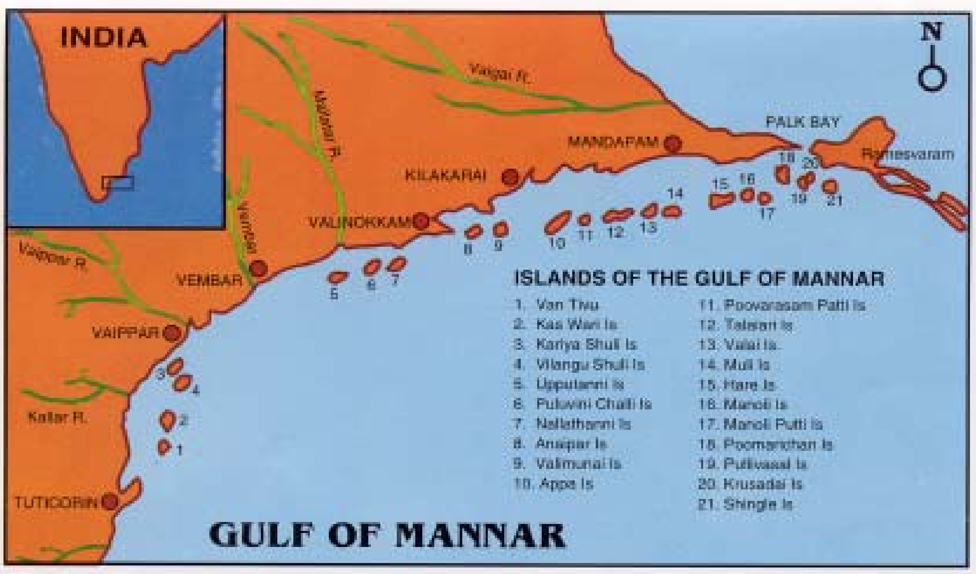

Fig. 8. The islands of the Gulf of Mannar and Palk Bay (adapted from Krishnamurthy, 1987).

For the sake of convenience and towards a better understanding and management of the coral reef ecosystem of the Gulf of Mannar, this Gulf has been divided into 4 regions:

Region 1. This region lies between Pamban and Kilakarai comprising 9 islands viz. Appa island, Talaiari island, Valai island, Mulli island, Musal island, Manoli island, Poomarichan island, Krusadai island and Shingle island. The core zone of this region has Krusadai island, Shingle island, Manoli island and Poomarichan island. The buffer zone comprises four islands viz., Valai island, Mulli island, Appa island and Talaiari island and the immediate sea surrounding them.

Region 2. This region comprises eight islands between Kilakarai and Mukkaiyur viz. Upputhanni island, Puluvinichalli island, Nallathanni island, Anaipar island, Talaiyari island, Valai island, Vallimunai island and Poovarasanpatti island. Core zone of this region comprises three islands, viz. Nallathanni island, Puluvinichalli island and Anaipar island. The buffer zone of this region consists of Vallimunai island and Poovarasanpatti island and the immediate sea surrounding these islands.

Region 3. This region lies between Mukkaiyur and Tuticorin comprising 4 islands viz. Van island, Kasuwar island, Vilanguchalli island and Karaichalli island. The core zone in this region is the pearl banks near and away from Tuticorin whereas the buffer zone comprises Van island, Kasuwar island, Karaichalli island and Vilanguchalli island.

Region 4. This region lies between Tuticorin and Kanyakumari and extends to about 110 kms. The core zone in this region embraces pockets of pearl banks and chank beds and the remaining areas come under the buffer zone (Krishnamurthy, 1991).

Physico-Chemical Parameters

The waters of the Palk Bay and Gulf of Mannar mix freely at the Pamban pass and at Adam's bridge between Dhanushkodi and Sri Lanka. Though northeast and southwest monsoons prevail in this area, the former contributes the major portion of the annual rainfall. The range of annual rainfall varies from 792 to 1270 mm. There is no major freshwater flow into this area. The average monthly atmospheric temperature ranges from 25° to 31°C with the maximum and minimum during May and January respectively. The average temperature of the surface water varies from 25° to 30°C. The surface water temperature of the Gulf of Mannar is slightly higher than that of the Palk Bay (Prasad, 1957). The currents in this area are swift. The sea is rough between April and August and it is calm during September (Krishnamurthy, 1987).

The atmospheric temperature near Hare island (Musal island) ranged from 27 to 32.6°C during the study period. Surface water temperature ranged from 27.6 to 28.4°C. The ranges of surface and bottom water salinity were 32.4 – 32.8 ppt whereas the range of dissolved oxygen in surface and bottom water were 4.5 – 4.6 ppm. The range of pH was 7.6 – 8.4. The ranges of dissolved nutrients phosphate, silicate, nitrate, and nitrite were 1.55 – 4.02 ppm, 61.8 – 266.81 ppm, 14.0 – 21.01 ppm and 0.03 – 0.70 ppm, respectively (Kumaraguru and Jayakumar, 1998).

Heavy metal concentration was reported for different areas of Gulf of Mannar and Palk Bay. The levels of Cd were in the order of Arumuganeri > Tuticorin > Thondi > Mandapam. In contrast, Pb levels were found to be maximum at Kanyakumari and minimum at Arumuganeri, while Hg was found to be maximum at Arumuganeri and minimum at Mandapam. Cd levels were found to decrease towards sea from the coast at Tuticorin. However, no definite trend was observed at Mandapam and Thondi. Unlike Cd, Pb showed seaward increasing trend at Thondi transect. However, no definite trend was evident for other transects as seen in Cd. Bottom waters showed higher concentration of Cd and Pb compared to surface water. Hg did not show any trend in its distribution. Data on sediments showed maximum Cd levels at Arumuganeri (4.33 ppm) while Kanyakumari exhibited the minimum (0.4 ppm). Similarly the levels of Pb were found to be minimum (1.15 ppm) at Kanyakumari. In conclusion, among the transects studied, Arumuganeri appeared to be polluted. Heavy metal concentrations of water and sediment in different places of Gulf of Mannar and Palk Bay are given in Tables 15 & 16 and the textural composition of the sediment of Gulf of Mannar in Table 17 (Palanichamy and Rajendran, 2000).

Table 15. Heavy metal concentration in sea water (ppb).

	Sea water (ppb)							Sediment (ppm)	
Transects	**St.no**	**Cd**		**Pb**		**Hg**		**Cd**	**Pb**
		S	**B**	**S**	**B**	**S**	**B**		
Kanyakumari	1	BDL	-	48.6	-	BDL	-	1.0	3.25
	2	BDL	BDL	86.7	62.8	BDL	BDL	0.4	4.05
	3	BDL	BDL	71.37	52.25	BDL	BDL	0.4	1.15
Arumuganeri	4	1.6	2.5	1.2	1.4	1.76	0.94	4.33	9.45
	5	2.3	2.8	2.1	2.5	2.05	1.96	1.25	4.20
	6	2.2	0.8	0.5	2.5	1.25	1.05	BDL	BDL
Tuticorin	7	0.46	0.7	1.38	1.86	1.63	0.93	2.1	40
	8	0.48	0.44	1.62	2.3	1.21	1.37	3.95	23
	9	0.38	0.34	0.56	2.54	1.63	1.29	BDL	BDL
Mandapam	10	0.42	0.64	12.45	13.15	0.32	0.13	3.6	13.6
	11	0.36	BDL	18.18	10.68	0.28	0.69	2.3	24
	12	0.6	0.8	1.4	2.8	BDL	0.93	1.15	36
Thondi	13	0.7	0.14	1.28	3.0	0.48	0.70	2.9	15.85
	14	0.1	0.24	1.65	2.4	0.10	0.28	1.55	20.1
	15	0.68	0.68	2.64	3.94	0.21	0.19	2.0	8.85

S - Surface, B - Bottom, BDL - Below Detection Limit

Source: Palanichamy and Rajendran (2000)

Table 16. Heavy metal concentration in sediment (ppm).

Transect	St. no.	Cd	Pb
Kanyakumari	1.	1.0	3.25
	2.	0.4	4.05
	3.	0.4	1.15
Arumuganeri	4.	4.33	9.45
	5.	1.25	4.20
	6.	BDL	BDL
Tuticorin	7.	2.1	40
	8.	3.95	23
	9.	BDL	BDL
Mandapam	10.	3.6	13.6
	11.	2.3	24
	12.	1.15	36
Thondi	13.	2.9	15.85
	14.	1.55	20.1
	15.	2.0	8.85

BDL = Below Detection Limit

Source: Palanichamy and Rajendran (2000)

Table 17. Percentage of soil texture in the Gulf of Mannar.

SI.No.	Depth (m)	Granule (> 2mm)	Very coarse sand (> 1 mm)	Coarse sand (> 0.5 mm)	Medium sand (> 0.25 mm)	Fine sand (> 0.12 mm)	Very fine sand (> .06mm)	Silt & clay (< 0.06 mm)
1	2	0.75	1.15	3.25	24.25	28.75	40.80	1.05
2	20	1.15	2.27	3.64	26.25	30.15	35.81	0.73
3	35	2.58	4.21	6.24	36.05	29.67	21.25	Nil
4	1.5	0.64	0.82	2.48	6.24	64.50	24.82	0.50
5	8	1.25	3.64	61.25	31.36	2.5	Nil	Nil
6	11	2.42	3.85	56.45	36.75	0.53	Nil	Nil
7	3	1.23	2.05	8.42	17.29	30.06	25.45	15.5
8	7	1.19	1.92	6.62	23.41	40.50	20.28	6.05
9	10	3.05	7.35	26.45	41.64	21.39	0.12	Nil
10	5	0.15	0.525	0.85	6.125	28.15	59.17	5.03
11	7	0.45	1.17	3.45	6.25	32.45	52.78	3.45
12	8	0.25	0.77	1.75	5.56	31.86	54.82	4.99

Source: Palanichamy and Rajendran (2000)

The distribution of trace metals (Fe, Mn, Zn and Cu) in the reef sediments and seagrass sediments of islands Manoli and Hare in the Gulf of Mannar region was studied. The metal concentrations were in the following order: Fe > Mn > Zn > Cu (Kumaresan *et al.,* 1998).

The sandy coral bed areas were found to have greater percentage of coral stones and shell fragments and very low silt and clay fractions. About 0.5 to 40% by dry weight of the sediments were made up of Ca derived from the coral and molluscan organisms, due to weathering processes. The coral reef sediments recorded low salinity and higher pH compared to seagrass bed and adjacent areas (Fig. 9). Total organic carbon (TOC) content (1.38 to 9.11 mg/g) of the reef sediments was low compared to the seagrass bed and adjacent areas. Higher concentrations of total nitrogen and total phosphorus were found in the coral reef zone and seagrass bed suggesting that these areas may be viewed as sinks for nutrients, whereas the adjacent areas act as reservoir for nutrients (Fig. 10). The seagrass and reef associated organisms play an important role in the recycling of nutrients in these environments. The seagrass bed sediments recorded higher Na and K concentrations than the coral reef zone and adjacent areas (Table 18 & Fig.11) and it could be due to the utilization and trapping of these ions by seagrass and associated organisms (Vinithkumar *et al.,* 1999).

Based on heavy mineral distribution, the southern coast of Tamil Nadu has been divided into five blocks namely Mandapam, Valinokkam, Tuticorin, Manappad and Kanyakumari blocks. The heavy mineral concentration by wt% varied from 2 to 87%. Zircon, colourless garnet, pink garnet, chlorite and biotite were the predominant minerals. The abundance of these minerals varied in each block. Chlorite, sillimanite, mica, few hornblendes and kyanite are characteristic of Mandapam block while biotite and glaucophane of Valinokkam block, euhedral zircon, hypersthene, tourmaline of Tuticorin block, broken zircon, andalusite and topaz of Manappad block and rounded zircon, rutile and monazite of Kanyakumari block. Chlorite, mica and other flaky minerals were dominant in Mandapam and Manappad blocks, whereas in Kanyakumari and Valinokkam block, minerals like zircon, garnet and other denser heavy minerals were abundant. Granular minerals like zircon and garnet, were presumed to have been derived from the recycled sediments (Angusamy and Victor Rajamanickam, 2000).

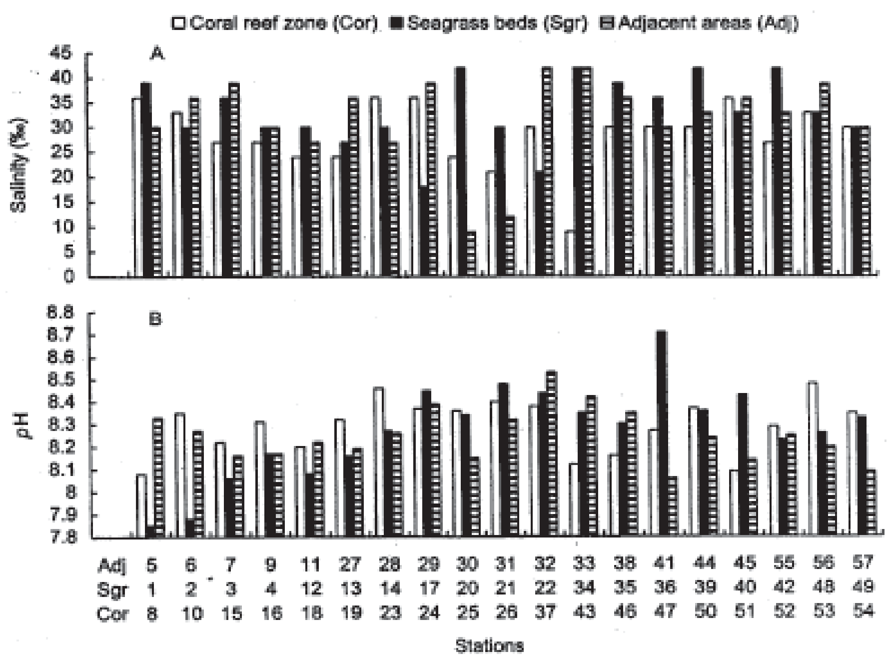

Fig. 9. Distribution of salinity (A) and pH (B) (adapted from Vinithkumar *et al.*, 1999).

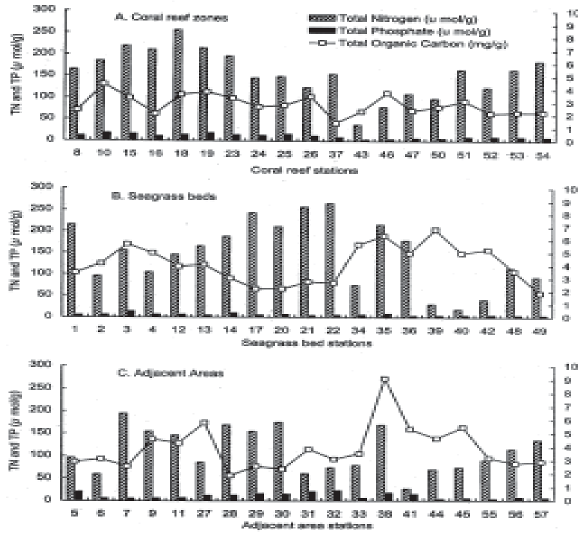

Fig. 10. Distribution of total organic carbon (mg/g), total nitrogen (µmol/g) and total phosphorus (µmol/g) in coral reef zone (A), seagrass beds (B) and adjacent area (C) (adapted from Vinithkumar *et al.,* 1999).

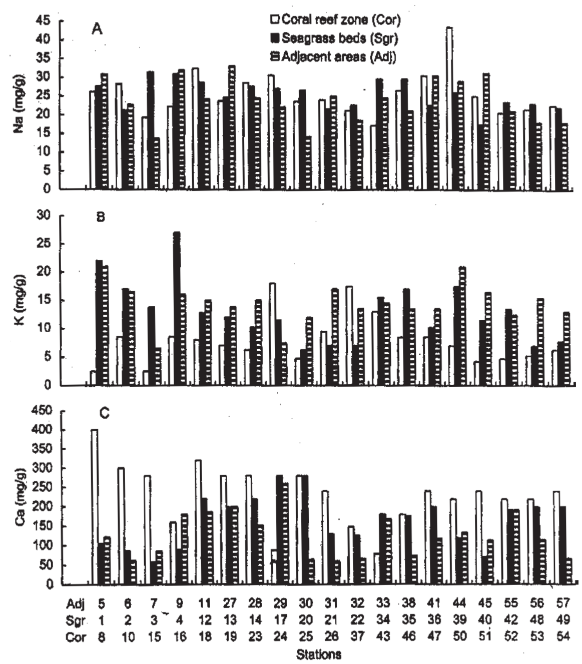

Fig. 11. Distribution of major ions Na (A), K (B) and Ca (C) concentrations (mg/g) (adapted from Vinithkumar *et al.,* 1999).

Table 18. Textural composition, minimum and maximum values observed in sedimentological parameters of coral reefs.

Sl.No.	Parameters	Coral reef zone
1	Textural composition (%) (Mean values) a) Stones and gravel (> 2 mm) b) Sand (0.025mm) c) Coarse silt (> 0.31mm) d) Medium, fine silt and Clay (< 0.031mm)	5.69±4.33 90.6±40.29 2.40±3.17 0.41±0.69
2	Depth (m)	0.25-3.0
3	Salinity(‰)	9-36 (28.58±6.58)
4	pH	8.08-8.48 8.29±0.12
5	Total organic carbon (TOC) Mg/g	1.38-4.35 (2.82±0.76)
6	Total nitrogen (TN) (µ mol/g)	38.56-256.3 (157.5±53.41)
7	Total phosphorus (TP) (µ mol/g)	3.66-18.68 (11.48±4.33)
8	C:N ratio	0.14-0.95:1 (0.34:1±0.20:1)
9	C:P ratio	1.59:1-7.94:1 (3:1±1.66:1)
10	N:P ratio	6.1-13.1 (9:1±2:1)
11	Sodium (Na) (mg/g)	17.25-43.75 (25.79±5.98)
12	Pottasium (K) (mg/g)	2.5-18 (7.92±4.28)
13	Calcium (Ca) (mg/g)	78-400 (232.32±78.13

Source: Vinithkumar *et al.* (1999)

The principal heavy minerals, of beach placers were zircon (1.74-33.78%), colourless garnet (10.61-37%), pink garnet (10.40-41.17%), chlorite (0.47-39.96%), and biotite (0.19 %-14.62%). In Mandapam block, the heavy mineral assemblage was found predominantly represented by colourless garnet (27.24%), chlorite (17.91%), and pink garnet (14.26%). Chlorite, biotite, garnet and hypersthene showed strong etching. The heavy mineral assemblage in Valinokkam block was similar to that of Mandapam block with relatively higher zircon content especially in Vembar (37%) zone. The absence of flaky minerals like chlorite, biotite and muscovite was very much evident in this block. In Tuticorin block, the Vaippar, Sippikulam and Kallar stations were marked by the abundance of garnet, zircon (rounded 11% to 28%), rutile, tourmaline and topaz. The zircon content varied from 2% (Vellar) to 7% (Kallar) of the total 40-55% heavy mineral assemblage. But at Tuticorin and Kayalpattinam stations, the rounded zircons were reduced by 5% with a subsequent upshot in chlorites (20.22% -36.06%). Prismatic, elliptical and elongated forms of pink tourmaline were found in this block. Colourless garnet with a characteristic dodecahedral cleavage, pink garnet and flaky minerals were preponderant with more topaz at Tiruchendur, Alantalai and Manappad stations in the Manappad block (Figs. 12 & 13) (Angusamy and Victor Rajamanickam, 2000).

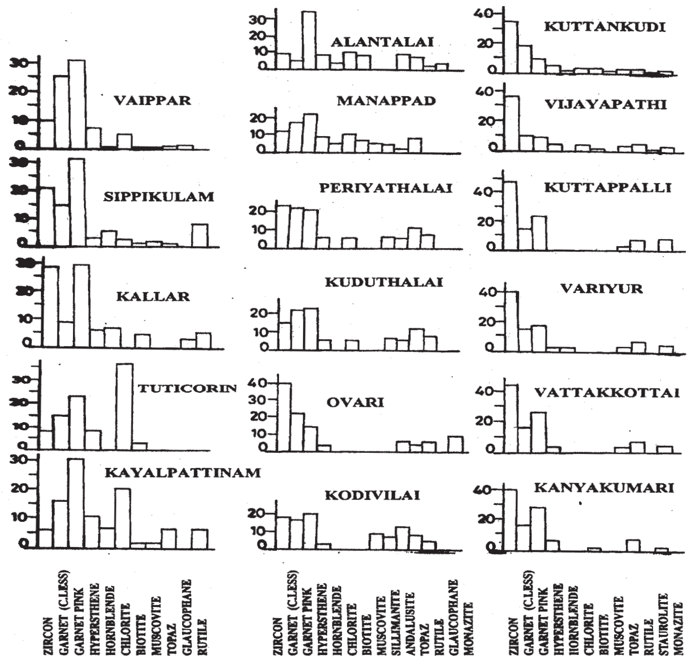

Fig. 12. Distribution of heavy minerals in different stations of Tuticorin, Manapad and Kanyakumari blocks (adapted from Angusamy and Victor Rajamanickam, 2000).

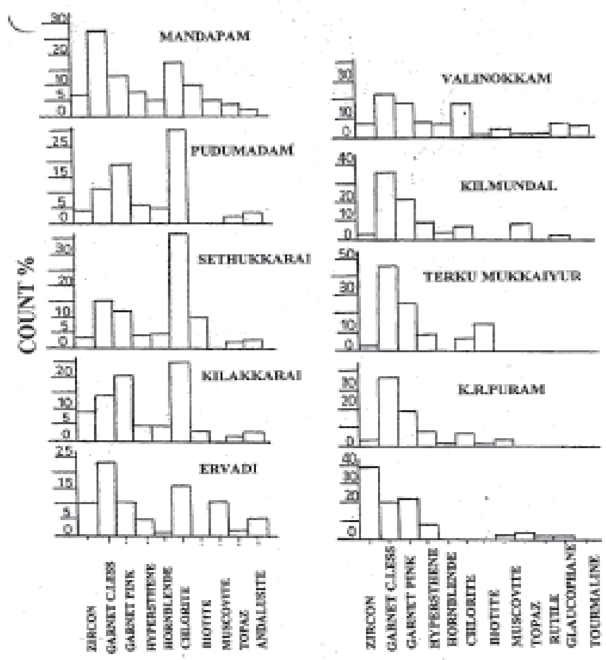

Fig. 13. Distribution of heavy minerals in different stations of Mandapam and Valinokkam blocks (adapted from Angusamy and Victor Rajamanickam, 2000).

Distribution of Corals

The reefs of this area are fringing or patchy types, thriving in very shallow waters encircling few islands. Most of the reef framework is composed of dead and semifossilised *Porites* sp. The shallow waters are muddy and at present the reef seems to be in a state of deterioration. Ninety four scleractinian coral species under 37 genera were recorded in the Gulf of Mannar and Palk Bay (Gopinadha Pillai, 1971, 1973). In the Gulf of Mannar, southern side of the island is covered with dense corals which are more diversified than the northern side. This may be due to the physical processess working upon the reef flat. The steep southern side slopes have free circulation with open oceanic water, but the northern side of the islands has poor circulation of water. Of the 18 species of stony corals recorded from Tuticorin, *Acropora formosa*, *Porites compressa*, *P. somaliensis*, *Favia valenciennesi* and *Tubipora* sp. alone contribute 82% (Santhanam and Venkataramanujam, 1996).

Montipora and *Acropora* put together constitute 39% of the total species recorded and species belonging to *Poritidae* and *Faviidae* constitute the dominant reef builders here (Gopinadha Pillai, 1971). There is scope for sustained income through the exploitation of natural resources in any ecosystem. In order to fulfil our requirements, it is essential that attention shoud be focused on any particular ecosystem with a view of its utilization for a longer time without destroying it. Looking at the Palk Bay and Gulf of Mannar coral reef ecosystem, one can understand the ruthless destruction of that habitat by human activity (Patterson Edward and Ayyakkannu, 1996).

Bleached coral constituted of 89% of the coral cover and bleaching related mortality was 23% in Gulf of Mannar. The shallow reefs of the Gulf of Mannar had 33.6% coral cover, and a large proportion of old dead and turfed coral (32%). *Montipora,* tabular *Acropora* and *Porites* were the most dominant of the 12 genera recorded in Mannar reefs. Nearly 90% of the coral cover in the Gulf of Mannar showed signs of bleaching stress. Between 30% and 40% of the coral cover in these reefs was severely bleached, and more than 20% dead in both reef areas because of bleaching related stress (Rohan Arthur, 2000).

Coral *Acropora* sp. collected from the relict coral reef at 125 m depth off Karaikal, Bay of Bengal yielded a radiocarbon age of 18390 ± 220 yr BP. The depth of occurrence of relict coral reef and its age attest to the lowest sea-level position of the Last Glacial Maximum (LGM). It is inferred that in the eastern continental shelf of India, the sea-level rose at the rate of 4.61 m/kyr, since the LGM about 11,000 yr BP (Vaz, 2000).

Biodiversity and Productivity

Monthly mean productivity in the Gulf of Mannar was 74.460 gC/m^3 (surface and bottom samples). There were two peaks of primary productivity, one in April – May and another in October. In the offshore waters of Tuticorin where the photosynthetic zone extends upto 40 m, the productivity was $5gC/m^3$/day. Monthly average of the standing crop of phytoplankton in terms of plant pigment units (Harvey Units) ranged from 9,000 H U/m^3 (October) to 58,000 H U/m^3 (April) (Raghu Prasad and Ramachandran Nair, 1963). Primary productivity of coral reefs in Manauli (Manoli) island, was estimated by the diurnal changes of oxygen in the sea water flowing over the reefs. Manauli reefs are autotrophic with annual net production of 2500 gC/m^2 (Gopinadha Pillai and Ramachandran Nair, 1969).

The hermatypic corals are harbouring boring filamentous algae in their skeleton as well as symbiotic zooxanthellae in their soft tissue. These imprisoned algae produce much more quantity of oxygen by photosynthesis than the respiratory needs of the coral. The ratio of production to consumption varied from 1.97 to 3.58 mg/hr. The lowest production to consumption ratio was 1.97 mg/hr, shown by *Goniastrea pectinata* and the highest ratio by *Porites solida* (3.58 mg/hr). *Acropora* sp., *Pocillopora* sp. and *Goniopora* sp. also showed higher ratios of production as well as consumption indicating their high metabolic rates. The boring filamentous algae on a coral colony are also contributing to the total production, but their share may vary in different species (Gopinadha Pillai and Ramachandran Nair, 1969).

Totally 37 strains from the three biota were isolated with predominance of *Bacillus* spp. followed by *Pseudomonas* spp., *Spirillium* spp., and *Vibrio* spp. Based on the fatty acid profile, a few of the strains were identified as *Pseudomonas mesophilico*, *P. caryophylli* and *Bacillus cereus*. Of the three biota studied, the coral reef harbours higher percentage of magnetotactic bacteria followed by the mangroves and estuaries (Kannapiran *et al*., 1999).

A total number of 35 species of heterotrophic bacteria (THB) belonging to 11 genera were identified. They included 22 species of ammonifying bacteria, 16 species of nitrate-reducing bacteria, 2 species of free living N_2- fixing bacteria (*Azotobactor*), 24 species of phosphate-solubilizing bacteria and 26 species of phosphatase-producing bacteria (Table 19). Among the 35 species of THB tested, 16 species showed proteolytic activity, 10 species displayed lipolytic activity and 9 species exhibited amylolytic activity (Table 20) (Kannan *et al.,* 1998).

Population density of all the groups of heterotrophic bacteria showed spatio-temporal changes according to the prevailing environmental conditions. The THB population in water varied from 0.88 to 105 x 10^4 CFU ml^{-1} and from 0.55 to 91 x 10^4 CFU ml^{-1} respectively at Manoli and Hare Islands. In sediments, it ranged from 7.1 to 98.2 x 10^6 CFU g^{-1} and between 98.2 and 93.5 x 10^6 CFU g^{-1} respectively at Manoli and Hare Islands. The density in sediments was higher than that of the water. The population density was still higher in the dead coral sediments at both the stations (124.5 to 165 x 10^6 CFU g^{-1} at Manoli and 15 to 110.5 x 10^6 CFU g^{-1} at Hare island (Table 21)).

Forty nine species of diatoms out of 51 species of phytoplankton were observed to be common in the plankton samples of the Gulf of Mannar and Palk Bay. The data suggested that the Palk Bay is having a larger stock of autochthonous diatoms which are mostly neritic, whereas the Gulf of Mannar has more oceanic diatoms (Raghu Prasad and Ramachandran Nair, 1960).

Table 19. List of different groups of bacteria identified from water, sediments and dead corals sediments of Manoli and Hare islands.

Species	Am B	NiR B	NiF B	PSB	PPB
Arthrobacter aurescens	+	+	-	+	-
A. histidinolovorans	+	-	-	+	-
A. ilicis	-	+	-	+	+
A. ramosus	+	+	-	-	+
A. viscosus	+	-	-	-	+
Azotobacter chrococcum	-	-	+	-	-
A. vinelandii	-	-	+	-	-
Bacillus campestris	+	+	-	-	-
B. cereus	+	+	-	+	+
B. circulans	-	-	-	+	+
B. filicolonicus	+	+	-	+	+
B. frendenreichi	+	+	-	+	+
B. globisporus	-	-	-	+	-
B. laterosporus	+	+	-	+	-
B. megaterium	-	-	-	+	+
B. pantothenticus	+	-	-	-	+
B. polymyxa	+	-	-	-	+
B. sphaericus	-	+	-	+	+
Brevibacterium acetylicum	+	-	-	+	+
Flavobacterium aquatile	+	+	-	+	+
Flavomonas oryzhabitans	-	-	-	+	+
Kurthia gibsonii	-	-	-	-	-
Micrococcus luteus	+	-	-	+	+
M. agilis	-	+	-	+	+
M. brochothrixcampestris	+	-	-	-	+
M. varians	+	-	-	-	+
Pseudomonas mendocina	+	+	-	+	+
P. caryophylli	+	+	-	+	+
P. mesophilica	-	+	-	+	+
P. pseudoalcaligenes	+	-	-	+	+
P. stutzeri	-	+	-	+	+
Sporosarcina urea	-	-	-	-	-
Vibrio furnissi	+	+	-	+	+
V. alginolyticus	+	-	-	-	+
V. parahaemolyticus	+	-	-	+	+

Source: Kannan *et al.* (1998)

Table 20. Physiological grouping of total heterotrophic bacteria isolated from water, sediments and dead corals of Manoli and Hare islands.

Species	Proteolytic	Lypolytic	Amylolytic
Arthrobacter aurescens	-	+	-
A. histidinolovorans	-	-	+
A. ilicis	+	-	-
A. ramosus	-	+	-
A. viscosus	+	+	-
Azotobacter chrococcum	-	-	-
A. vinelandii	-	-	-
Bacillus campestris	-	-	+
B. cereus	+	+	-
B. circulans	+	-	+
B. filicolonicus	+	+	+
B. frendenreichi	-	-	-
B. globisporus	-	-	-
B. lateroporus	+	-	-
B. megaterium	+	+	-
B. pantothenticus	-	-	-
B. polymyxa	+	-	-
B. sphaericus	+	+	-
Breevibacterium acetylicum	+	-	-
Flavobacterium aquatile	-	-	+
Flavomonas oryzhabitans	+	-	-
Kurthia gibsonii	-	-	+
Micrococcus luteus	+	-	-
M. agilis	-	+	-
M. brochothrixcampestris	-	-	-
M. varians	-	-	-
Pseudomonas mendocina	+	-	-
P. caryophylli	+	-	-
P. mesophilica	-	+	-
P. pseudoalcaligenes	-	-	+
P. stutzeri	-	+	-
Sporosarcina urea	-	-	+
Vibrio furnissi	+	-	-
V. alginolyticus	+	-	+
V. parahaemolyticus	-	-	-

Source: Kannan *et al.* (1998)

Table 21. Density of different groups of bacteria in water, sediments and dead coral sediments collected from Manoli and Hare islands.

Group	Sample	Manoli island		Hare island	
		Minimum	Maximum	Minimum	Maximum
THB	Water (CFUml^{-1})	8.885	105 X 10^4	0.55	91 X 10^4
	Sediment (CFUg^{-1})	7.1	98.2 X 10^6	1.6	93.5 X 10^6
	DCS(CFUg^{-1})	124.5	165 X 10^6	15	110.5 X 10^6
	Water (MPNl^{-1})	39	15,000 X 10^6	75	15,000 X 10^6
Amonifiers	Sediment (MPNg^{-1})	4	930 X 10^6	11	1,500 X 10^6
	DCS(MPNg^{-1})	7	11,000 X 10^6	42	11,000 X 10^6
Nitrate	Water (CFUml^{-1})	140	46,000 X 10^5	150	15,000 X 10^5
Reducers	Sediment (MPNg^{-1})	15	2,400 X 10^5	14	2,400 X 10^5
	DCS(MPNg^{-1})	20	11,000 X 10^5	93	4,600 X 10^5
Azotobactors	Water (CFUml^{-1})	2100	13,000 X 10^4	1200	12,700 X 10^4
	Sediment (CFUg^{-1})	2.1	19.4 X 10^4	2.5	17.9 X 10^4
	DCS(CFUg^{-1})	1.1	18.4 X 10^4	4.7	18 X 10^4
IPSB	Water (CFUml^{-1})	2.25	24 X 10^4	1.03	21.4 X 10^4
	Sediment (CFUg^{-1})	1.1	31.5 X 10^6	5	23 X 10^6
	DCS(CFUg^{-1})	3.35	105.5 X 10^6	4.5	98.5 X 10^6
PPB	Water (CFUml^{-1})	2.2	15 X 10^4	1.4	17 X 10^4
	Sediment (CFUg^{-1})	6	53.6 X 10^6	4	43.4 X 10^6
	DCS(CFUg^{-1})	14	51.7 X 10^6	12.5	47.6 X 10^6

Source: Kannan *et al.* (1998)

A total of 126 species of phytoplankton were recorded (Table 22) in which diatoms constituted the major components. Species composition of diatoms showed the following trend with respect to contribution of species by various genera: *Coscinodiscus, Pleurosigma* and *Rhizosolenia* (8 species each), *Navicula* (7 species), *Triceratium* (5 species), *Bacteriastrum* (4 species), *Amphora, Fragilania, Gyrosigma, Nitzschia, Synedra* and *Thalassiothrix* (3 species each) and *Biddulphia, Cyclotella, Melosira, Odontella, Skeletonema, Thalassiosira* and *Thalassionema* (2 species each). All the other genera were represented by one species each. Dinoflagellates with 16 species constituted the second largest group. Among them, the genus *Ceratium* was represented by 6 species followed by *Protoperidium* (4 species), *Dinophysis* (3 species) and all the others by one species each. Though the blue-greens formed the third dominant group, they were represented by only 7 species (Kannan *et al.,* 1998).

Phytoplankton population density varied from 34,000 to 86,000 cells 1^{-1} at both the Manoli and Hare islands. The minimum (34,000 cells 1^{-1}) and maximum (86,000 cells 1^{-1}) were recorded at Manoli during the monsoon season (October 1995) and postmonsoon season (February 1995) respectively. Species diversity varied from 3.64 to 5.95 and both the minimum and maximum values were recorded at Manoli during the summer season. Dominant index also showed variations during different months of study (4.5 to 18.7) with different dominant species ranging from diatoms to dinoflagellates (Table 23). Chlorophyll 'a' concentration ranged between 0.18 and 0.59 mg m^{-1}. Gross primary productivity ranged from 0.30 to 1.21 mg C^{-3} hr^{-1} and net primary productivity varied from 0.2 to 0.79g C^{-3} hr^{-1} at both Manoli and Hare islands (Table 23). A close similarity in fluctuation curves and direct relationship were observed between population density, chlorophyll 'a' concentration and primary productivity (Kannan *et al*., 1998).

The mean density of zooplankton in the Gulf of Mannar was 71 ind./1. The copepods, nauplii and tintinnids generally formed the bulk of the zooplankton standing crop with a mean value of 23.4%, 24.8% and 28.0% respectively. Gastropod larvae, polychaetes etc. were found to occur commonly but not in large numbers (Raghu Prasad and Ramachandran Nair, 1963).

The total plankton volume reached the peak during monsoon in Palk Bay and Mandapam, and high volume was recorded during summer at Kudankulum. The volume declined during postmonsoon at Palk Bay and Mandapam and during monsoon at Kudankulam. The meroplanktonic forms of this study included the nauplius, protozoea, mysis and post-larvae of *Penaeus semisulcatus, P. indicus, P. monodon, P. merguiensis, Metapenaeus monoceros, M. dobsoni* and *M. affinis*; zoea and megalopa of crab *Scylla serrata* and *Portunus pelagicus*; veliger larvae of gastropods and bivalves and fish larvae. The species diversity index of the meroplankton was high during premonsoon at Palk Bay (September) and Kudankulam (July) and during summer (May) in Mandapam. The highest species diversity was encountered in Mandapam followed by Kudankulam and Palk Bay (2.18 > 2.1 > 1.9) indicating the high fertility and optimal environmental conditions of Gulf of Mannar. It was also underscored by high species evenness at Mandapam followed by Kudankulum and Palk Bay (1.5 > 1.4 > 1.3). The influence of west coast current, and conglomeration of open ocean species caused the maximum of species richness at Kudankulum followed by Mandapam and Palk Bay (3.26 > 3.13 > 3.0). Dominance index (79.3 > 74.6 > 71.6) was found maximum at Mandapam followed by Palk Bay and Kudankulum (Fig. 14) denoting protective nature of coral beds for these young ones at Gulf of Mannar and Palk Bay (Table 24) (Krishnamoorthy and Subramanian, 1999).

Meroplankton productivity and the fish landing were recorded from Mandapam and Kudankulum along the east coast of India. Meroplankton such as nauplius, protozoea and mysis of shrimps; zoea and megalopa of crabs; veliger larvae of molluscs; fish larvae and eggs were segregated and quantified from the zooplankton sampled. The meroplankton production was compared with fishery potential and found that both meroplankton production and fishery potential go hand in hand during most months of the study period. It revealed that these locales are the ideal breeding sites for such fishes and shell fishes (Tables 25 & 26) (Krishnamoorthy *et al.,* 1999).

Except the genera *Merismopedia* and *Oscillatoria,* all the others were represented by one species each. Green algae were less in number (3 species in three genera). The other species recorded were *Coccolithus* sp., *Ceramium* sp. and *Rhabdosphaera* sp. as compared to 126 species of phytoplankton recorded during the study period from the Gulf of Mannar Islands (Kannan *et al.,* 1998).

The area covered from Athankarai to Rameswaram (45 km coastline) in the Palk Bay and from Mandapam to Welamidalam (413 km coastline) including 21 islands of the Gulf of Mannar showed higher density of algal distribution. Standing crop of the macroalgae from the total area of 17,125 ha (above said area) was 22,044 tonnes (wet weight), consisting of 1,709 tonnes of agarophytes, 10,266 tonnes of alginophytes and 10,069 tonnes of other seaweeds. The commercially important species *viz. Gelidiella acerosa* contributed 74 tonnes; *Gracilaria* sp., 974 tonnes; *Hypnea* sp., 798 tonnes; *Sargassum* sp. 9,381 tonnes and *Turbinaria* sp., 714 tonnes (Kalimuthu *et al.,* 1990).

Table 22. Checklist of phytoplankton collected from Manoli and Hare islands of the Gulf of Mannar Biosphere Reserve.

	Manoli	Hare Island
Bacillariophyceae	+	+
Amphora coffeaeformis (Ag.) Kutz	+	+
A. ostrearia Breb.	+	+
A. ovalis (Kutz) Kutz	+	+
Amphiprora palaudosa W.Sm.	+	+
Asterionella glacialis Cast.	+	+
Bacillaria paradoxa Gmel.	+	+
Bacteriastrum comosum Pavill.	+	+
B. delicatulum C1.	+	+
B. hyalium Lauder	+	+
B. varians Lauder	+	+
B. heteroceros Grun.	+	+
B. pulchella Gray.	+	-
Chaetoceros affinits Lauder	+	+
C. coarctatus Lauder	+	+
C. didymus Ehr.	+	+
C. diversus C1.	+	+
C. dichaeta Ehr.	+	+
C. aciniosus Schutt non Gran	-	+
C. lauderi Ralfs	+	+
C. indicus Karsten	+	+
C. socialis Lauder	+	+
C. orientalis Schiller	+	+
Cocconeis littoralis R. Subrahm	+	+
Corethron hysterics Hens	+	+
Coscinodiscus centralize Ehr.	+	+
C. curvatulus Grun.	+	+
C. gigas Ehr.	+	+
C. granii Karste	+	+
C. jonesianus (Grer.) Ostenj	+	+
C. lineatus Ehr.	+	+
C. marginatus Her.	+	+
C. radiatus Ehr.	+	+
Cyclotella kuetzinglana Thw.	+	+
C. stelligera (C1. And Grun.) V.H.	+	+
Cymbella turgida Greg. non Hass.	+	+
Diatoma vulgare Bory	+	+
Diploneis interrupta (Kutz.) C1.	+	+
Dictyoneis marginata (Lewis) C1.	+	+
D. robustus Subrahm. non (C1.)	+	+
Ditulum brightwellii (West) Grun	+	+
Fragilaria intermedia (Grun.) Grun.	-	+
F. oceanica C1.	+	+
F. pinnata Ehr.	+	+
Gyrosigma balticum (Ehr.) Robenh.	+	+
G. scalproides (Rabenh.) C1.	+	+
G. variipunctatum Hagelst	+	+

Hemidiscus hardmannianus (Grev.) Mann.	+	-
Leptocylindrus danicus C1.	+	+
Melosira granulata (Ehr.) Ralfs	+	+
Melosira minuta Greville	+	+
Navicula cuspidata (Kutz.) Kutz.	+	+
N. clavata Greg.	+	+
N. gastrum (Ehr.) Kutz.	+	+
N. granulata (Ehr.) Ralfs	+	+
N. hennedyii W. Sm.	+	+
N. longa (Greg.) Ralfs	+	+
N. lyra Ehr.	+	+
Nitzschia closterium (Ehr.) Sm.	+	+
N. filiformis (W. Sm) Schutt	+	+
N. longissima (Breb) Ralfs	+	+
Odontella mobiliensis (Bail.) Grun.	+	+
O. sinensis (Grev.) Grun.	+	+
Planktoniella sol (Wallich) Schutt.	+	+
Pleurosigma aestuarii Breb. W. Sm.	+	+
P. angulatum (Kutz.) W. Sm.	-	+
P. directum Grun.	+	+
P. elongatum W. Sm.	+	+
P. normanii Ralfs	+	+
P. intermedium W. Sm	+	+
P. sulcatum (Grun)	+	-
Rhaphoneis discoides Subrahm. R.	+	+
Rhizosolenia alata Btw.	+	-
R. castracanei Perag. H.	+	+
R. cylindrus Cleve	+	+
R. hebetata (Bait.) Gran	+	+
R. imbricata Btw.	+	+
R. robusta Norman	+	+
R. setigera Btw.	+	+
R. styliformis Btw.	+	+
Skeletonema costatum (Grev.) C1.	+	+
Skeletonema sp.	+	+
Synedra acus Kutz.	+	+
S. ormosa Hant.	-	+
S. alna (Kutz.) Ehr.	+	+
Thalassiosira eccentrica (Ehr.) C1.	+	+
T. subtilis (Ostenf.) Gran	+	+
Thalassionema lineatum Jouse.	-	+
T. nitzschioides Grun.	+	+
Thalassiothrix elongata Grun.	+	+
T. frauenfeldii Grun. non C1	+	-
T. longissima C1. and Grun.	+	+
Triceratium dubium Btw.	+	+
T. bergonii Temp. and Brun.	+	+
T. reticulum Ehr.	+	+
T. favus Ehr.	+	+
T. roperianum Grev.	+	+

Dinophyceae	+	+
Ceratium breve (Ost. and Schm). Sch	+	+
C. condelobrum (Her.) Stein	+	+
C. fusus (Ehr.) Duj.	+	+
C. furca (Ehr.) Clap. Lachm.	+	+
C. gibberum Gouret	+	+
C. linrsyum (Her.) Cleve	+	+
Dinophysis acuta Her	-	+
D. caudata Saville-Kent	+	+
D. hastata Stein	+	+
Ornithocercus magnificus Stein	+	+
Peridinium bipes Stein	-	+
Protoperidinium brochii (Kofoid and Swegs)	+	+
P. conicum (Gran.) Balech	+	+
P. divergens (Ehr.) Balech	+	+
P. oblongum (Aur.) Par. and Dod.	+	+
Oblea rotundata (Lebn. Balech)	+	+
Cyanophyceae		
Calothrix sp.	+	+
Merismopedia elegans Smilth A. Br.	+	-
M. glauca (Ehr.) Nag.	+	+
Oscillatoria lamosa Ag. Ex Gomont	+	+
O. martinii	+	+
Phormidium fragile (Menegh)	+	+
Trichodesmium erythraeum Ehr.	+	+
Chlorophyceae		
Desmidium swartzii Kutz.	+	-
Protococcus vulgaris Lemm.	+	+
Tetrasrum sp.	+	+
Others		
Coccolithus sp.	+	+
Ceramium sp.	+	+
Rhabdosphaera sp.	+	+

+ denotes presence of species

- denotes absence of species

Source: Kannan *et al.* (1998)

Table 23. Phytoplankton characteristics recorded from Manoli and Hare islands during June 1994 to May 1996.

	Manoli island		Hare island	
Characteristics	Minimum	Maximum	Minimum	Maximum
Population Density	34,000	86,000	39,000	83,000
(Cells l^{-1})	(Oct. 1995)	(Feb. 1995)	(May 1996)	(Sep. 1994)
Species diversity (H')	3.64	5.95	3.74	5.79
	(April 1995)	(May 1995)	(July 1994)	(Dec. 1994)
Chlorophyll 'a'	0.23	0.58	0.18	0.59
Concentration (mg m^{-3})	(Sep. 1995)	(Feb. 1995)	(Jan. 1995)	(Feb. 1995)
Gross primary production	0.0	1.12	0.50	1.21
(g C m^{-3} hr^{-1}) -	(Apr. 1995)	(Jan. 1996)	(Nov. 1995)	(Jan. 1996)
Net primary production	0.20	0.79	0.22	0.75
(g C m^{-3} hr^{-1}) -	(July, Mar. 1995)	(Jan. 1996)	Mar. 1995)	(Jan. 1996)

Source: Kannan *et al*. (1998)

Table 24. Mean seasonal planktonic biomass in different study stations.

Seasons	Palk Bay		Mandapam		Kudankulam	
	Total plankton ml/m^3	No. of Meroplankton	Total plankton ml/m^3	No. of Meroplankton	Total plankton ml/m^3	No. of Meroplankton
Monsoon (Oct. Dec)	22.5	37550	21.0	35900	11.1	26200
Postmonsoon (Jan-Mar)	1.3	26700	13.0	23800	15.5	25000
Summer (Apr. - Jun.)	16.0	24200	15.0	23000	19.0	33500
Premonsoon (Jul. - Sep.)	21.0	21600	18.5	22100	15.1	25700

Source: Krishnamoorthy and Subramanian (1999)

Table 25. Fluctuation in total zooplankton biomass by volume during different seasons of the study period 1993 to 1995.

	Plankton volume (ml/m^3)			
Seasons 1993-1995	Mandapam Maximum	Mandapam Minimum	Kudankulam Maximum	Kudankulam Minimum
Monsoon (Oct. - Dec.)	20.0	25.0	13.0	17.0
Postmonsoon (Jan. - Mar.)	11.0	15.0	15.0	17.0
Summer (Apr. - Jun.)	14.0	18.0	17.0	20.0
Premonsoon (Jul. - Aug.)	17.0	21.0	15.0	19.0
Monsoon (Oct. - Dec.)	18.0	22.0	11.0	17.0
Postmonsoon (Jan. - Mar.)	13.0	16.0	14.0	17.0
Summer (Apr. - Jun.)	11.0	16.0	18.0	19.0
Premonsoon (Jul. - Aug.)	19.0	23.0	14.0	16.0

Source: Krishnamoorthy *et al.* (1999)

Table 26. Percentage and numerical contribution of different meroplanktonic components.

		Percentage among meroplankton		Number of individuals no/m³	
Larval forms	Years	St 1	St 2	St 1	St 2
Nauplius	I	8.8	9.8	3300	3000
	II	7.6	9.9	3500	3250
Protozoea	I	7.0	9.2	2600	2800
	II	6.3	7.6	2900	2500
Mysis	I	5.3	5.9	2000	1800
	II	3.6	4.9	1700	1600
Zoea and Megalopa	I	0.4	0.4	160	150
	II	0.3	0.4	145	150
Eggs and fish larvae	I	0.1	0.04	50	15
	II	0.05	0.1	25	35
Veliger	I	46.5	51.4	21400	16750
	II	35.4	25.4	16300	8300

I - Nov. '93 - Oct. '94
II- Nov. '94 - Oct. '95
Source: Krishnamoorthy *et al*. (1999)

Burton (1937) recorded more than 90 species of sponges from the Gulf of Mannar and most of them were found on the reef flats. Fauvel (1930) recorded 119 species of annelid fauna with a good number of polychaetes. Sathyamurthy (1952) recorded 450 species of molluscs. Boring bivalves were identified as one of the dominant reef dwellers causing considerable destruction to the reef systems. A total of 22 species of boring bivalves belonging to 11 genera and 6 families viz. Mytilidae, Veneridae, Petricolidae, Aloidae, Gastrochaenidae and Pholadidae were reported from the Indian coast (Appukuttan, 1973). The gastropods, *Pyrene versicolar, Drupa* sp. and *Cerithium* sp. were found common in the branching corals. The bivalves, *Saccostrea cuccullata, Arca* sp., *Isognomon* sp., *Pinctada* sp., and *Lithopaga* sp. were common in dead parts of ramose corals. Mytilids were found rare in the living parts of ramose corals. *Pyrene* sp., *Drupa* sp., *Cerithium* sp., and *Lambis* sp. were found to be crawling on the surface of the massive corals (Jeyabaskaran *et al.,* 1996). In Pulli island, 32 species of scleractinian corals belonging to 9 families were recorded. Of these *Acropora* sp. was the most dominant species. The scleractinian corals were found dominant in shoreward slope whereas the coral associated living resources were abundant in the reef crest (Patterson Edward and Asir Ramesh, 1996).

The giant sea anemone, *Stoichaetis giganteum* (Forsk), was found to grow both on sandy areas as well as on rocky bottom. Often many clown fishes such as, *Amphiprion* spp. and damsel fishes such as, *Dascyllus trimaculatus* (Ruppells) were found swimming over the anemones. Sacred chank *Xancus pyrum* (Linnaeus) was found in shoreward areas, shallow waters and also at greater depths of 10 meters and above. Other invertebrates found included *Clypeaster humilis, Salmacis bicolor,* and *Murex tribulus*. Sea cucumbers *Holothuria atra* and *Holothuria scabra* were also found. Dense growth of *Echinolampus* spp., *Clypeaster humilis,* and some *Astropecten* spp., were also observed. Alcyonarians, Pennatulids, and filamentous green algae were also found at deeper areas. Lobsters, sea fans, sea horses, echinoderms, ornamental shells like cowries and tiger shells and a number of species of crabs including edible and non-edible ones were also found (Kumaraguru and Jayakumar, 1998).

The antibacterial activities of 12 species of anthozoans (4 gorgonians, 5 soft corals and 3 antipatharians) collected off the east coast of India were assayed against four dominant marine fouling bacterial strains isolated from the biofilm of fouled aluminium panels. Of the 48 combinations (12 corals x 4 bacteria), 18 interactions showed antibacterial activity (37.5%). Such activity was most apparent in gorgonians, which inhibited bacterial growth in ten out of sixteen interactions (62.5%) compared with that of five out of twenty interactions (25%) among soft corals and three out of twelve interactions (25%) among antipatharians. The activity scores varied with different extracts and test organisms used, and was highest in antipatharians. Among the four bacterial strains *Vibrio* sp. was the least sensitive (2/12) when compared with *Flavobacterium* sp. (6/12). This is the first report of antibacterial activities of antipatharian colonies against marine microfoulers. The results implied that anthozoan corals harbour potent agents which could be exploited for the development of antifouling technology (Wilsanand *et al.,* 1999).

A variety of beautifully coloured fishes inhabit the reef corals. The fishes belong to the genera *Holocentrus, Lutjanus, Pomacanthoides, Chaetodontopsis, Chaetodon, Linophora, Abudefduf, Thallasoma* and *Zanclus.* Two species of eels *Gymnothorax undulatur* and *G. punctatur* were found densely populated around the reef flat (Reddiah, 1970).

A study of the percentage composition of the different species in the total catches from the Gulf of Mannar showed *Lethrinus cirnereus* (emperor fish) to form 57%, the next important fish *Callyodon ghobbham* to form 26%, *Lutjanus johni* (snapper) 5% and *Terapon puta* 4%. Other fishes such as *Psammoperca waigiensis, Epinephelus tauvina,* (grouper fish), *Teuthis marmorata, Pelates quadrilineatus, Plectorhinchus schotaf* (sweetlip fish), *Parupeneus indicus* (goat fish), *Upeneus tragula, Halichoeres* spp., *Chiloscyllium indicum, Plotosus* spp., *Gerres* spp., and *Acanthurus* spp., (Surgeon fish) formed 8% and *in situ* observations were made on the food and feeding habit and behavioural patterns of various coral reef associated fishes such as squirrel fishes, butterfly fishes, goat fishes, parrot fishes, damsel fishes, puffer fishes and box fishes (Table 27) (Kumaraguru and Jayakumar, 1998). Total organic production and total fish landings were found interrelated (Raghu Prasad and Ramachandran Nair, 1963). Association between the coral head and the fish fry depends on the density of coral head in an area, coral head size, interbranchial space and season (Asir Ramesh, 1996a). When the beach sand stone layer got exposed after the fall of the tide, a large number of birds mainly the large crested tern (*Sterna bergil*) and the eastern golden plover (*Pluvialis dominicafulva)* were found to flock the exposed areas. The most common echinoderms of this area were *Holothuria atra, H. scabra* and *H. edulis* which were found on the sandy mud shore of the islands. *Protereaster lincki* is a common starfish in this area (Reddiah, 1970). Dolphins were also found common in the Gulf of Mannar near Mandapam. Sighting of dolphins (single or in pairs) in the channel areas during winter months was very common. The most common species recorded in this area were *Tursiops aduncus* and *Delphinus delphis* (Krishna Pillai and Kasinathan, 1987). The Gulf of Mannar islands viz. Musal island, Talaiari island, Valai island, Appa island and Sethukarai were found to offer the pasture ground for dugong species population. But for 10 years prior to 1984, no dugong was even seen or captured around the islands near Tuticorin namely Van island, Kasuwar island, Karaichalli island and Vilanguchalli island (Silas and Fernando, 1985).

Table 27. Shelter and food of various coral reef associated fauna in the Mandapam group of islands.

Family	Species	Shelter	Food items
Holocentridae	*Sargocentron* spp. (Silver spot Squirrel fish) *Myripristis* spp. Violet soldier fish	RE & RF URS	Benthic crustaceans Plankton
Pomacanthidae	*Pomacanthus imperator* *Abudefduf saxatilis* (Sergeant major)	RE & URS URS	Sponges and encrusting organisms Zooplankton
Pomacentridae	*Amphiprion clarkii*	RE	Omnivorous associated with sea anemone
Chaetodontidae	*Chaetodon collaris* *C. melanotus* *C. meyeri* *C. auriga*	RE & URS RE & URS RE & URS RF & URS	Coral polyp Soft corals Coral polyp Small invertebrates
Serranidae	*Anyperodon Leucogrammicus*	RE & URS	Fish and crustacean
Scaridae	*Scarus sordidus*	RF & RE	Algae
	S. gibbus	RE	Algae
	Scarus ghobbam	RE & URS	Algae
Lutjanidae	*Lutjanus bohar*	URS	Fish and crustacean
	L. monostigma	URS	Fish and crustacean
Lethrinidae	*Lethrinus* spp.	RF & URS	Benthic invertebrates

RF - Reef flat, RE - Reef edge, URS - Upper reef slope

Source: Kumaraguru and Jayakumar (1998)

Current Status

The Gulf of Mannar coral reef ecosystem is healthy and there is not much of deterioration due to natural calamities. But the anthropogenic impact especially coral quarrying poses severe threat to the coral reef ecosystem of the Gulf of Mannar (Asir Ramesh, 1996b). Most of the corals which were present here have been dredged by local fishermen for building houses and for industrial purposes (Jeyabaskaran and Lyla, 1996). The Gulf of Mannar Marine Park Authority has recorded 3 live specimens of dugong species in 1997. The local fishermen have been advised to return the dugong specimens to the sea when they get entangled accidently in the fishing nets (Shanmugaraj, Gulf of Mannar National Marine Park: Per. Com). Transplantation of corals *viz. Pocillopora damicornis, Psammocora contigua, Montipora digitata* and *Acropora formosa* was done during July 1993- June 1994. Based on the survival, it was concluded that *Acropora formosa* is the only suitable and successful species for transplantation. It was also recommended that the transplantation of head colony is better and advisable in this ecosystem (Asir Ramesh and Patterson Edward, 1996).

The corals which cover about 683 ha here act as a natural barrier against sea erosion. There are about 20 coral islands in the Gulf of Mannar region of the Southeast coast of India, covering about 683 ha from Mandapam to Tuticorin. This fragile ecosystem is under severe threat due to the anthropogenic effects such as pollution, mining, aquaculture, fishing and tourism. The corals of the Gulf of Mannar are more diverse and abundant than those of the Palk Bay (Gopinadha Pillai, 1971). Turbid waters from September to May and the siltation have a greater effect on the corals in the inshore areas of Palk Bay than in the Gulf of Mannar.

Quarrying corals for various purposes has been in existence for a long time in South India. Hornell (1909) described about the challi (dead broken pieces of corals) collection from this area and the market rate for a canoe full of challi varied from Rs.1-3. Three factories in Tirunelveli district are using corals as a raw material for their products. Around 50 boats, each manned by 5 to 6 people were engaged in collection of corals and the exploitation was around 250 cubic meters per day. In other words, a reef of 250 m length and 1 m width and height was daily removed from the sea (Gopinadha Pillai, 1971). Messers Industrial Chemicals Ltd., Sankar Nagar, Tirunelveli District, pioneer in the manufacture of calcium carbide in India is exploiting more than 20,000 mt of live as well as dead corals per annum (Patel and Bhaskaran, 1978). Once Mandapam and Tuticorin were the two important bases for the collection and stocking of the coral stones. After the establishment of the National Marine Park Authority, coral quarrying has been completely stopped in Mandapam but in Tuticorin area quarrying of corals is still going on. The 60 hectare fringing coral reef area of Tuticorin is under constant threat due to human activities as quarrying, sewage disposal and the release of heated water from thermal power plants. The annual exploitation of corals in this area is between 0.55 and 1.07 lakh tonnes. The heated water released from the thermal power plant increases the coastal water temperature by 3-4°C above ambient temperature and the rate of 'dumping' of flyash is around 5,000 tonnes / day. The dumping of the ash has also affected the recolonization of *Acropora formosa*. The release of sewage has resulted in heavy load of organics (210 tonnes of BOD/year) and low primary production (167mg $C/m^3/hr$) which inturn would drastically affect the massive coral habitat (Santhanam and Venkataramanujam, 1996). Eventhough there are rules and regulations in Gulf of Mannar Marine National Park to minimize the damages to the coral reefs, they seem to be more often flouted than followed. Excessive exploitation of corals (around the islands) has very much affected and altered the ecology of the islands, resulting in the loss of certain land portions of islands and their associated flora and fauna from the ecosystem.

Kilakarai is the foremost place for the exploitation of dugong for consumption. During 1960, the capture of dugong in the Gulf of Mannar and Palk Bay was around 250 ind./yr. A special bottom set gill net is used for catching dugongs. Valivalai, Thirukkaivalai (gill nets) and shore seines are the other gears used for catching the dugong (Silas and Fernando, 1985). This kind of overexploitation would certainly lead to the species extinction.

7. CORAL REEF ECOSYSTEM OF THE PALK BAY

The reef in the Palk Bay runs parallel to land (east to west direction) between Lat. 9° 17' N and Long. 79° 17' E and 79° 8' E. The Bay is a very shallow flat basin and its depth hardly exceeds 9 meters. The coral reef in the Palk Bay starts from Munakad as a wall like formation (1-2 m broad) and runs east upto Tonithurai to a distance of about 5.5 km, where the width of the reef attains more than 300 m. East to the Pamban pass, the reef again starts near Thangachimadam and ends near Agnitheertham (Rameswaram) (Mahadevan and Nagappan Nair, 1969).

Physico-Chemical Parameters

This area is under the spell of both southwest and northeast monsoon. Southwest monsoon contributes little towards the total annual rainfall of this area. Rain is moderate to heavy during October to January (northeast monsoon). The mean annual rainfall varies from 820 to 1650 mm. The monthly average temperature of the waters of the Palk Bay ranges between 24.6° and 29.1°C (minimum during December and the maximum during May). The tidal elevation is around 1m. Palk Bay is practically calm except during the northeast monsoon when turbulent condition prevails (Gopinadha Pillai, 1969). The salinity of the water decreases gradually along an axis in the southwest direction running from the strait. High saline water is 'pocketed' in the south-west corner of the bay. This may be due to the incursion of the Gulf of Mannar water through Pamban pass. The density of the water also decreases along an axis on the southwestern direction from the Strait. The North-east wind velocity at Nagapattinam is about 8 to 10 knots (North of Palk Bay) and at Pamban the wind strength reduces between 2 and 4 knots (South of Palk Bay). Temperature, salinity, density and dissolved oxygen values of the surface waters of the Palk Bay would indicate that the Bay of Bengal waters entering into the Palk Strait influence the hydrographic condition of the Palk Bay, unlike the Gulf of Mannar waters whose influence on the hydrological parameters of the Palk Bay is only minor (Murty and Udayavarma, 1964).

The bottom sediments of Mandapam consist of silt and clay, clayey silt and sand, fine to medium sand, coarse sand and coarse sand with gravel. Distribution of various size classes indicates that the offshore sediment in this area is usually unimodal with the primary mode around 1.5 to 2 (medium sand) and a secondary mode around 3.5. Beach samples have prominent mode around 2.25, 1.75, 2.75 and 3.25 suggesting the polymodal nature of the sediments. Grain size parameters of the Palk Bay samples near Mandapam are shown in Table 28. The distribution patterns of heavy minerals are shown in Table 29 (Mallik, 1983). Most of the offshore areas contain a high amount of opaques (16-80%) with maximum concentration in small patches. Majority of opaques consist of ilmenite. Other minerals are magnetite, rutile, hydroxide of iron and minor amounts of pyrite (Mallik, 1983).

Coral Distribution

Gopinadha Pillai (1969) listed 20 corals species from this area and classified the reefs of the Palk Bay into 5 zones viz. shore, lagoon, shoreward slope, reef crest and seaward slope. Asir Ramesh and Kannupandi (1997) recorded 25 species of corals from Vellaperukkumunai reef.

Table 28. Grain size parameters of Palk Bay samples off Mandapam.

Sample No.	Mean	SD	Skewness	Kurtosis
	Off shore			
Ps-5	1.2866	0.7242	0.4999	1.7060
Ps-9	2.2066	1.0321	-0.1611	1.9899
Ps-18	-0.4000	0.3600	-0.0300	1.1065
Ps-25	2.1100	1.4185	-0.0352	0.9133
Ps-29	2.0333	0.9412	-0.1585	1.8897
Ps-45	1.6333	1.1204	0.2076	0.9221
Ps-49	1.6466	1.1010	0.2387	0.7985
Ps-64	2.8233	0.4955	1.4076	0.1912
Ps-73	1.1100	0.8511	-0.3061	0.4822
Ps-82	2.6600	1.3775	-0.6885	0.9121
Ps-84	1.9433	0.4199	0.1540	1.5993
Ps-100	1.8266	0.5763	-0.0297	0.8652
Ps-105	2.2500	0.4750	1.8332	1.7553
Ps-109	1.9266	1.5969	-0.4453	0.9521
Ps-113	1.5333	1.1700	-0.0358	0.7586
Ps-123	2.0100	0.6733	0.0224	1.6393
Ps-125	1.8833	0.7147	-0.1717	1.6393
Ps-135	1.5966	0.2420	0.3479	1.3831
Ps-143	1.4833	0.5178	-0.4189	0.0118
	Beach			
PsB-2	0.7133	0.7760	0.0224	0.9287
PsB-7	2.7333	0.3850	-0.2857	1.1034
PsB-10	2.1833	0.4147	-0.7333	1.3071
PsB-15	2.2500	0.600	-0.0202	1.027
PsB-21	2.5666	0.4553	0.0319	1.038
PsB-25	6.3433	0.5149	-0.0486	1.0088
PsB-30	2.3166	5.6632	-0.9940	1.1938
PsB-34	1.8666	0.7109	0.2075	1.0473
PsB-42	1.3500	0.0956	-0.1923	1.7564
PsB-44	2.3600	0.3894	0.0961	1.0200
PsB-46	1.7766	2.0800	0.1480	0.8800
PsB-50	1.7266	0.9760	0.2722	1.8063

Source: Mallik (1983)

Table 29. Heavy mineral variation of samples from Palk Bay off Mandapam (values represent % by number counts).

ST	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
PS 3	12.08	2.34	1.0	2.0	1.0	1.0	19.12	2.67	0.33		0.67	0.33	3.69	0.67			0.33	2.34	0.33
PS 15*	22.4	3.27	1.09	8.19	34.42		16.93	5.46			3.27	1.09	1.09	7.65				0.54	
PS 21	11.22		1.53	4.08	43.36		18.36	9.69			3.57				0.51				
PS 24	15.17	1.48	2.35	3.27	45.83		14.58	12.5					2.64		1.16	0.89			
PS 27	21.8	3.75	2.63	4.51	39.47	1.12	9.39	5.63			4.13		4.51	1.5		1.5			
PS 42	16.87	2.11	4.64	5.06	37.97	0.42	13.08	10.12			2.95		2.95	1.68	0.84		0.84		0.42
PS 44	10.79	0.31	1.26	1.26	67.61		11.74	2.53			0.94		2.53	0.31			0.31		
PS 49=	18.99	0.77	0.77	3.48	43.41		18.62	8.13			0.77	0.38	1.54			1.54			0.77
PS 79 '	5.79			0.48	75.36		10.62	0.96	0.96	0.48	0.48	0.48	2.41	0.48			0.48	0.48	0.48
PS 82	16.28	1.51	3.03	3.03	41.66	1.13	19.31	5.68	0.74		3.4	0.37	3.78						
PS 86	5.53	3.43	1.11	0.74	52.41	12.26	13.38	4.46	0.74				4.08		1.48	0.74			0.37
PS 88	3.46	0.76	0.76	1.53	75.76		6.92	3.46			0.76		4.23	0.38	0.76	0.76			
PS 91	4.03		1.0	1.0	60.45	1.25	23.17	2.29			0.25		5.28	0.25		0.25	0.75		
PS 99	31.95		6.07	2.88	26.52		17.89	9.27					1.59	0.96		0.64		1.59	0.32
PS 100	27.51	1.31	0.83	1.67	31.44		21.83	7.42	1.67				4.36		0.83	0.83			
PS 109	23.15	1.4	1.75	2.45	26.66	1.05	25.26	14.91			1.75		5.61	0.7	0.7		1.4	1.05	1.4
PS 112	5.35	0.7	0.35	0.35	71.42		10.71	3.21		0.35	1.4	0.35	4.64			0.7			0.35
PS 117	10.27	1.18	0.79	0.79	59.68		11.46	4.74			2.38	1.18	5.92	0.79					0.79
PS 119	23.49	1.2	1.2	4.21	47.59	1.8	9.63	2.4			3.01	1.2	4.21						
PS 125	4.0	0.72	0.72	0.72	80.36	0.36	6.54	1.8					3.63	0.36	0.36	0.36			0.36
PS 140	16.12	0.58	2.983	3.81	56.01	1.75	10.26	1.75			0.87	1.16	2.32		0.58	0.29			0.29

* Glauconite, 1.09, = Chlorite,0.77, + Staurolite, 0.3, . Riebeckite,0.7

St-Station; A-Hornblende; B-Tremolite, Actinolite; C-Clinopyroxene; D-Orthopyroxene; E-Opaques; F-Carbonate; G-Garnet; H-Sillimanite; I-Kyanite; J-Andalusite; K-Epidote; L-Clinozoisite; M-Zircon; N-Monazite; O-Rutile; P-Apatite; Q-Biotite; R-Muscovite; S-Tourmaline

Source: Mallik (1983)

Shore: The shore of the reef is mostly sandy with dead pieces of corals except at the extreme eastern side and near the Pamban bridge where one can see traces of sand stones. The vegetation on the shore comprises *Cocos nucifera, Borassus flabellifer, Casuarina equisetifolia, Azadirachta indica* and a few other thorny shrubs.

Lagoon: The width of the lagoon varies from 200 to 600 metres at different places with a depth of 1 to 2 metres. The bottom is sandy with molluscan shells and pieces of disintegrating corals. Living corals are absent in the lagoon probably due to the absence of any hard substratum on which coral planulae can settle. Sponges such as *Hercina fusca, Dysidea fragilis, Spirastrella inconstans* and *Calispongia diffusa* are fairly common at the bottom (Gopinadha Pillai, 1969).

Shoreward slope: The shoreward slope distributed corals are all encrusting and massive types with comparatively large polyps such as *Favia pallida, F. favus, Favites virens, Goniastrea pectinata, G. retiformis, Platygyra lamellina, Hydnophora* sp., *Cyphastrea* sp., *Leptrastrea* sp., *Symphillia* sp. and *Goniopora* sp. Living colonies of *Porites* sp. are rare or small in size. *Galaxea fascicularis, Turbinaria peltata* and *Pavona varians* are the rarest species. This zone of the reef supports a good number of reef dwellers like encrusting sponges, bryozoans and calcareous algae. Among the fleshy corals, *Lobophytum* sp. and *Sarcophytum* sp. are represented in odd numbers.

Reef crest: The reef crest often gets exposed at low tides. Corals are rare at the reef crest, probably due to over exposure to the sun which is deleterious. But under the rocks, occasionally *Leptastrea transversa* and G*oniopora duofaciata* are seen.

Seaward slope: On the seaward side of the reef slope, coral growth is comparatively richer (in terms of distribution and diversity) than the shoreward side. Majority of the corals are ramose forms viz. *Pocillopora* sp., *Acropora* sp. and *Montipora* sp.

Biodiversity

A total of 61 species of marine macroalgae was recorded and they belonged to three major groups viz. green algae (14 genera and 28 species), brown algae (8 genera and 13 species) and red algae (17 genera and 20 species). The frequency of occurrence of different species in the quadrate samples showed *Halimeda opuntia* to be the dominant algal member of the reef. Species of *Caulerpa* and *Sargassum* were the next most common algal species found in the reef. The physical conditions like the nature of the substratum and the water level above the substratum were found to influence the distribution of the flora of the coral reef area.

Other vegetational elements recorded were *Cymodocea* sp., *Ulva reticulata, Turbinaria* sp., *Padina* sp., *Halimeda* sp. and *Amphiora* sp. which are common. Animals such as *Holothuria scabra, H. atra* and *Pentaceraster australis* were found as the common inhabitants of the sandy lagoon floor. Here the vegetation comprised of *Turbinaria* sp., *Sargassum* sp., *Padina* sp., *Caulerpa* sp. and rarely *Cymodocea* sp. and *Halimeda* sp. Few other encrusting calcareous algae were also commonly seen on the seaward slope of the reef (Gopinadha Pillai, 1969).

The reef flora of the Palk Bay and the Gulf of Mannar regions is given in Table 30. (Umamaheswara Rao, 1969). Boring sponges are the major group among the marine organisms causing considerable destruction to the reef system. The 'bores' left by the sponges weaken the entire 'fabric' of the reef and the reef becomes more susceptible to the wear and tear caused by the waves and is unable to withstand the impact. Altogether 20 species of boring sponges were recorded from the Gulf of Mannar and Palk Bay belonging to 9 genera. The abundant and conspicuous genus recorded was *Cliona,* both in number of species and in distribution (Thomas, 1969).

Bivalves were also observed to cause considerable damage to the coral reefs as they act as biological agents in the erosion of hard coral stones. In the Palk Bay and the Gulf of Mannar, about 17 boring bivalve species (under 10 genera of 6 families) were found to occur (Appukuttan, 1973). Seventy three species of molluscs were observed to be associated with corals in the Palk Bay (Table 31). The branching corals *Acropora corymbosa* and *Pocillopora damicornis* showed large number of molluscan associates compared to other branched living corals (Asir Ramesh *et al.,* 1996).

The dried sea horse (*Hippocampus kuda)* is in great demand in the Southeast Asian countries especially in Singapore and China not only for extraction of soup but also for medicinal purposes. Due to the demand in the international markets, this animal has been overexploited and it is now 'endangered'. An estimated 300 to 400 kgs of sea horses are exported from the Palk Bay coast alone which may fetch an average revenue of about Rs. 80,000/month (Marichamy *et al.,* 1993). During 1970s the fishermen of the Palk Bay region bitterly complained about the disappearance of large beds of algae owing to the 1964 cyclone effects. Therefore, there was near total absence of turtles and dugongs from this area. Now fishermen gladly inform that the algal beds have sprung up once again in the area (Silas and Fernando, 1985).

The types and distribution of nematocysts in four coral species were studied. Of the 20 major categories of nematocysts recognized in the phylum Cnidaria, five types were encountered in these four corals. They were holotrichous isorhizas, atrichous isorhizas, microbasic mastigophore, microbasic amastigophore and macrobasic mastigophore. The type of nematocysts and their abundance varied from coral to coral and even within a single species, the relative distribution of a given type of nematocyst varied in different parts of a polyp (Table 32) (Wafar, 1974).

Table 30. Reef flora of Gulf of Mannar and Palk Bay.

Green algae :	
Ulva lactuca	*P. tetrastromatica*
U. reticulata	*Pocockiella variegata*
Cladophora sp.	*Pocockiella* sp.
Chaetomorpha sp.	*Hydroclathrus clathratus*
Neomeris annulata	*Chnoospora implexa*
Acetabularia moebii	*Hormophysa triquetra*
Halicystis boergesenii	*Sargassum sp.*
Valonia aegagropila	*Turbinaria conoides*
Boergesenia forbesii	*T. ornata*
Microdictyon agardianum	**Red algae :**
Struvea delicatula	*Gelidiella acerosa*
Caulerpa cupressoides	*Gelidium pusillum*
C. fergusonii	*Amphiroa fragilissima*
C. mexicana	*Chondrococcus harnemanni*
C. micropysa	*Gracilaria crassa*
C. peltata	*G. folifera*
C. racemosa. v. clavifera	*G. lichenoides*
C. racemosa v. coryneflora	*Hypnea* spp.
C. scalpelliformis	*Champia globulifera*
C. serrulata v. typica, formalata	*Wrangelia argus*
C. sertularioides forma brevipes	*Ceramium* spp.
C. sertularioides forma longiseta	*Centroceras clavulatum*
C. taxifolia	*Spyridia filamentosa*
C. verticillata	*Martensia fragilis*
Udotea javensis	*Roschera glomerulata*
Halimeda opuntia	*Leveillea jungermannioides*
H. tuna	*Cohondria dasyphylla*
Codium sp.	*Acanthophora spicifera*
Brown algae :	*Laurencia obtusa*
Dictyota spp.	*L. papillosa*
Padina commersonii	**Seagrasses :**
P. gymnospora	*Cymodocea* sp.
P. pavonia	*Diplanthera wrightii*
	Syringodium filiforme
	Halophila ovalis

Source: Umamaheswara Rao (1969)

The penaeid prawns contributed 16.70% of the total trawl landings at Mandapam during 1986-'93. Out of the ten species represented in the catches four species namely *Penaeus semisulcatus, Metapenaeopsis stridulans*, *Trachypenaeus pescadoreensis* and *Metapenaeus burkenroadi* supported the fishery throughout the year. The other species such as *Penaeus merguiensis, P. latisulcatus, Metapenaeus affinis, Parapenaeopsis maxillipedo, Metapenaeopsis hilarula* and *Parapenaeopsis uncta* occurred in the catches irregularly. Contributing over 50%, *P. semisulcatus* was the dominant species, followed by *M. stridulans*. Over the years a gradual decline of *P. semisulcatus* in the species percentage composition and a steady increase of that of *M. stridulans* were observed. Two peak seasons, one during May - August and the other during November – December were observed for *P. semisulcatus*. The annual fishing effort fluctuated between 3,54,055 and 6,48,513 hours with an average of 4,90,361 hours. The annual prawn catch ranged from 547.5 to 1,065.7 t, the average annual catch being 703.5 t. The annual catch per hour ranged from 0.8 to 2kg. The MSY and corresponding optimum fishing effort was 726.2 t and 5,61,415 hours respectively (Table 33) (Maheswarudu *et al.,* 1996).

Table 31. Molluscs associated with corals in Palk Bay

	S	D	L		S	D	L
Class GASTROPODA				**Cassididae**			
Haliotidae				*Phalium canaliculatum* (Bruguiere)	-	+	+
Haliotis varia (Linne)	+	-	+	*Phalium ponderosum* (Gmelin)	-	+	+
Fissurellidae				**Muricidae**			
Diodora lima (Sowerby)	+	-	+	*Drupa leptagonalis* (Reeve)	-	+	+
Diodora funiculata (Reeve)	-	+	+	*Drupa margariticola* (Broderip)	+	-	-
Diodora clathrata (Reeve)	-	+	+	**Pyrenidae**			
Emarginula obovata (A. Adams)	-	+	+	*Pyrene versicolor* (Sowerby)	+	-	+
Trochidae				*Pyrene zebra* (Gray)	+	-	+
Euchelus asper (Gmelin)	-	+	+	**Buccinidae**			
Cantharidus interruptus (Wood)	+	-	-	*Engina zonata*	+	-	+
Clanculus clanguloides (Wood)	+	-	+	**Class BIVALVIA**			
Trochus radiatus (Gmelin)	-	+	+	**Arcidae**			
Trochus stellatus (Gmelin)	-	-	+	*Arca complana* (Chemnitz)	+	-	+
Trochus tentorium (Gmelin)	-	-	+	*Arca fusca*	-	+	+
Trochus pustulosus (Philippi)	-	+	+	**Mytilidae**			
Turbinidae				*Modiolus metcalfei* (Hanley)	+	-	+
Liotia cidaris (Reeve)	-	+	+	*Brachidontes variabilis* (Krauss)	+	-	+
Turbo intercostalis (Menke)	-	+	+	*Septifer bilocularis* (Linne)	+	-	+
Turbo petholatus (Linne)	-	+	+	*Lithophaga teres* (Philippi)	+	+	-
Neritidae				*Lithophaga gracilis* (Philippi)	+	+	-
Nerita albicilla (Linne)	+	-	-	*Lithophaga nigra* (d'Orbigny)	+	+	-
Nerita chameleon (Linne)	-	+	+	*Lithophaga stramineus* (Dunker)	+	+	-
Nerita polita (Linne)	-	+	+	*Lithophaga cinnamomea* (Lamarck)	+	+	-
Nerita plicata (Linne)	-	+	+	**Isognomonidae**			
Nerita maura (Recluz)	-	+	+	*Isognomon nucleus* (Linne)	+	-	-
Nerita rumphii (Recluz)	-	+	+	**Pteriidae**			
Nerita squamulata (LeGuillou)	-	+	+	*Pteria chinensis* (Leach)	-	+	-
Littorinidae				**Ostreidae**			
Littorina scabra (Linne)	-	+	+	*Ostrea forskalii*	+	-	-
Rissoidae				**Erycinidae**			
Rissoina clathrata (A. Adams)	-	-	+	*Galeomma paucistriata* (Deshayes)	+	-	-
Turritellidae				*Scintilla hanleyi* (Deshayes)	+	-	-
Turritella acutangula (Linne)	-	+	+	**Chamidae**			
Turritella attenuata (Reeve)	-	+	+	*Chama reflexa* (Reeve)	+	-	+
Architectonica perspectiva (Linne)	-	+	+	**Cardiidae**			
Vermetidae				*Cardium setosum* (Redfern)	-	+	+
Vermetid sp.	+	-	-	*Lunulicardia retusa* (Linne)	-	+	+
Spiroglyphus spiralaeformis (de Serres)	+	-	-	**Verneridae**			
Vermicularia inopertur (Ruppell)	+	-	-	*Venus reticulata*	-	+	+
Cerithiidae				*Venerupis macrophylla* (Deshayes)	+	+	-
Cerithium morus (Lamarck)	+	-	+	*Irus exoticus* (Lamarck)	+	-	+
Cerithium obeliscus (Bruguiere)	-	-	+	**Petricolidae**			
Xenophoridae				*Petricola lithophaga* (Retzius)	+	+	-
Xenophora corrugata (Reeve)	-	-	+	**Solenidae**			
Strombidae				*Solen lamarckii* (Deshayes)	-	+	+
Strombus gibberulus (Linne)	-	+	+	*Solen aspersus* (Dunker)	-	+	+
Strombus canarium (Linne)	-	+	+	**Gastrochaenidae**			
Pterocera lambis (Linne)	-	+	+	*Gastrochaena gigantea*	+	-	+
Cypraeidae				*Gastrochaena apertissima*	+	-	-
Cypraea moneta (Linne)	+	-	+	**Pholadidae**			
Cypraea errones (Linne)	+	-	-	*Pholas orientalis* (Gmelin)	+	-	+
Ovulum formosum (Adams & Reeve)	-	+	+				

S-coral sand; D-Dead coral; L-Live coral; --Present; +- absent

Source: Asir Ramesh *et al.* (1996)

Monthly fishing effort, catch per hour (CPH) and total penaeid prawn catch during 1986-'93 showed that total penaeid prawn catch varied from 7.6 t (January 1989) to 280.2 t (July 1992) (Fig. 14). The fishing effort ranged from 6,200 hours (January 1989) to 85,500 hours (June 1989). The lowest CPH was observed in September 1992 (0.473 kg) and the highest in July 1992 (4.35kg). The peak season for prawn fishery was from May to August (Fig. 14) when about 50% of the annual fishing effort, more than half of the annual prawn catch and higher CPH were recorded. The lean period for prawn fishery in the Palk Bay was during September – October and January – April.

Table 32. Types of nematocysts and their distribution in different parts of the body of four species of corals.

Nematocyst category	Coral species											
	Favia pallida			*Favia valenciennesi*			*Favites abducens*			*Goniopora pectinata*		
	T	OD	M	T	OD	M	T	OD	M	T	OD	M
Hlotrichous isorhizas	XX	XX	XX	XX	XX	XX	XX	XX	XX	-	-	-
Atrichous isorhizas	-	-	-	X	X	-	-	-	-	XX	XX	XX
Microbasic mastigophore	-	-	-	X	-	-	X	-	-	XX	XX	XX
Microbasic amastigophore	-	-	-	X	-	-	-	-	-	-	-	-
Macrobasic mastigophore	X	X	X	X	X	X	XX	XX	X	XX	X	XX

XX - Occur in abundance, T - Tentacle, OD - Oral Disc, M - Mesenteries
X - Occur in few numbers or rare.

Source: Wafar (1974)

Table 33. Estimated effort, penaeid prawn catch, catch per hour and percentage of prawn catch of trawlers operated in the Palk Bay off Mandapam during 1986 - '93.

Year	Fishing effort (hours)	Prawn catch (tonnes)	Catch per hour of prawn (kg)	Prawn catch in total trawl landings (%)
1986-1987	4,38,260	719.5	1.6	23.6
1987-1988	3,54,055	561.0	1.6	22.6
1988-1989	6,48,513	547.5	0.8	13.5
1989-1990	4,79,241	669.2	1.4	15.1
1990-1991	5,00,517	661.2	1.3	13.6
1991-1992	4,82,440	700.1	1.5	13.0
1992-1993	5,29,500	1065.7	2.0	20.0
Average	**4,90,361**	**703.4**	**1.4**	**16.6**

Source: Maheswarudu *et al.* (1996)

Current Status

Compared to the description of Gopinadha Pillai's (1969), the coral reef ecosystem has now completely changed in its pattern of distribution. The lagoon is having large number of boulders occupied by various species of scleractinian corals. Six scleractinian coral species have been recorded from the lagoon of Vellaperukkumunai reef (Asir Ramesh and Kannupandi, 1997) whereas Gopinadha Pillai (1969) recorded only two species from the lagoon (*Porites somaliensis* and *Favia pallida).* Fishermen report that the sponge and soft coral populations have been decreasing over the past two decades. The present findings also confirm that the boring sponge species are more whereas the macrosponges are reduced in number (Asir Ramesh and Kannupandi, 1997). Table reefs are also found in the lagoons. The newly found boulders and table reefs are due to the wind drifting processes. Being located nearer to the outlets of the processing industries (lagoon and its shoreward slope), the native green algal community has increased compared to other algal groups.

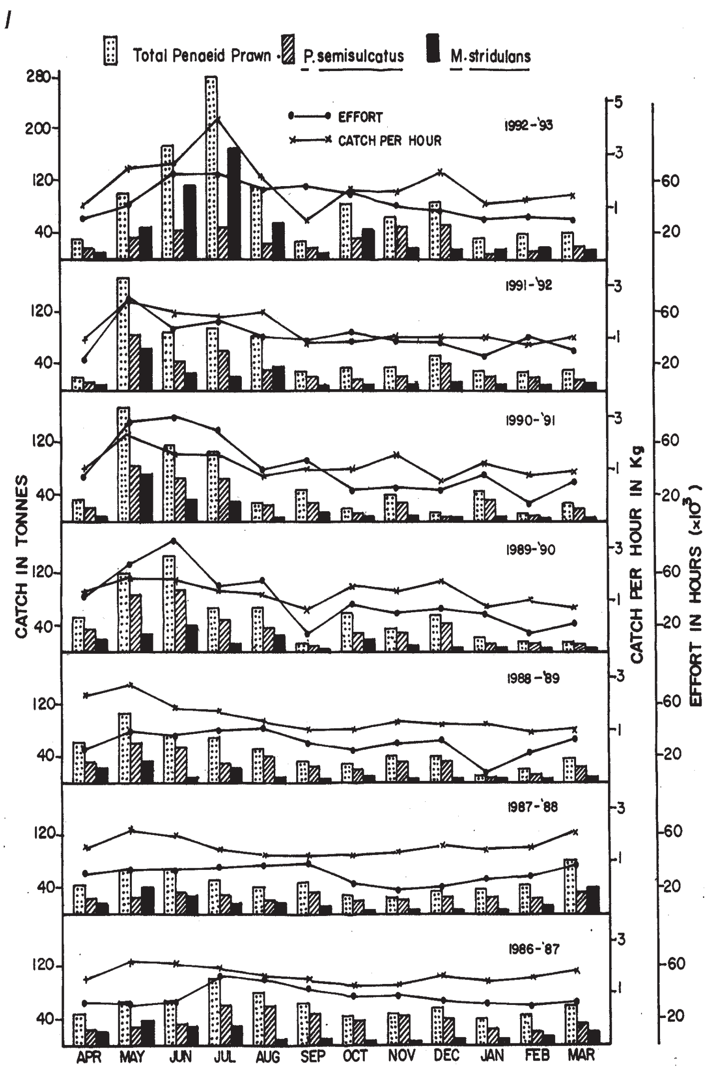

Fig. 14. Monthwise total penaeid prawn catch, *P. semisulcatus* catch, *M. stridulans* catch, effort and catch per hour at Mandapam during the year 1986 - 1993 (adapted from Maheswarudu *et al.,* 1996).

On the shoreward slope, the coral population has increased significantly in distribution and diversity. Gopinadha Pillai (1969) recorded 11 species of scleractinian corals but the present investigation (Asir Ramesh and Kannupandi, 1997) revealed the presence of 20 coral species which have the density of around 50 colonies/10m^2. Most of them are ramose corals. Sponge populations are comparatively higher here than the lagoon. The coral species, *Platygyra lamellina, Hydnophora* sp. and *Galaxea fascicularis* which were recorded by Gopinadha Pillai (1969) have now disappeared from the Palk Bay. Gopinadha Pillai (1969) recorded all the ramose corals in the sea-ward slope with 6 species but the investigation by Asir Ramesh and Kannupandi (1997) showed the presence of 10 ramose coral species on the shoreward slope and lagoon.

Inshore waters of the Palk Bay during the monsoon become muddy due to the presence of suspended sand and silt stirred up from the sandy shore by wave action. The large degree of silt settlement has a remarkable effect especially during the northeast monsoon. Cyclonic winds during monsoon season, with high velocity, cause enough mechanical damage to the corals of this area. Huge quantity of silt settlement during the northeast monsoon has a remarkable effect on the distribution and diversity of the coral reef associated plants and animals.

Increased organic and inorganic nutrient loads in the coral reef environment create direct and indirect problems to the ecosystem. Nutrients enhance the production of algal biomass of this area. Presence of excess algae upon the coral reef does not allow planulae (larvae of corals) to settle and the algae become the space competitors for the growing coral populations. However, *Diademma* sp. and herbivorous fishes limit the growth of algal populations of the coral reef area by grazing. But over exploitation of the herbivorous fishes reduces the grazing pressure on the algae. Enrichment of nutrients in the coral reef ecosystem increases the phytoplanktonic population and reduces the sunlight penetration into the water column thus paving way for ecosystem changes. The 'processing industries' and nearby households discharge hot or cold, dirty or sewage water directly into the sea. Wherever (this kind of processing) industries are located, coral reef ecosystem changes have become more visible. *Perna viridis* which is a very rare bivalve in the coral reef ecosystem can be collected in good numbers and in huge sizes from the Palk Bay. The same bivalve is neither available nor can be collected from the Gulf of Mannar islands lying adjacent to the Palk Bay. The composition of lagoon fauna is poor in the Palk Bay as compared to that of the Gulf of Mannar coral ecosystem (Asir Ramesh, 1996b).

Fishermen's observation in this area is that the sea cows (*Dugong*) and the turtles occur here only in small numbers. Public awareness about the ecological and genetic significance of the coral reef ecosystem and the legislations made by the Biosphere and Marine Park Authority of the ecosystem prohibit fishermen from exploiting the sea cow and turtle populations. But the fishermen never leave the animals that are accidentally caught in the fishing nets. People fishing molluscs opine that catch is reducing eventhough the fishermen are using some improved technologies compared to the past (Asir Ramesh and Kannupandi, 1997).

8. CORAL REEF ECOSYSTEM OF THE ANDAMAN AND NICOBAR ISLANDS

The Andaman sea is one of the least explored region of the Indian ocean. The Andaman and Nicobar Islands are located between Lat. 6° and 14° N and Long. 91° and 94° E. Coral reefs stretch over an area of 11,000 sq.km in the Andamans while the Nicobar islands have 2,700 sq.km (Krishnakumar, 1997). There are 350 islands along with a number of exposed islets and rocks, of which, only 38 are inhabited. The total population here is around 88,741 (1981 census). The Andaman sea is a relatively extensive basin with a maximum depth of 4360 m and an uneven bottom topography. The sea is connected with the South China sea through the Strait of Malacca (Vineeta Hoon, 1997).

Physico-Chemical Parameters

Rainfall in this area is around 300cm/yr. Evaporation calculated from pan measurement is around 10.8 mm/day. At Chiriatapu, the wind speed is fairly constant (3-4 m/sec=5knots) during ordinary conditions, but during cyclonic periods it exceeds the Beaufort force 4 (7 m/sec=12-13knots) (Biswarup Mukherjee and Prakash Mehrotra, 1992). The tidal amplitude of the Andaman is 2.5 m (Dorairaj and Soundararajan, 1997). Surface temperature ranges from 27° to 28.5°C with an increasing trend from north to south on the western section of the Bay of Bengal. The depth of the mixed layer in the Bay of Bengal side of the islands is 70-80 m, whereas in the Andaman sea, it varies from 50 to 75 m. There is a noticeable difference in the temperature of the waters below 1500 m on either side of the island chain (Rama Raju *et al.,* 1981). The average minimum and maximum atmospheric temperature at Port Blair varies between 28.6 and 35.4°C. The mean salinity ranges between 29.73 and 32.81‰ (Rangarajan and Marichamy, 1972). Salinity in the southern Andaman sea (below 9° N) varies from 32 to 33‰ at the surface. Salinity is higher on the western side of island compared to the eastern side (Bhattathiri and Devassy, 1981). Alternative increase and decrease in salinity with respect to various zones of the reef are accompanied by a change in the chemical environment, of which the most notable is the CO_2 system of the reef, along with its associated parameters, total alkalinity and pH. The chemical environment and its fluctuation in the fringing reef zones of Chiriatapu are shown in Table 34 (Biswarup Mukherjee and Prakash Mehrotra, 1992).

Table 34. The chemical environment in the fringing reef at Chiriatapu.

Zones	Salinity (%0)	pH	Total alkalinity (equiv/m^3) MoXS R So	Total alkalinity (equiv/m^3) MR	Total Co_2 (mole/m^2) MoXS R So	Total Co_2 (mole/m^2) MR
6	36.53	7.8	2.570	2.570	2.376	2.376
5	35.72	8.3	2.515	2.349	2.352	1.930
4	36.64	7.8	2.577	2.567	2.383	2.421
3	35.74	8.2	2.514	2.360	2.324	2.000
2	36.64	7.8	2.577	2.567	2.383	2.421
1	35.75	8.2	2.513	2.358	2.320	2.005

Source: Biswarup Mukherjee and Prakash Mehrotra (1992)

Mean particle size of the sediment characters varies from 1.28∅ to 3.63∅ (Ansari and Ingole, 1983). Bromine and iodine content in sponges on dry weight basis varies from 0.025 to 1.29% and from 0.001 to 0.085% respectively. Iodine concentration varies from 0.0119 to 0.03 % and Br content varies from 0.008 to 0.128% in algae. Iodine content is generally low in brown algae, intermediate in red and high in green algae (Solimabi *et al.,* 1981). Late quaternary sea level fluctuation is evident from the record of benthonic foraminifera associated with coral and algal debris distributed over the North–South trending submerged invisible Bank in Andaman Sea. Two distinct sediments types viz. (1) coralline gravels, large algal concretions with foraminifera and other biogenic coarse sand between 28 and 90 m isobath and (2) coralline pebbles and brownish gray coral sand with small calcareous concretions and benthonic foraminifera in finer sand between 90 and 220 m isobaths, are identified (Bhattacharjee and Ghosh, 2000).

A detailed chemical examination of the Indian Ocean soft coral *Sinularia flexibilis* yielded two new cembranolide epsilon -lactones, sandensolide monoacetate (1) and flexibolide (4), in addition to the previously reported cembranolide delta -lactones, flexibilolide and dihydroflexibilolide, and the known cembranoid derivatives, sandensolide, cembrene A, and flexibilene (Anjaneyulu *et al.,* 1997). The ethyl acetate extract of the soft coral *Lobophytum catalai* collected from Diglipur Island of the Andaman and Nicobar group of islands, furnishes two new cembranoids 2 and 3, nephthenol 1, a novel furanosesquiterpene 4, four polyhydroxysterols 5-8 along with a mixture of sesquiterpenes and a mixture of monohydroxysterols and a glycolipid. 7(15)-Dehydrosarcophytin, 4 a new member of this novel class of diterpenoids has been isolated from the Indian Ocean soft coral *Sarcophyton elegans* besides sarcophytin 1 and 7-dehydrosarcophytin 2 (Anjaneyulu *et al.,* 1998).

Chemical examination of an unidentified species of the genus *Sinularia* yielded 9^{15}-africanene 1, ethyl arachidonate 2, 24-methylenechloesterol 3, batyl alcohol and a mixture of eicosyl, octadecyl and hexadecyl palmitates 5-7. The structures were determined on the basis of physical and spectral data. The crude ethanolic extract showed antibacterial effect against *E. coli, Bacillus pumilis, B. subtilis, B. megatherium, Proteus vulgaris, Staphylococcus aureus* and *Salmonella typhii* at 500 µg/ml concentration (Rao *et al.,* 1996).

The soft coral *Lobophytum microlobulatum* collected from the Havelock Island furnished nine lobane diterpenoids of which four are new, one norsesquiterpene and three polyhydroxysteroids along with a mixture of monohydroxysterols and a glycolipid (Anjaneyulu and Rao, 1996) and a new spingosine mixture in which the N-palmitoyl-2 amino-1,3 dihydroxyoctadeca-4, 8-diene (6) is the major component has been isolated from two soft corals- a new species of *Lobophytum* and *Sinularia conferta* of the Andaman and Nicobar Islands (Subrahmanyam *et al.,* 1996).

Two new sphingosine derivaties, N-hexadecanoyl- 1,3,-dihydroxy-2-amino-4, 8-octadecadiene 1 and N-heneicosanoyl- 1,3,4-trihydroxy-2-aminotetradecane 5 have been isolated from a soft coral *Sinularia crassa* of the Andaman and Nicobar Islands (Anjaneyulu and Radhika, 1999). N-(2'-Hydroxyeicosanoyl)-1,3,4-trihydroxy-2-aminoheptadec-5-ene 1, a new monounsaturated sphingosine derivative and a new sterol glycoside, (24 S)-24-methylcholest-5-ene- beta , 25-diol-3-O- alpha -L-fucopyranoside 2 have been isolated from a soft coral, *Sinularia gravis* of the Andaman and Nicobar Islands (Anjaneyulu *et al.,* 1999).

Two new sphingolipids, (2S,3S,4R) - 1,3,4-trihydroxy-2-[((R) -2'-hydroxytetradecanoyl) amino] tricosane (4) and (2S,3S,4R)-1,3,4-triacetoxy-2-[((R)-2'-acetoxyoctadecanoyl) amino]octadecane (5) along with africanene (1, reasonably good yield), 23-demethylgargosterol (2) and batyl alcohol (3) have been isolated from the soft coral *Sinularia leptoclados*. Preliminary studies for pharmacological activity (blind screening and toxicity studies) of africanene were conducted. Africanene exhibited *in vitro* and *in vivo* cytotoxicity, dose dependent hypotensive activity as well as antiinflammatory activity. The pharmacological and toxicity studies on africanene were done for the first time and findings strongly encouraged further investigation. Compounds 1, 4 and 5 were studied for the antibacterial, antifungal and antiviral activity while compounds 4 and 5 were also studied for the short term *in vitro* cytotoxic activity (Reddy *et al.,* 1999). Three new oxygenated africanenes (1-3) have been isolated from the soft coral *Sinularia dissecta* and were characterized by spectral and chemical studies (Ramesh *et al.,* 1999).

A new diterpene loba-8, 10, 13, 15, 17-pentaene 3 along with two known diterpenes 13, 15-epoxy loba-8, 10, 16-trien- 18-ol and fuscol 2 have been isolated and characterized from hexane soluble fraction of the methanolic extract of *Lobophytum punciflorum* (Babu *et al.,* 1998).

Three steroid glycosides, 24-methylenecholest-5-en-3 beta -16 beta -diol 3-O alpha -L-fucoside 1, 24-methylenecholest-5-en-3 beta , 7 beta , 16 beta -triol-3-O- alpha -L-fucoside 2, and 24-methylenecholest-5-en-3 beta , 7 beta, 16 beta -triol-4'-acetyl-3-O- alpha -L-fucopyranoside 4, in addition to 24-methylenecholesterol have been isolated from a new species of *Sinularia* of the Andaman and Nicobar coasts (Vanisree *et al.,* 1999).

A new sterol, 23,24(S)-dimethylcholest-5, 22-dien-3 beta, 7 alpha -diol (1), has been isolated from the soft coral *Lobophytum crassum* and characterized by interpretation of spectral data (Rao *et al.,* 1999). The soft coral *Sinularia maxima* yielded five terpenoids and one sterol, including two new furanocembranoid diterpenoids (1 and 2) (Venkateswaralu *et al.,* 1999).

Chemical examination of two new terpenoid from a new soft coral species of the genus *Nephthea* of the Indian Ocean furnished a new sesquiterpenoid and a new diterpenoid along with some sesquiterpenes and steroids. The structure of the new sesquiterpenoid has been established as 1S, 3R, 4S, 5S, 7S-3, 4-epoxy guaia- (10^{12}) -ene 3 and that of a new monohydroxy diterpenoid as 4 by a study of their physical and spectral data. Other known compounds isolated are (9^{15}) - africanene 1, 9-aristolene 2, the ubiquitous batyl alcohol 7, two 4 alpha -methylsteroids, 4 alpha -methylcholest-24(28)-en-3 beta -yl acetate 5 and 4 alpha, 23-24-trimethylcholest-22-ene-3 beta -yl acetate 6 two tolyhydroxy steroids, 3 beta, 7 beta, 19-trihydroxyergosta-5, 24 (28)-diene 11 and 24-methylenecholestane-3 beta, 5 alpha, 6 beta -triol 12 in addition to three monohydroxysteroids, 24-methylcholest-7, 25-diene-3 beta -ol 8, 24-ethylidenecholest-5-en- beta -ol Delta super(5)-avenasterol, 9) and 24-ethylcholest-5-en - 3 beta -ol 10. Besides the report of two new terpenoids, this is the first report on the presence of 4 alpha -methylesteroids in a *Nephthea* species (Anjaneyulu and Murthy, 2000).

Coral Distribution

Andaman and Nicobar islands comprise 135 species of scleractinian coral species belonging to 59 genera. Species of *Alveopora, Coeloseris, Seriatopora, Plerogyra, Physogyra* and *Oulastrea* are present here (only record from reefs of the Indian subcontinent). The reefs of Andaman are dominated by either *Acropora* sp. or massive *Porites* sp. in different parts. Wherever *Acropora* sp. is dominant *Porites* sp. is scarce and *vice* *versa.* The common species of *Acropora* are *A. humilis*, *A. pacifica, A. florida, A. prolifere, A. nobilis* and *A. formosa* along with *Seriatopora* and *Pocillopora* (James *et al.,* 1990). The coral reefs could be identified in MSS, TM, SPOT and LISS-II, FCC images, but not in SAR images due to the moisture content of the reefs. The living and non-living corals are characterized by turquoise-blue and greenish-blue tone in SPOT, FCC image of band combination 2,3,4. The interpretation keys for mapping coral reefs through remote sensing are given in Table 35 (Krishnamoorthy *et al.,* 1993). List of corals, sponges and floral species recorded from different islands of the Mahatma Gandhi National Marine Park (MNP), Wandoor is shown in Table 36 (Dorairaj and Soundararajan, 1997).

Table 35. Interpretation keys for mapping coral reefs through remote sensing

Land form	Tone	Texture	Size	Shape	Pattern	Association	Remarks
Fringing reefs	Greenish / turquoise blue	Smooth	Varying	Irregular wide to narrow	Scattered	Adjoining the coast	The non-living corals give greenish-blue, living corals turquoise blue tone
Platform reefs	Greenish / turquoise-blue	Smooth	Large	Almost Circular	Scattered	Offshore coast	Forming islands without any central lagoon
Patch reefs	Greenish / turquoise-blue	Smooth	Small	Almost Circular	Scattered	Offshore coast	A very small type, are called coral pinnacles

Source: Krishnamoorthy *et al.* (1993)

Occurrence and new distributional records for 26 species of Alcyonaceans are given. These include 12 species of *Sinularia,* 6 of *Lobophytum*, 6 of *Sarcophytum,* one of *Cladiella* and one of *Nephthea*. The ecological information as habitat and associations with the other organisms is also noted. A major factor limiting the distribution of soft corals is the availability of hard substratum for settlement. Other factors that determine their faunistic composition and abundance are correlated with resistance to harsh environments and life history parameters. Competitive interaction with other benthic reef-organisms also plays a major role in the distribution of soft corals in the Andaman and Nicobar Islands (Jayasree *et al.,* 1996).

Nearly 4% of the reef area of Mahatma Gandhi Marine National Park was covered with live and luxuriant corals of different species. Soft corals formed about 3% and dead corals 36% of the reef areas. Of the 31 corals recorded under 25 genera, *Acropora, Porites* and *Millepora* were the dominant forms (Dorairaj *et al.,* 1997).

Table 36. List of corals, sponge and floral species recorded in different islands of Mahatma Gandhi National Marine Park (MNP), Wandoor, Andamans.

Species	Jolly Boys	Red Skin	Tarmugil	Boat	Twins
HARD LIVE CORALS					
Pocilliporidae					
Seratopora hystrix	+	+	+	+	+
Stylopora pisitata	+	+	+	+	+
Pocillopora verrucosa	+	+	+	+	+
Acroporidae					
Acropora gravida	+	-	+	-	+
A. hyacinthus	-	+	+	+	+
A. nobilis	+	+	+	+	+
A. humilis					
A. efflorescens	+	+	+	-	+
A. Palifera	+	+	+	+	+
Acropora sp.	+	+	+	+	+
Asteropora sp.	-	+	+	-	+
Montipora sp.	+	+	+	+	+
Agaricidae					
Pavono sp.	+	+	+	+	+
Pachyseris sp.	-	+	-	-	+
Fungidae					
Fungia sp.	+	+	+	+	+
Herpolitha sp.	+	+	-	-	-
Poritidae					
Goniopora sp.	+	+	+	+	+
Porites sp.	+	+	+	+	+
Faviidae					
Favia sp.	+	+	+	+	+
Favites sp.	+	+	+	+	+
Platygra sp.	+	+	+	+	+
Leptoria sp.	+	+	+	+	+
Hydnopora sp.	+	+	+	+	+
Diploastrea sp.	+	+	+	+	+
Echinophora sp.	+	-	-	+	+
Oculinidae					
Galaxea sp.	-	+	+	+	+
Merulindae					
Merulina sp.	+	+	+	+	+
Mussidae					
Lobophyllia sp.	+	+	+	+	+
Symphyllia sp.	+	-	+	-	-
Pectinidae					
Mycedium sp.	-	-	-	-	+
Milliporidae					
Millepora sp.	-	-	-	-	+
SOFT CORALS					
Dendrophyllidae					
Turbinaria sp.	+	+	-	-	-
Sargophytum sp.	+	+	+	-	+
Sinularia sp.	+	+	-	-	+
Gorgonia sp.	-	-	-	+	-
SPONGES					
Phyllospongia sp.					
FLORA					
Sargassum sp.	+	+	+	+	+
Tubinaria sp.	+	+	+	+	+
Padina sp.	+	+	+	+	+
Halimeda sp.	+	+	+	-	-
Gracilaria sp.	+	-	-	-	-
Filamentous sp.	+	+	+	+	+
Seagrass	+	-	+	+	+

+ : Present - : Absent

Source: Dorairaj and Soundararaj (1997)

A severe incidence of coral bleaching was observed during July 1998 in some reefs in the Andamans. While more than 85% of corals near Ross island and Marina Park exhibited partial bleaching, upto 10% were totally bleached (Table 37). Necrotic lesions were also extremely prevalent in *Porites* sp. in Marina Park, Andaman about 90% of corals in these beds, comprising specimens of 15-30 cm in size, were affected. A number of fungi from necrotic lesions and bleaching coral colonies as well as from healthy colonies were isolated (Ravindran *et al.,* 1999).

Biodiversity and Productivity

The primary production of the reef near Port Blair, in Andaman Sea was found as 1200 g C/m^2/year which was found not to meet the respiratory requirements of the organisms and hence not self supporting (Nair and Gopinadha Pillai, 1969). The surface primary productivity varied from 1.3 to 9.7 mg C/m^3/day (Bhattathiri and Devassy, 1981). Gross production decreased from 4.51 g C/m^2/day over the corals to about 0.66 g C/m^2/day over the channels. In the channels, respiration exceeded production and the P/R ratio decreased to about 0.9. Over the corals, the P/R ratio increased to about 1.1 suggesting the ecosystem to have reached the stabilized state. The high rate of primary production with the help of the energy trappers of the first trophic level and with the calcification by corals, initiates the differentiation of the reef ecosystem from the general oceanic biome (Biswarup Mukherjee and Prakash Mehrotra, 1992). Lower oxygen value (0.2 ml/l) in the central region of the eastern section indicated that the central basin of the Andaman sea is cut off from the northern and southern regions by shallow sills (Sen Gupta *et al.,* 1981).

The alga was growing on coral debris in the subtidal (0.5 to 0.7 m) zone, and a few fronds were observed only from Indira Point. The most common associated algae in the vicinity of *Metamastophora flabellata* were, green algae: *Boodlea composita, Caulerpa* spp., *Cladophora patenteramia* and *Halimeda* spp.*,* brown algae: *Padina gymnospora* and *Turbinaria ornata* and red algae : *Amphiroa* sp. Coral species in association were mainly represented by *Acropora* and *Porites.* Stray occurrence of *Metamastophora flabellata* was recorded, for the first time from the Andaman Sea, India. Earlier this alga was reported to be confined only to the coasts of southern Australia and Africa. The specimen recorded here was smaller than that described from Australia and Africa. The presence of this alga at Great Nicobar Island indicated its further northward distribution (Jagtap and Chaugule, 1997).

Altogether 55 species of seaweeds were collected from the Andaman and Nicobar islands, of which 16 species belong to Chlorophyceae, 17 species to Phaeophyceae and 22 species of Rhodophyceae. Harvestable quantities of alginophytes as species of

Turbinaria and *Sargassum* were noticed in the western side of Diglipur jetty, coastal areas of Table Island and the Ariel Bay as a whole. The agarophytes and other algal groups were poorly represented (Gopinathan and Panigrahy, 1983).

Table 37. Causes of mortality in different locations.

Area surveyed	Location	Period of time	Colony	Cause of mortality
Kavaratti	Lagoon	Apr. 96-Nov. 98	*Porites lutea*	Necrotic patch
Kavaratti	Lagoon and intertidal	Nov. 97 and Feb. 98	*P. lutea*	Bleaching
Kavaratti	Lagoon	Nov. 97 and Feb. 98	*Acropora palmata*	Bleaching
Kavaratti	Reef slope	Nov. 97 and Feb. 98	*A. humilis*	Bleaching
Kavaratti	Lagoon	Apr. 97	*P. lutea*	Predation by *Acanthaster planci*
Kavaratti	Lagoon	Apr. 97-Feb. 98	*P. lutea*	Black band disease
Kavaratti	Lagoon	Apr. 97-Feb. 98	*P. lutea*	Coralline algal over-growth
Kavaratti	Reef slope	Feb. 98	*Porites* sp.	White band disease
Kadamat	Reef slope	Feb. 98	*Acropora* sp.	Bleaching
Kadamat	Reef slope	Feb. 98	*Porites* sp.	Bleaching
Kadamat	Reef slope	Feb. 98	*Acropora* sp.	Predation by *Acanthaster planci*
Kadamat	Reef slope	Feb. 98	*Goniastraea* sp.	Bleaching
Kadamat	Reef slope	Feb. 98	*Siderastraea* sp.	Algal over-growth
Kadamat	Reef slope	Feb. 98	*A. humilis*	Algal over-growth
Kadamat	Reef slope	Feb. 98	*Acropora* sp.	Algal over-growth
Kadamat	Reef slope	Feb. 98	*Acropora* sp. (table coral)	Algal over-growth
Vadinar	Reef flat	Aug. 96	*Favia* sp.	Bleaching
Vadinar	Reef flat	Aug. 96	*Pseudosiderastrea* sp.	Bleaching
Vadinar	Reef flat	Aug. 96	Favia sp.	Sedimentation
Vadinar	Reef flat	Aug. 96	Pseudosiderastraea sp.	Sedimentation
Vadinar	Reef flat	Aug. 96	P. lutea	Sedimentation
(Paga reef)	Reef flat	Sep. 97	Dead reef	Sedimentation
(Mangunda reef)	Reef flat	Sep. 97	Dead reef	Sedimentation
Ross island, Marina Park and North Bay (Andaman island)	Fringing reef	July 98	All branching and massive corals	Bleaching
Ross island, Marina Park and North Bay (Andaman Island)	Fringing reef	July 98	*Porites* sp.	Necrotic lesion

Source: Ravindran *et al.* (1999)

In the Middle Andaman, Aves, Soud, Ray Hill and Stewart islands were surveyed besides the coastal areas of Mayabunder. Most of the areas surveyed showed luxuriant growth of alginophytes such as *Padina, Turbinaria, Sargassum, Dictyota* and *Hormophysa,* especially at Oyster Point and German Jetty region of Mayabunder, western side of Ray Hill and Stewart Island. The harvestable quantity of agarophytes was found to be very poor. The seaweed vegetation was seen on the southern side of the Rangat jetty upto Nambuthalai at depth of 1-3 m with the domination of alginophytes which were in harvestable quantities. Seaweed vegetation with harvestable quantities of alginophytes was found in the rocky intertidal area of Havelock and lagoons of John Lawrence. The agarophytes were poorly represented (Gopinathan and Panigrahy, 1983).

The rocky coasts have seaweeds with the domination of alginophytes, but were not in harvestable quantity of Neil and Sir Hugh Rose islands. Seaweed vegetation was noticed in the coastal region of Macpherson strait towards Chiriatapu point. *Padina* spp. were dominant but did not occur in harvestable quantity.

The shores of Corbyn's Cove and Phoenix Bay of Port Blair region are rocky and have good algal vegetation. Harvestable quantity of alginophytes was noticed in Phoenix Bay. No good algal vegetation was found in the rest of the areas except Sesostris Bay and North Bay where *Ulva* spp. occur as drift weeds. The results of survey conducted in these areas showed that generally the algae were not abundant and most of them were not in harvestable size. Surveys made in 15 ha area in the Hut Bay and Butler Bay showed a potential of about 120 tonnes of fresh alginophytes from this area. Agarophytes such as *Laurencia papillosa, Gracilaria crassa, G. corticata* and *Halimeda peltata* were also seen as drift weeds in small quantities.

Almost the entire coast of Car Nicobar was surveyed and algal vegetation was found to be poor. In the Sawai Bay, alginophytes such as *Padina, Dictyota, Turbinaria* and *Hormophysa* and agarophytes such as *Gracilaria* and *Laurencia* were found in the sandy beaches as drift weeds.

The east and west bays of Katchall were surveyed and negligible quantities of seaweeds were seen on the sandy beaches as drift weeds. In the West Bay, the high wave action on the coralline rocky shore prevents the seaweeds from thriving, whereas in the East Bay, near Kapanga jetty, small areas have a good algal vegetation comprising species of *Amphiroa, Galaxuara, Turbinaria* and *Sargassum.*

Species of *Ulva, Halimeda, Laurencia* and *Gracilaria* were attached on the fringing corals and also found as drift weeds in the shore region of the Cross harbour and the Kakana regions of Camorta. The algal zone is very limited due to the steep increase of depth and luxuriant growth of corals around the island.

In the Champin and Spiteful Bay regions of Nancowry, a few alginophytes such as *Sargassum, Turbinaria* and *Padina* were observed. The agarophytes were represented by few numbers and *Ulva* spp. occurred in patches. In the coastal area of Trinkat which has a luxuriant growth of fringing corals, the algal vegetation was found very poor. On these coral reefs some of the attached forms such as *Gracilaria corticata, G. millardtii* and *Turbinaria conoides* were seen, but not in harvestable quantity. In the Campbell Bay region of Great Nicobar, in the vicinity of the jetty, Vijayanagar, Dilla-nalla and the coastal waters, *Turbinaria* spp., *Gracilaria* spp. and *Ulva lactuca* were noticed as drift weeds. They were not in harvestable quantity (Gopinathan and Panigrahy, 1983).

Phytoplankton population in Andaman and Nicobar Islands ranged from 1,400 to 4,900 cells/1. Dinoflagellates form an important constituent unlike those of Arabian Sea. The distribution of surface phytoplankton around little Andamans is shown in Table 38 (Devassy and Bhattathiri, 1981).

Among the reef inhabiting invertebrate fauna, the major groups found in the order of abundance were Gastropods (35%), Bivalves (25%) and Echinoderms (25%) (Dorairaj and Soundararajan, 1997). The general distribution of fauna in the intertidal zone showed more or less the same patterns as reported elsewhere. A quantitative estimation of the relative density showed the different groups of meiofauna to constitute 80% of fauna and Copepods, Isopods, Polychaetes and Archiannelids. Amphipods, Turbellaries and Nematodes to constitute about 10% of the fauna.

The total meiofaunal population was between 600 and 1,200/100CC (Chandrasekhara Rao, 1975). Nematodes constituted the dominant group (53.7%) followed by Harpacticoids, Polychaetes, Turbellarians, Isopods and Oligochaetes (Ansari and Ingole, 1983). Occurrence and distributional records of soft corals revealed 26 species. Further, new coral growth has been mapped offshore in a few places of MGNP (Krishnakumar, 1997).

Trochus niloticus was found as the common top shell of commercial importance, exploited in large quantities in and around Andaman and Nicobar islands. Shells of *Turbo* sp. were collected from a depth ranging from 6 to13 fathoms by skin diving. These shells were always seen underneath the rocks, coral stones and crevices of rocks or burried in the mud. A rough estimate of average quantity of shell landed from the islands ranged between 400 and 600 tonnes for *Trochus* sp. and 100-150 tonnes for *Turbo* sp. per year. Apart from *Trochus* and *Turbo* shells, *Xancus* sp., *Cassis cornuta,* *Lambis lambis, L. chiraga, Murex* sp., *Nautilus* sp., *Conus* sp. and *Cypraea* sp. were found commonly in this area (Appukuttan, 1977).

Table 38. Distribution of surface phytoplankton around little Andaman Islands.

	1198		1199	1200						1201			1202			1203		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Diatoms																		
Amphora sp.						100								200				
Coscinodiscus spp.	300		100		400	100		200	300	100		100	100					
Denloneis sp.	100	100				100		300	100				100			100		
Eucampia sp.	100			100														
Fragilaris oceanica															200			
Licmophora sp.													100	400			400	
Navicula sp.	700	600	200		1300	100	600	100		500	400		700	500	100	100	400	300
Nitzschia closterium			100															
Pleurosigma sp.		100									100							
Rhizosolenia sp.										100								
Total	1200	800	400	100	1700	400	600	600	400	700	500	100	1000	1100	300	200	800	300
Green Algae																		
Flagellates	1500	900	1000	700	1600	2100	700	1400	2200	900	1700	700	800	1400	2900	600	1800	1200
Blue Green Algae																		
Merismopedia sp.						400		400									200	
Symechocystis sp.							200					200					200	
Trichodesmium erythraeum		200	200			200				500			400					
T. thiebautii	500	700	500	400	500	400	100	200	300	600	300	200	800	900	100	200	200	600
Total	500	900	700	400	500	1000	300	600	300	1100	300	400	1200	900	100	200	600	600
Dinoflagellates																		
Ceratium spp.		100				100			100		100							
Peridinium spp.	700	200	200	200	100	100	200	100	400	200	400	200	200	100	100	100	100	100
Prorocentrum sp.		100		100			100		100			400					100	
Total	700	400	200	300	100	200	300	100	600	200	500	600	200	100	100	100	200	100
Unidentified																		
		200		100	100				100	100								
Total phytoplankton	**3900**	**3200**	**2300**	**1600**	**4000**	**3700**	**1900**	**2700**	**3600**	**3000**	**3000**	**1800**	**3200**	**3500**	**3400**	**1100**	**3200**	**2200**

a,b,c indicate the radial transect of each station

Source: Devassy and Bhattathiri (1981)

Four hundred and ninety species of fishes from the Andaman waters draw our attention to the paucity of information on the pelagic fishes of this area (Heere, 1941). The fish assemblage on the reef region was moderate on Twin islands, followed by Red Skin, Tamugil, Boat and Jolly Boys islands. Pomocentrids were represented by 5 species whereas Lutjanids, Acanthurids and Chaetodontids with 6 species each. These groups were common than the other groups. An overall fish assemblage analysis showed the Angel fishes to form 32%, Snappers and Fusilers 19%, Surgeon fish 18%, Coral fish 12%, Spine foot 4% and Wrasses 3%. Out of the 55 fish species recorded in the park area, many of them were highly priced ornamental fishes and tuna live bait fishes (Dorairaj and Soundararajan, 1997). Seven new records of labrid fishes belonging to four genera collected from reef areas of Andaman and Nicobar Islands were reported with distinctive characters and distribution (Rao *et al.,* 1992). The islands have the nesting beaches for Leather-back, Hawksbill, Olive Ridley and Green turtles and marine mammals such as Dugong. Several hundred estuarine crocodiles occur in densities inversely proportional to human population (Whitaker and Whitaker, 1978). Ahlawat *et al.* (2000) detailed the modern approaches to conserve the biodiversity of coral reef ecosystem of Andaman and Nicobar islands.

Current Status

Changing land use in the islands, including intensive modern agriculture practices using pesticides and organic and inorganic fertilizers are damaging the coral health (Krishnakumar, 1997). Today only some sites in the Andaman and Nicobar islands remain in pristine condition and the live corals show patchy growth in the reef area (Devaraj, 1997). According to Vineeta Hoon (1997) the Andaman reefs are in a better condition than the reefs in Lakshadweep and the Gulf of Mannar. The National Marine Park at Wandoor with an extent of 281.5 sq km enclosing 14 small islands is closely watched by the WWF of India.

There are several reports on the damage to and death of corals due to siltation and effluent discharges from the shore areas of south and middle Andamans (Dorairaj *et al.,*1987; Wood, 1989; James *et al.,* 1990). Factors like predation by crown-of-thorns, siltation of coastal waters, unfavourable environmental conditions, human interference etc. are also stated to be responsible for the damage and destruction of corals in Andaman and Nicobar islands. In some areas like Red skin island, corals in the reef slope are badly damaged mostly due to boat anchorage. Persistant shell collection has also caused considerable damage to corals on Twins island and Tarmugil island. Sedimentation appears to be the major cause for the declining health of most coral reefs. It leads to large scale mortality in reefs, reduced coral growth, reduced fertility, increased mortality of coral planulae and abnormal changes in polyp behaviour (Rogers, 1990). The mud deposits have been found on the reef area at few places near Port Blair, Flat Bay, Reef island etc. (Wood, 1989). Corals, particularly the branching types, are prone to breakage, especially in the areas open to tourists or fisherfolk and others. Mean dissolved petroleum hydrocarbons in the Andaman sea water was estimated as 51±1 g/1, using UV spectrophotometry, at 0 and 10 m. The contamination may be attributed to movement of passenger and cargo ships, fishing trawlers, land runoff and atmospheric fall out (Topgi *et al.,* 1981).

The "Crown-of-Thorns" Star fish *Acanthaster planci* feeds on coral polyps and often a plague of them is observed in many parts of the Indo-Pacific reefs causing mortality to vast areas of reef corals and their subsequent degradation. The species was previously recorded from several localities from Andaman and Nicobar islands such as Neil, Havelock, Sir Hugh Ross, Narcondum, Hut Bay, Chiriatapu and Nancowry but aggregation of the starfish which is extensively damaging the reef corals was never noticed upto 1980. Forest department and Fisheries department noticed a fairly good number of *A. planci* in the National Marine Park area at Wandoor. Crown-of-thorns are more common on *Acropora* sp. thickets than *Porites* sp. community. The maximum concentration of *Acanthaster* sp. was observed in Grub Island, nearly 50 m away from shore, in shallow waters. The skin divers collected 20 to 30 specimens in 20 minutes of slow swimming in this area. Fairly good abundance of *Acanthaster* sp. was also noticed at Twin Islands (85 specimens / 30 minutes). *Acanthaster* sp. is present in almost all reefs, surveyed in Andamans. At Wandoor, siltation was found as the prime factor causing mortality to corals in the nearshore area. Predation by *Acanthaster* might have played some role in the death of corals but was not found alarming. However, control of *Acanthaster* sp. will become virtually impossible when its population reaches millions. A single adult individual can produce as many as 20 million eggs in a spawning season. If conditions are favourable, hundreds of thousands of them can settle on the reef and cause total bleaching of the reef (James *et al.,* 1990).

There is also over exploitation of molluscs from the Andaman reefs in the recent past. In few stations, corals were partially damaged due to boat anchorage, trampling, over turning the coral blocks, snorkelling and SCUBA diving, human interference and crown-of-thorns starfish predation (Dorairaj and Sundararajan, 1997). Based on the species diversity and extent of live coverage, the status of coral reefs of the park is broadly classified as 'good' in Red Skin and Twin Islands and as 'fair' in Jolly Boys, Tarmugli and Boat Islands (Dorairaj *et al.,* 1997). Due to the over exploitation of marine resources in the Island, conservation of coastal and marine resources in the protected areas of Andaman and Nicobar Islands is necessary. Adherence to the (1) Constitution of India, (2) Wildlife Protection Act 1972, (3) Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), (4) Environment Protection Act, 1986, as the Coastal Regulation Zone Notification 1991 and (5) The Fisheries Act of Andaman and Nicobar Islands (Kumar, 1997) in letter and spirit will help in achieving it.

9. CONSERVATION AND MANAGEMENT OF CORAL REEF ECOSYSTEMS

Reef resources are traditional sources of food and income to the local coastal people. In India, coastal people exploit most of the biological resources especially algae, reef fishes, holothurians, shrimps, lobsters, crabs, molluscs etc. Significant increase in human population and poverty so also utilization and competition for the reef resources have resulted in indiscriminate harvest of the biodiversity of the coral reefs. Compared to a developed nation like Australia which has the Great Barrier Reef, we are lacking in facilities, equipment, trained manpower and resources for marine biodiversity conservation. It would be more appropriate if alternate livelihood is found out for the coastal people and this in turn will take care of marine biodiversity conservation. Other than the anthropogenic impacts, the natural calamities like E1 Nino, cyclones, sea level variations, current pattern changes, increased nutrient levels etc. also affect the health of the coral reefs directly or indirectly. Sediment deposition over the coral reefs due to erosion of coasts arising out of destruction of coastal vegetation has become a major problem in all the coral reef areas. Sedimentation and siltation are not only related to anthropogenic impacts but can also be caused by natural events like current patterns, upwelling etc. The mudflat formed over the reef areas in the Gulf of Kachchh could be due to Indus river deposits.

In the coral reef ecosystem of India no concerted biodiversity assessment has been done which will help to compare the changes brought out by anthropogenic influences and natural calamities. Broad scale surveys using manta tows will give an estimate of coral cover, both live and dead, besides biodiversity and distribution and such technique has not been used so far.

The available information on coral reef fishes of India shows that Lakshadweep received considerable attention. Similar attention was not paid to coral reef fishes inhabiting the reefs of Andamans and the Gulf of Mannar. Gulf of Kachchh received the least ichthyological activity. However, intensification of efforts in the Gulf of Kachchh region is not likely to yield good results due to an almost dead environment (Anand and Pillai, 1995).

For the effective management and monitoring of the Indian coral reefs, the following suggestions are made.

- At present, there are no clear cut data about the qualitative and quantitative assessment of coral reef resources. So the policy makers and managers could not make any legislation to conserve the coral reef ecosystem for the sustainable utilization of its resources. Hence, we have to fill up the gap by understanding, micro and macro level surveys with special reference to coral reef resources.

- Legislation must be enacted to protect the coral reefs. Legislation without enforcement gives little protection. Although Marine Park and Biosphere Reserve legislations have been introduced, occasional poaching continues. This needs immediate attention.

- Reef management through protected areas should be given thrust to facilitate the recovery of devastated areas, which will protect the breeding stocks, improve recruitment from neighbouring areas, help in the sustainable utilisation of reef resources and halt further degradation. Reserves for breeding stocks need to be established in healthy habitats to increase the spawning potential in the reef ecosystem.

- Research priorities should be given for artificial breeding of reef organisms, to study the effects of sedimentation, fishing in reef zones, regeneration rates, comparing the productivity of stressed and unstressed reefs and determining the sustainable yield.

- Artificial reefs can be established in suitable locations of the islands and their performance evaluated. Pollution indicator studies need to be conducted to select healthy habitat for the protected areas and the discharge of pollutants to be restricted.

- Over-exploitation of reef resources for the ornamental trade need to be controlled.

- Strict enforcement of a ban on picking of live corals shoud be done.

- Entry to the islands shoud be strictly restricted with proper permission from the Marine Park Authority and that too only for special and essential purposes such as education and research.

- Removal of coral stones and beach sand for construction purpose should be curtailed. Efforts should also be made to get bricks and granite stones available at subsidized rates for people in these areas.

- Anchoring of boats over good coral cover areas should be prohibited. Fishermen should be made to understand the need for anchoring the boats only in non - reef areas.

- Collection of aquarium fishes and live bait shoud be restricted to designated areas only. This would greatly help to create undisturbed breeding grounds for coral reef fishes.

- Data on the potential harvest rates, carrying capacity, habitat selection, coexistence and species interaction of the coral reef ecosystem have to be collected.

- Documentation of genetic characteristics of reef communities is required to enable the management of reef ecosystems through modern techniques.

- Our knowledge on economic values of the biological resources of the coral reef ecosystems of India in the International market has to be improved for integrating it with the coral reef management.

- International collaboration and regional strategies are to be strengthened in the conservation and management of marine resources, especially for the migratory members of reef system.

- Staff strength, facilities and training needs of the agencies concerned with coral reef management for monitoring and sustainable utilization of the Indian coral reef ecosystems have to be increased.

- As the coral mass mortality may have profound ecological and socio-economic implications, sustained monitoring of coral reef has to be undertaken.

- Zoning plan on coral reef ecosystems for management purposes and legal status for each category have to be implemented.

- Coral reef ecosystem modelling for the sustainable utilization of the coral reef resources of India has to be evolved.

- Over fishing in the reef zone should be avoided. Reef mining should be controlled and sufficient time be given for the corals to grow and build up.

- Fishing using dynamite and other explosives in the reef environment should be banned. Stringent actions should be taken to save this fragile ecosystem.

- Research works should aim at understanding the influence of biotic and abiotic factors on the patterns and distribution of coral reef associated plants and animals.

- Remote sensing of coral reef is also becoming an increasingly useful technique to monitor the changes in reef and it can be used extensively.

- Deforestation should be avoided to eliminate massive siltation.

- The network between the managerial agencies of coral reef ecosystems of India has to be strengthened.

- Environmental education programmes in schools and villages are also extremely important to help local people to understand the importance of reef resources. Such programmes will help in effective enforcement of regulations.

- Pamphlets and guidelines need to be issued to chartered boat operators.

- An awareness shoud be created among the fishermen and the public not to overexploit the coral reef resource. The importance of the coral reefs shoud be taught to them.

10. CONCLUSION

Coral reefs are beyond doubt one of the planets greatest attractions and beautiful presentations. Having a riot of colours, they present, a breathtaking and enchanting sight to the viewers. Individual coral animals, mostly existing in colonies, are the primary building blocks of the reef. Corals are described as the rich repository of biodiversity due to high number of habitat opportunities afforded by this environment. In the Indian subcontinent, the reefs are distributed along the east and west coasts at restricted places. The major coral area in the west coast includes Gulf of Kachchh, apart from Lakshadweep and in the east coast, the Gulf of Mannar and Palk Bay.

Over 578 research papers concerned with Indian Coral reefs have been published. Ecological studies dominate constituting around 27.16% of the papers followed by faunal studies which include 17.30% of the papers published. Research work in the fields of microbiology, geology, hydrobiology, taxonomy, toxicology, plankton and flora contributed each around 10% with toxicological studies forming the least with 1.9%. Consolidation of all the works carried out and detailed investigations on the gaps existing and evolving of suitable policies will go a long way for the proper utilization, management and preservation of this wonderful creation of Mother Nature.

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APPENDIX –1

LAW AND POLICY FOR PROTECTION AND CONSERVATION OF THE CORAL REEFS OF INDIA

The law and policy for coral reef conservation in India is virtually non-existent, but there are very few laws in the country that can be activated for the protection of coral reef areas such as the Environment Protection Act, 1986, and the Coastal Regulation Zone (CRZ) Act (the only law explicitly outlaw coral reef degradation) 1991, issued under the broad Environment Protection Act (EPA) as well as the Wild Life Protection Act (WPA), 1972. The other laws that would have a bearing on coral reef area conservation are, Indian Forest Act, 1927, the Forest Conservation Act, 1980 and the Indian Fisheries Act. Various State Fisheries Acts would be relevant for conservation and management of coral reefs. It must, however be noted that in WPA, coral reef areas have no separate legal status. The Marine National Park which is the governing authority of some coral reef areas is coming under the charge of the Ministry of Environment and Forests, Govt. of India. However, the National laws that are applicable to coral reef areas involve various Government Agencies (State Forest Department, Fisheries Department and most recently the State Coastal Management Authority.

CONSTITUTION OF INDIA

Art. 48-A: The State shall endeavour to protect and improve the environment and to safeguard the forests and wildlife of the country.

Art. 51(g): Impose a similar responsibility on every citizen to protect and improve the natural environment including forests, lakes, rivers and wild life and to have compassion for living creatures.

ENVIRONMENT PROTECTION ACT, 1986

SECTION 3(1): Central Government shall have the power to take all such measures as it deems necessary or expedient for the purpose of protecting and improving the quality of the environment and preventing controlling and abating environmental pollution.

WILD LIFE PROTECTION ACT, 1972 (last amended in 1991)

SECTION 29: No person shall destroy, exploit or remove any wild life from a sanctuary or destroy or damage the habitat of any animal or deprive any wild animal of its habitat within such sanctuary except under and in accordance with permit granted by the Chief Wildlife Warden and no such permit shall be granted unless the State Government is satisfied that such destruction, exploitation or removal of wildlife from the Sanctuary is necessary for the improvement and better management of wildlife therein and authorizes the issue of such permit.

SECTION 35(I): Declaration of National Parks (this includes the Coastal and Marine Protected areas).

SECTION 35(6): Prevention against destruction, exploitation, removal of any Wild life from a National Park or destruction or damage of the habitat of any wild animal or deprive any wild animal of its habitat such National Park is necessary for the improvement and better management of wildlife therein, authorizes the issue of such permit.

SECTION 39:

Every

a) wild animal other than vermin which is hunted under section 11 or sub sec. 35 or kept or bred in contravention of any provision of this act or any rule or order made there under, or found dead, or killed by mistake.

b) animal article, trophy or uncured or meat derived from any wild animal referred to in CI (a) in respect of which any office against this act or any rule made thereunder has been committed,

c) ivory imported into India and an article made from such ivory in respect of which any offence against this, Act or any rule or order made thereunder has been committed.

d) vehicle, vessel, weapon, trap or tool for committing an offence under the provision of the act – shall be the property of the State Government and, where such animal is hunted in a Sanctuary or National Marine Park declared by the Central Government such animal, trophy, uncured trophy, or meat derived from such animal or any vehicle, vessel, weapon, trap or tool that has been used in such hunting, shall be the property of Central Government.

THE COASTAL REGULATION ZONE NOTIFICATION 1991 (NOTIFICATION NO.114(E) OF 19 FEBRUARY 1991).

Notification under section 3(1)and section 3(2)(v) of the Environment (Protection) Act 1986 and rule 5(3)(d) of the Environment (Protection) rules, 1986, declaring coastal stretches as Coastal Regulation Zone (CRZ) and regulating activities in the CRZ. For regulating the development activities, the coastal stretches within 500 mts. of the high tide line of the landward side are classified into 4 categories.

Some of the prohibited activities in the CRZ are listed below:

*setting up of new industries and expansion of industries in the CRZ areas.

*manufacture and handling or storage or disposal of hazardous substances.

*setting up or expansion of fish processing units including warehousing (excluding hatchery and natural fish drying)

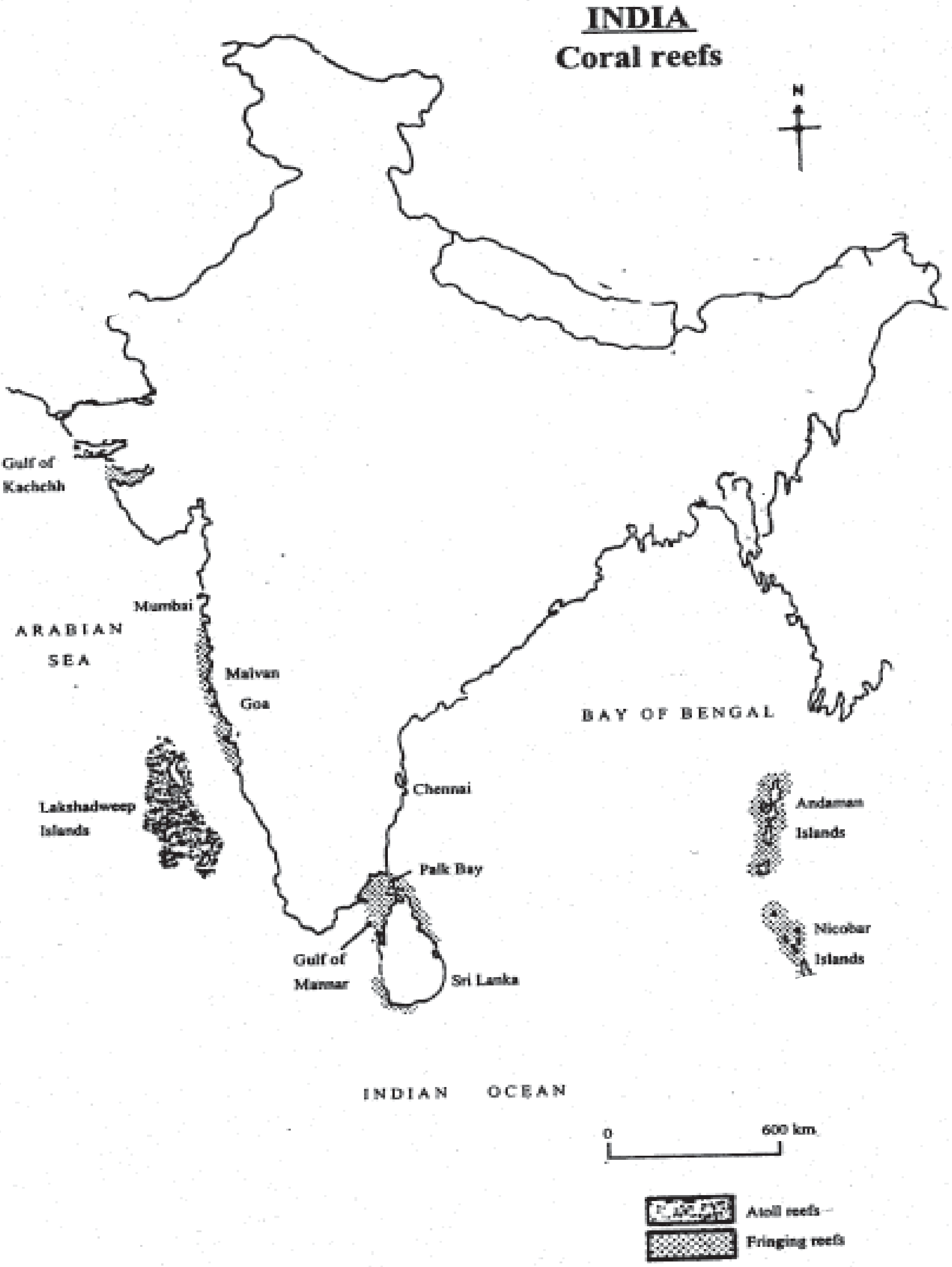
*land reclamation, bunding or destructing the natural course with similar obstructions except those required for control of coastal erosion.

*mining of lands and other substrate materials.

*harvesting or trawl of ground water and construction of mechanisms, within 200 mts of HTL in the 200 mts-500 mts it shall only be permitted when done manually through ordinary wells for drinking, horticulture, agriculture and fisheries.

*construction activities in the ecologically sensitive areas.

*any construction activity between the LTL and HTL except facilities for carrying treated effluents and waste water discharges into the sea, facilities for carrying sea water for cooling purposes, coil, gas and similar pipelines under this notification.



Published by the Environmental Information System Centre, Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai - 608 502, Tamilnadu, India.