PRESENT STATUS OF CORAL EROSION IN LAKSHADWEEP
WITH SPECIAL REFERENCE TO MINICOY

THESIS SUBMITTED

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By

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CERTIFICATE

This is to certify that this thesis entitled "Present status of coral erosion in Lakshadweep with special reference to Minicoy" embodies the bonafide original research work conducted by Shri Navas, K.A. under my supervision and guidance. I further certify that no part of this thesis has previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles or recognition.

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DECLARATION

I hereby declare that this thesis entitled "Present status of coral erosion in Lakshadweep with special reference to Minicoy" is a record of original and bonafide research carried out by me under the supervision and guidance of Dr. K.J. Mathew, Scientist, Central Marine Fisheries Research Institute, Kochi and that no part there of has been presented for the award of any other degree, diploma, associateship, fellowship or other similar recognition.

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NAVAS, K.A.

C O N T E N T S

PREFACE

Coral Reefs are marine, biogenic, wave resistant carbonate structures, formed of the skeletal remains of hermatypic, or reef building organisms. The main reef builders are calcifying Rhodophytes, molluscs, sponges, polychaetes and Cnidarians. Among them, scleractinian corals and hydrocorallians are by far the most important contributors to the formation of reefs. Coral reefs cover approximately 600 thousand square kilometres of the earth's surface (Crossland et al., 1991) which is about $2x10^6$ square kilometres of tropical oceans (Achituv and Dubinsky, 1990).

Coral reefs are possibly the most productive marine ecosystems in the world and contribute about 1% of the total net primary production in marine realms. Despite their relatively small contribution to overall marine primary production of the globe their existence is of great importance from the social and resource point of view. Coral reefs are important to many islands and continental margins because they protect the coastline againt waves and storm surge. They also provide nursery grounds for juveniles of coral reef fishes and hence influence commercial fisheries too. Coral reefs also allow the development of shallow sedimentary basins and the associated mangrove and seagrass communities.

Ever since man first discovered coral reefs, he has devised means of harvesting their productivity and resources. Fish, turtles, spiny lobsters, octopus, conches, clams, oysters and sea weeds form the basis of harvestable coral reef resources. The coral reefs are estimated to have a potential yield of about 9% of global commercial oceanic fish landings (Smith, 1978). Reef fishes also form an important export industry in many developing countries. Dead coral rock and living colonies are mined from reefs for the production of lime and for building-blocks. SCUBA diving and snorkelling form the basis for tourism and economic development for many small island nations like Seychelles and Maldives. Local residents nonetheless benefit from the use of coral reefs for recreation, by employment opportunities.

Because of their importance, the International Union for Conservation of Nature and Natural Resources (IUCN), considered the maintenance of reefs, a global priority (Salm and Kenchington, 1988).

Coral reefs have often been described as fragile ecosystems which are in delicate balance with nature (Loya and Rinkevich, 1980). They are extremely vulnerable to forces of destruction. The destructive forces can be divided into the physical chemical and the biological. The most obvious of the physical-chemical group is the effect of waves, storms, reduced salinity, silting from land drainage, temperature changes, erosion effects from tidal and other currents, burying by shifting sand, dessication and solar radiation during low tides. As a result of man's activities in recent decades the effects of chemical pollution, dredging and blasting have also contributed for the destruction of corals. The biological agent of destruction include animals which feed directly on the coral such as polychaetes, fishes, as well as those organisms such as bacteria, blue-green algae, sponges, polychaetes sipunculids, and molluscs which bore the dead coral rock of reefs. The grazing animals such as fishes, molluscs and echinoids which scrape the surface layers of coral substrates which have often already been weakened by the boring organisms also contribute to the destruction of coral reefs. Other organisms which grow over living corals such as non-calcareous algae, tunicates and sponges also kill the corals. Hence a coral reef is not a static solid structure that it seems to be. It is an everchanging complex community representing at any moment an equilibrium between the destructive forces and the reproducing developing and growing reef organisms.

The Lakshadweep atolls are no exception to this phenomenon of destruction of coral reefs and their environment. Recently, the coral reefs at Lakshadweep and Minicoy in particular have been reported to be fast deteriorating due to natural and manmade interferences (Pillai, 1990). In view of the recession observed of reef building and reef dwelling organisms, the coral reefs of Lakshadweep have been identified as one area which needs highest priority for the protection of the ecosystem by the International Union of Conservation of Nature and Natural Resources (Anon, 1988).

A sound knowledge on the extent of coral degradation as well as the various agents of destruction acting the coral reefs is essential for the effective management of these degrading ecosystems. Detailed information on the role of the destructive agents in the breakdown and erosion of calcareous materials is also imperative to provide guidelines for developing and implementing rational policies for the conservation of the coral reefs. It would also serve as a pre-requisite for planning future optimum utilization of the resources by man.

Eventhough the problem of destruction of reefs and their environment is reported to be most severe in the Minicoy atoll among other Lakshadweep islands, long term studies on the present status of coral erosion in this atoll is lacking. Reports on the various biological agents of coral destruction as well as human interferences on coral reefs of Minicoy atoll in scanty. The few reports which are available are based on short term studies carried out at wide intervals in the island (Appukuttan, 1973; Murthy et al., 1979; James et al., 1989). The geographic isolation of this atoll from the mainland as well as from other islands of Lakshadweep has been one major reason for the dearth in information and long term studies.

In view of the lack of information on the topic under consideration, an attempt has been made in the present study to investigate qualitatively and quantitatively the agents of coral reef destruction and erosion of calcareous materials in the Minicoy atoll. This study is also considered relevant in the present context since, of late the Government of India has assigned top priority for a planned development of the Lakshadweep islands.

Results of the studies conducted for a period of two years (January 1990 to December 1991) in the Minicoy atoll is embodied in the present thesis entitled "Present status of Coral Erosion in Lakshadweep with special

Reference to Minicoy". The thesis consists of four chapters, a Summary and a Reference Section of the literature cited in the text. Each chapter from 1 to 3 has an 'Introduction' 'Review of Literature' relevant to the chapter, 'Materials and Methods', 'Results' and 'Discussion'. Chapter 4 has a brief description of the Influence of human interferences on coral reefs of Lakshadweep.

The first chapter gives an account of the survey carried out in the Minicoy lagoon giving percentage of live and dead coral cover. The species diversity and composition of the corals are also included.

Results of the ecological characteristics of the Minicoy Atoll such as hydrography, sedimentation and current pattern form the second chapter. A comparison of the ecological processes on the windward and leeward sides of the island is also included.

The third chapter deals with different faunal groups which are responsible for the erosion of reefs in the atoll. The distribution pattern and also the time dependent changes of some of these faunal components in the atoll are dealt with.

A brief description of the influence of human activities which contribute to the destruction of coral reefs and the precautions to be taken for the effective management of the ecosystem are presented in the fourth chapter.

CHAPTER - I

A SURVEY OF CORAL REEFS

INTRODUCTION

Physically and organically the coral reefs are complicated structures and are the result of a near balance of both constructive and destructive forces. The constructive forces are largely organic. Besides the growth of corals - the accumulation of materials such as calcareous algae, foraminiferans, molluscs - is included in the process of reef construction. Physical constructional forces are those that help in the consolidation of the accumulated debris by cementing with calcium carborate, which is precipitated from sea-water. The filling of cavities in corals and algae by the entrapment of particles is also an important physical constructional force.

Of the various destructive forces acting on coral reefs, bioerosion is one of the most important. It is often considered to be one of the major components of the destructive forces. Several species of boring sponges have been reported, causing extensive damage and destruction to the reef system. The polychaete Eunice burrows with hard jaws while some sipunculids burrow with hard skeletal material present at the anterior and posterior end of the body. The cirripede Lithotrya is another inhabitant of coral reefs excavating burrows in coral rocks by means of the studs on the peduncle. These studs consist of a chitinous core overlain by a calcareous covering. See urchins are also represented by forms such as Cidaris and Echinostrephus on the coral reef. Besides there are other species that are found in the sheltered areas of the reefs feeding on coralline and non-coralline algae. By far the most destructive agents of the coral reefs are the boring bivalves. These act as effective agents in the erosion of hard coral stones. These boring bivalves - are represented mainly by Lithophaga, Gastrochaena and Petricola. Fishes nibble off coral and calcareous algae, thus causing slow degradation of the coral reefs. Besides these, the solutions of calcareous materials also occur but the amount of material lost in this way is very small in comparison with the amount ultimately extracted from the sea.

There is a world-wide recession of reef-building and reef dwelling organisms as reported by many workers (Gardiner, 1936; Stoddart, 1969; Banner, 1974; Nishihira and Yamazato, 1974). In certain areas like Indonesia, destruction of coral reefs is proceeding at an alarming rate (Sukarno, 1984). In view of the significant contribution of coral reefs to productivity of coastal waters and their vulnerability to increasing rates of degradation, there is an immediate need for the rational management of these resources.

For the effective management of coral reefs, a sound knowledge on the extent of coral degradation is essential. A proper understanding of the various agents of destruction acting on the coral reefs would be useful for protecting these fragile ecosystems. A systematic survey of the coral reefs is also necessary for documenting information on the present status of coral erosion.

Till date, no effort has been made to describe the quality of corals in the Minicoy Atoll where the problem of coral bio-erosion and degradation is highly pronounced (Pillai, 1990). A survey of the lagoon was considered useful to provide information on the quality of corals in terms of percentage live and dead coral. This is particularly important in this context since Lakshadweep has been identified as an area which needs highest priority for the protection of the ecosystem (Anon., 1988). The present study was taken up with the following objectives:

1. to determine the percentage of live and dead coral cover in the atoll.
2. to determine the species diversity of corals in the lagoon.
3. to collect coral samples for studying the different bio-eroding agents causing coral destruction over different seasons and

4. to estimate the other associated fauna quantitatively

REVIEW OF LITERATURE

Earliest reports on the coral fauna of India were mainly based on two expeditions; the first one led by the British naturalist A. Alcock during 1891 (R.M.S. Investigator) followed by the expedition led by Prof. J. Stanely Gardiner in 1899 (Cambridge University Expedition). Results of the former expedition focussed mainly on the deep sea fishes while results of the latter gave a detailed account of the fauna and geography of the Lakshadweep (Gardiner, 1903, 1906). Several years later, a series of studies were carried out on the distribution of various genera of corals in the different islands of Lakshadweep (Pillai, 1971a,b, 1972, 1973 and 1986). Pillai (1987) presented a resume of corals and coral reefs of Minicoy, describing a total of 78 species of corals divided among 31 genera. Later Pillai and Jasmine (1989) increased the number of species to 104, comprising of 37 genera. Recently Suresh (unpublished) based on a survey extended to seven islands of Lakshadweep, except Minicoy, and described a total of 110 species divided among 40 genera.

The following is an account of the detailed survey carried out in the lagoon of Minicoy Atoll for understanding the present status of coral erosion.

MATERIAL AND METHODS

Site of study Minicoy Atoll

Location The atoll of Minicoy (Lat. 8°17'N - Long.73°E) is situated to the south-west of peninsular India about 400 km from the mainland. The Nine Degree Channel separates Minicoy from Kalpeni Atoll lying to the north-east. In the south the Eight Degree Channel separates Minicoy from Ihavandifulu Atoll of the Maldive Archipelago (Fig.1).

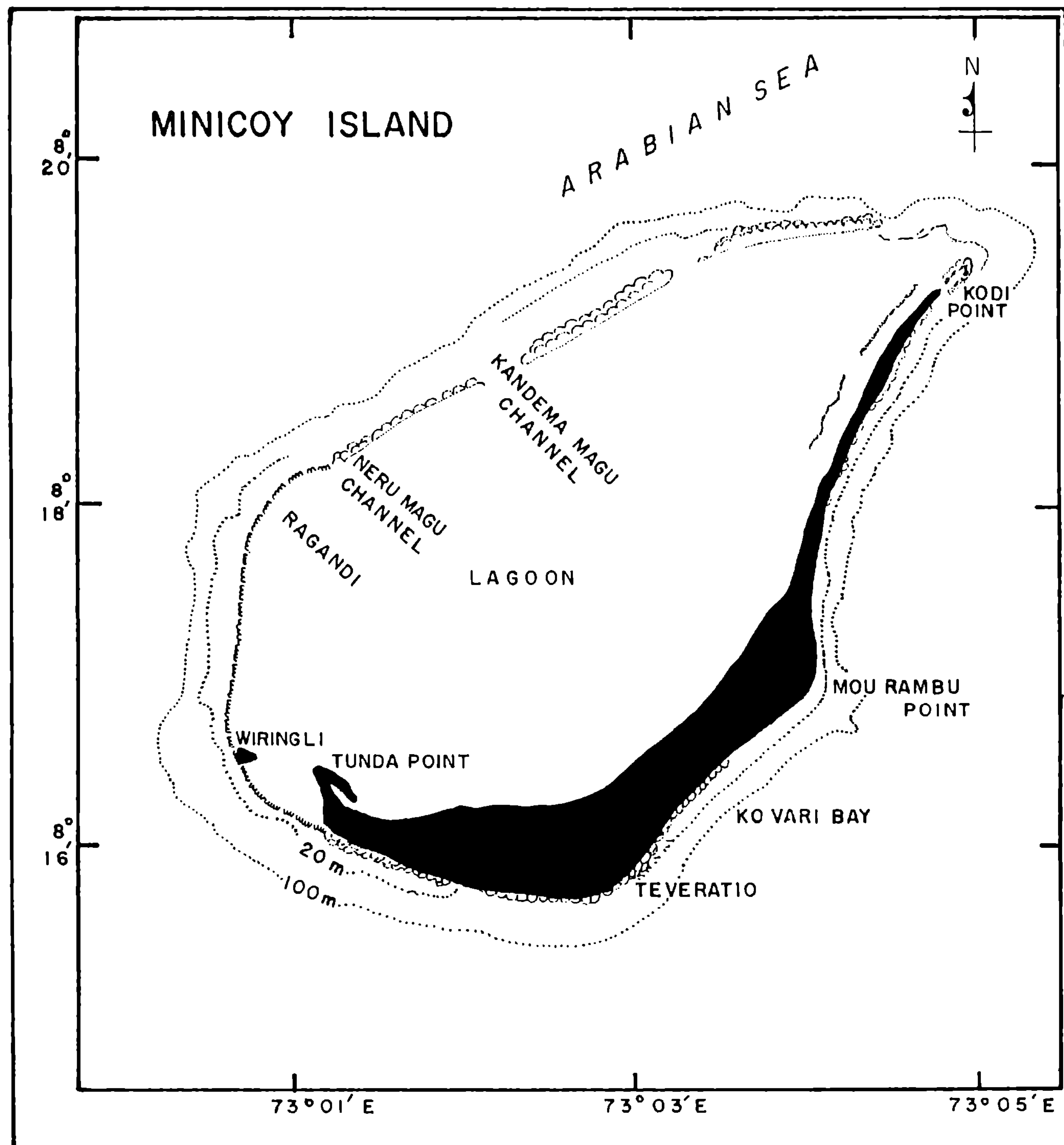


Fig. 1. Location of Minicoy Island.

Topography: Minicoy Atoll is approximately oval shaped, elongated in a north-east - south-east direction (Fig. 2). The atoll is about 8 km long with the greatest width of 4.6 km at the centre. The island is about 9.5 km in length. The maximum width of the island is about 600 metres. The villages are located at the mid length of the island. The lagoon side of the island (windward) is sandy. Coral shingle are piled up at the north-eastern and the south-western ends of the island. The seaward side of the island (leeward) is mostly rocky with the heavy breakers on the reef flat. The island has a height of 1.8 m from the mean sea level.

The lagoon: The lagoon occupies an area of about 35 sq. km. It is generally shallow with depth ranging from 1 to 13 metres. At several places in the lagoon, shoals arise from the bottom of which a few get exposed during neap tides. The major part of the lagoon is intersected by channels. On the southern side of the lagoon, there is a sand flat, covering about less than one third of the total area of the lagoon. This sand flat extends upto the reef on the west and north. Excepting a small part, the whole area remains always covered by water even during neap tides.

The Reefs: On the windward side, there are three channels on the atoll reef, viz: Neru-Magu, Kondi-Ma and Weli-Gandola (Fig. 2). The main passage, Tori-Gandu channel is situated at the northeastern side of the atoll. There are two small islands (Wiringli and Ragandu) on the reef extending from Tunda Point. These islands are composed of coral shingle and reef blocks, covered by loose sand. Between these two islands, there is a small channel, the Choru-Magu, formed by the removal of corals. The reef extending from Tunda Point to Neru-Magu gets exposed at low tides while the remaining area of the reef is always submerged.

The leeward reef is characterised by the presence of heavy breakers and coral boulders (Plate II).

Kalpeni Atoll: Kalpeni island is about 5 km long and 1.3 km wide (Fig. 3) situated in the north is the Cheriyam Island which is about 2.8 km long.

The maximum width of this island is about 300 metres. Situated to the west of the islands is the lagoon. It is about 10.5 km long and has a maximum width of 4.3 km in the centre. There are two small groups of small islands situated in the southwestern part of the lagoon. On the windward side, the beaches are sandy while on the leeward side, the beaches are in general made up of coral boulders and coral shingle. There are a number of surge channels on the leeward margin of the atoll (seaward margin).

The lagoon of the Kalpeni Island is situated to the west of the island. It is about 10.5 km long, with a maximum width of 4.3 km near the centre. The lagoon is shallow with the depth ranging from 1 to 5 metres.

THE SURVEY

During the two year period from January 1990 to December 1991, a series of day trip surveys were carried out.

The rapid survey technique (Harger, 1984) was adopted to study the extent of coral erosion in the lagoon. This method was preferred because it was less time consuming, less expensive and operable with a small number of people.

Prior to the actual survey, a pilot study was conducted to make a preliminary estimation of the distribution of coral communities in the lagoon. The objective of this pilot survey was to make a rapid and superficial coverage of the distribution of coral communities in the lagoon. This was then developed into a more precise programme of detailed studies at the sampling sites. For the pilot survey, a small outboard motor boat was used to pull a diver (the candidate) at the end of a 20 m long nylon rope of 3 cm diameter. This method is similar to that reported by Kenchington (1978) who used a 'manta board' at the end of the bowline.

For convenience of the survey, the atoll was divided into 9 zones (Fig. 2) as given by Pillai (1971). The zones 1, 2, 3, 4, 7 and 8 are located in the lagoon and 5 and 6 on the peripheral reef. Accordingly, a series

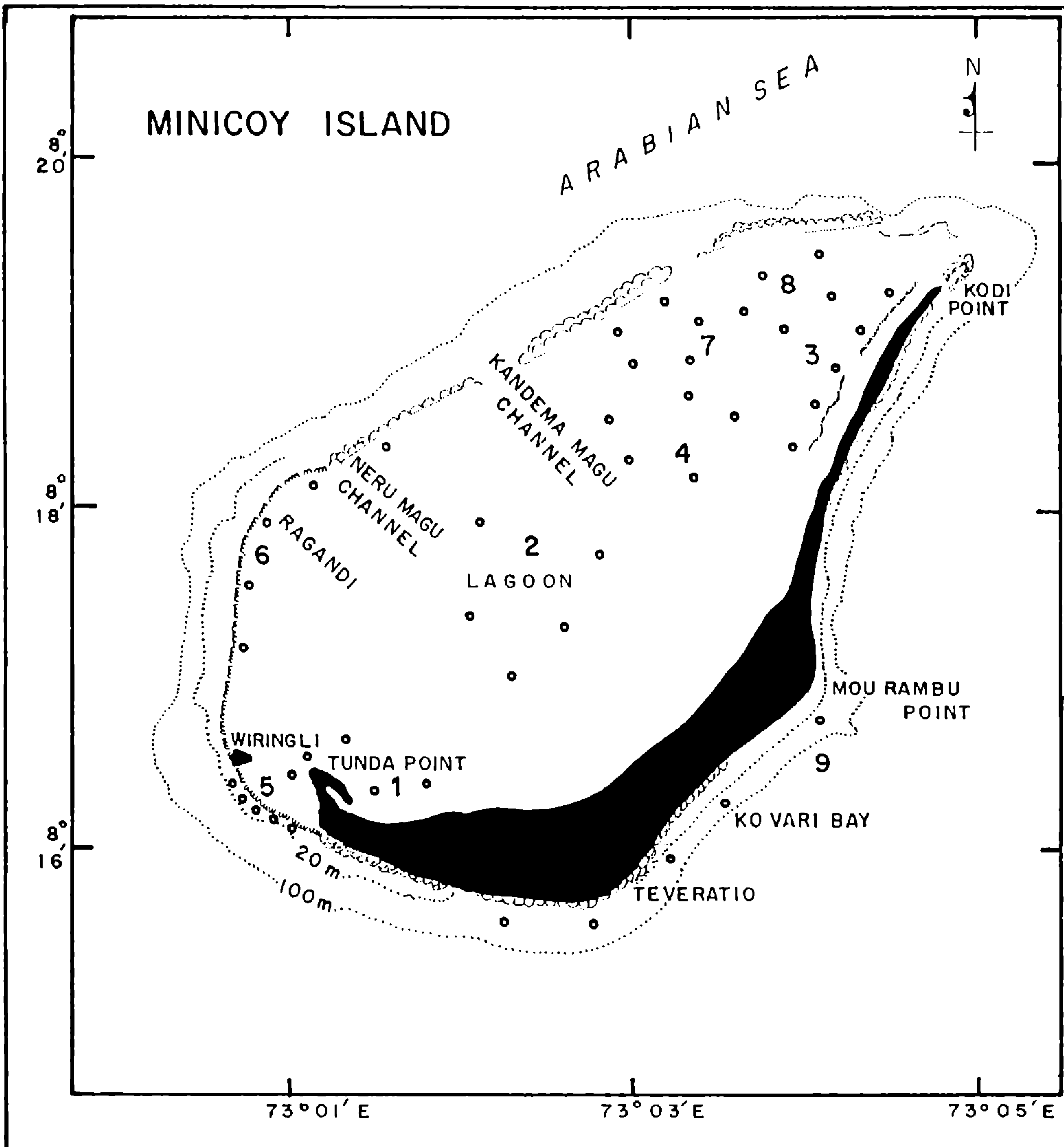


Fig. 2. The different zones and sampling stations in the Minicoy lagoon where the survey was conducted. Dotted line indicate the reef margin.

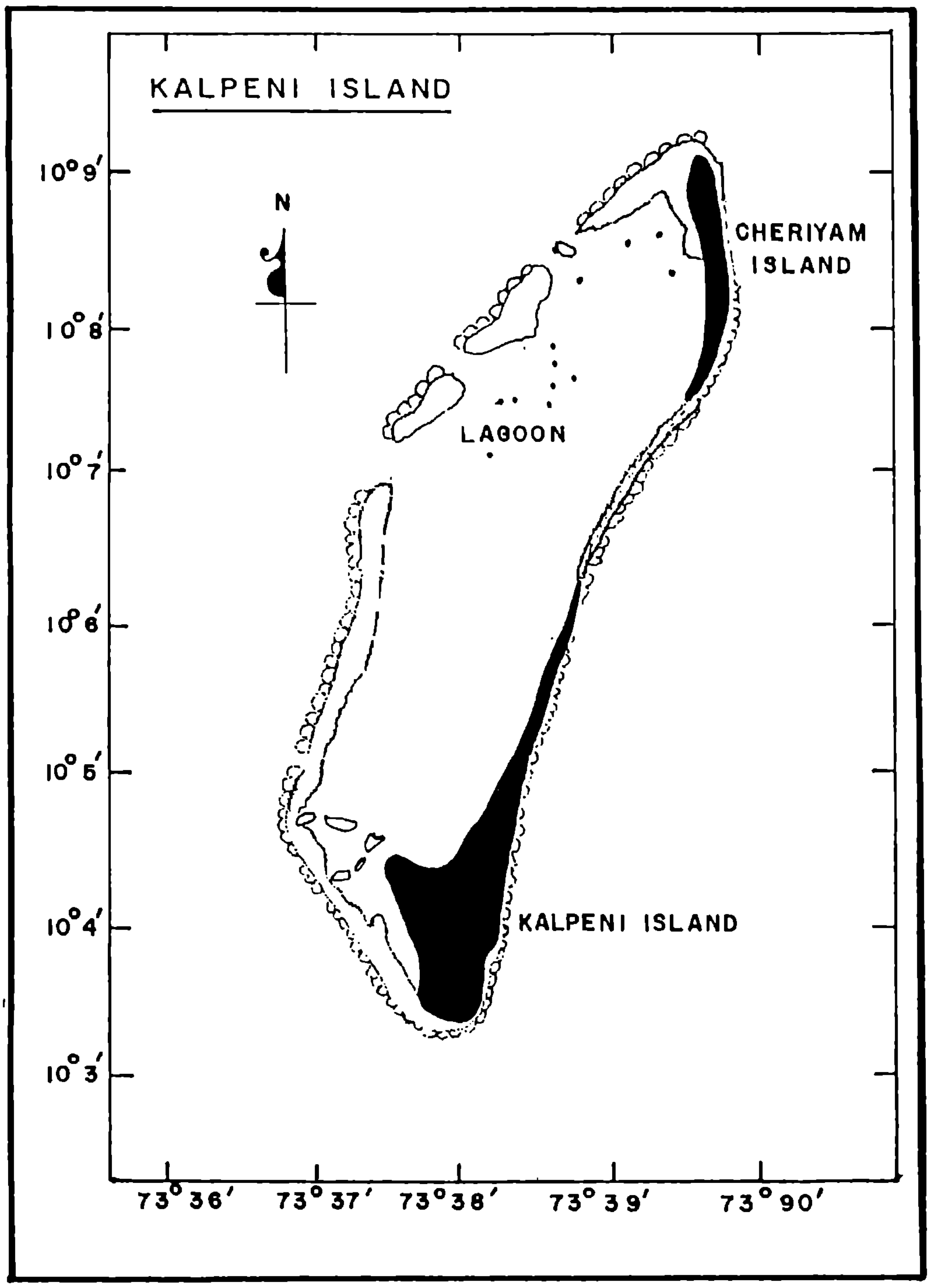


Fig. 3. The Kalpeni Island, lagoon and reefs.

of 45 sampling sites were set up around the lagoon and reefs, and at each sampling site, 4 samplings were carried out. In order to locate and sample the coral species, each sampling site was checked by free diving for one hour which was conducted by the candidate at low tide from an anchored boat.

In order to obtain information on the percentage of area covered by live and dead corals, quantitative surveys were made with a 1 m x 1 m quadrat. The quadrat was subdivided to form a grid of 16 meshes (25 cm x 25 cm). The 1 metre square quadrat size was choosen for reasons of maneuverability and because it is a standard dimension for coral reef survey (Gomez and Alcala, 1984).

The area covered by the different species of corals were calculated in the following manner.

a) for corals with a flat, horizontal growth form, the area was determined directly from the quadrat,

b) for massive forms with encrusting corallites on the vertical surface of boulders, the height of the boulders was recorded so that the surface area could be estimated.

Occurrence of other invertebrates (holothurians, echinoderms, tridacnid clams) and coralline algae was also recorded.

The quadrat was laid randomly at each sampling point and the number of species and area covered by the different colonies were estimated. No concerted efforts were made to make representative collections of corals. However, unusual specimens were gathered. At each sampling point, the time and depth of observation of water were also noted so that the chart datum could be calculated using predicted tidal levels.

Statistical Analysis

The Shannon-Weaver Index Species Diversity (H') was determined for each zone as given:

$H' = \sum pi \log pi$

Where $pi = \frac{n1}{N}$

$\sum$ = Sum

n1 = number of individuals

N = total number of individuals

log = $\log_2$

The computer program (basic) for calculating Species Diversity (H') was as given in Bakus (1990).

RESULTS

The different zones in the Minicoy lagoon and the various sampling stations where the survey was conducted are indicated in Fig.2. The results of the detailed sampling carried out at each sampling station giving species composition are given in Table 1 to 9. The indices of species diversity observed for the different sampling stations during the survey are given in Table 10. Fig.4 gives the percentage of live coral cover observed for the different sampling stations of each zone. A check list of the species of corals recorded from this stoll is given in Table 11.

Zone 1

The zone is situated at the south western part of the lagoon near the Tunda Point (Fig. 2). A major part of this zone gets exposed during low water level. In stations I and II the lagoon bottom is mainly sandy contributing 97.83% and 99.2% of the area of the quadrat during sampling. These stations were completely devoid of any live coral cover. In Station III where the depth was not more than one and half metre during high water level, the average live coral cover represented 14.95% while dead coral stones dominated with 47.55% in area and sand covered 37%. Porites (P. solida, P. lutea) was the most common species in this station contributing 6.13% while Heliopora caerulea contributed 3%, Acropora sp. 2.5% Echinopora sp. 1.13% and Psammacora contigua 1.12%. In Station IV the average live

Table 1. Percentage cover of live corals, dead corals, sand, coralline algae and echinoderms recorded in Zone 1. Values given in each sampling station represent the mean of four quadrat sampiings at each station

Species	STATIONS				
	I	II	III	IV	V
Depth (m)	0.55	0.78	0.98	0.95	1.03
Live coral	0	0	14.75	11.75	13.13
Sandy cover	97.83	99.2	37	36.5	46.13
Dead coral cover	1.25	0.63	47.55	50.5	40.75
Psammacora spp.	0	0	1.12	0	0.38
Favia spp.	0	0	0	0	0
Favites spp.	0	0	0	0	0
Fungia spp.	0	0	0	0	0.38
Pocillopora spp.	0	0	0.83	0	0.38
Acropora spp.	0	0	2.5	0.75	1
Pavona varians	0	0	0.5	0	0.38
Goniastrea retiformis	0	0	0	1.13	0.88
Diploastrea heliopora	0	0	0	0	0
Galaxea fascicularis	0	0	0	0	0
Lobophyllia corymbosa	0	0	0	0	0
Leptoria phyrgia	0	0	0	0	0
Symphyllia spp.	0	0	0	0	0
Platygyra lamellina	0	0	0	1.63	2
Porites spp.	0	0	6.13	7	5.25
Montipora sp.	0	0	0	0	0
Hydnophora microconos	0	0	0	1.25	0
Goniopora minor	0	0	0	0	0
Heliopora caerulea	0	0	3	0	2.5
Millipora spp.	0	0	0	0	0
Others	0	0	0	0	0
Seagrass/weeds	0.2	0.05	0	0.25	0
Coralline algae	0.23	0.13	0	0	0
Echinoderms	0	0	0	0	0
Zoanthids/sponges	0	0	0	0	0
Tridacna	0	0	0	0.13	0.13
Holothurians	0.5	0	0.5	0.88	0

coral cover constituted only 11.75% (Table 1) while the dead coral substrates covered 50.5% and sand covered 36.5%. In Station V dead corals constituted only 11.75% while the dead coral substrates covered 50.5% and sand covered 36.5%. In Station V dead corals constituted 40.75% while live coral heads represented only a meagre 13.13% of the quadrat area. In the Stations III, IV and V Porites lutea dominated in the quadrats constituting 6.13%, 7% and 5.25% respectively of the quadrat area. Other minor forms recorded from these stations include Pocillopora damicornis, Pavona varians, Acropora sp., Goniastrea retiformis, Platygyra lamellina, Hydnophora microconos, Fungia scutaria and Heliopora caerulea.

The indices of species diversity for corals calculated for the different stations in this zone recorded nil in Station I and II while the highest index of 1.7521 was recorded in Station V, followed by 1.6498 and 1.2208 in Stations III and IV respectively (Table 10).

In addition to the coral fauna, the associated fauna in this zone included the tridacnid clams and holothurians. The tridacnid clams mainly Tridacna crocera and T. gigas were recorded in Stations IV, and V projecting from dead coral substrates. The common holothurians encountered in this zone included Holothuria nobilis and H. atra which contributed about 0.5%, 0.5% and 0.88% of the quadrat area in Stations I, III and IV respectively. The associated flora recorded include the coralline algae, non-coralline algae, seaweeds and seagrass. Coralline algae were mainly represented by Lithophyllum sp. and Lithothamnion sp.

Zone 2

This zone is located at the central part of the sand flat (Fig. 2). The lagoon bottom possesses several shoals at a depth of 2 to 3 metres at low tide. The spaces between the shoals are sandy with dead coral fragments. In Station I, the dead coral cover constituted 46.5% while the live coral cover and sand cover represented 29.88% and 22% respectively. In Station II, the depth was 5.6 m and the live coral covered 66.69% of

Table 2. Percentage cover of live corals, dead corals, sand, coralline algae and echinoderms recorded in Zone 2. Values given in each sampling station represent the mean of four quadrat samplings at each station

Species	STATIONS				
	I	II	III	IV	V
Depth (m)	5.9	5.6	7.55	7.48	8.10
Live coral	29.88	66.69	56.56	74.56	71
Sandy cover	22	15.25	6.25	7.56	7.75
Dead coral cover	46.5	17.31	36.44	17.13	21.25
Psammacora spp.	0	0	0	43.56	50.75
Favia spp.	1.56	0	0	0	0
Favites spp.	1.63	0	0	0.75	0.88
Fungia spp.	0	0	0	0	0
Pocillopora spp.	0	0	0.88	0	0
Acropora spp.	1.75	2.69	0	0.75	0.75
Pavona varians	0	0	0	0	0
Goniastrea retiformis	0	0	0	0	0
Diploastrea heliopora	2.81	4.63	0	0	0
Galaxea fascicularis	0	0	0	0	0
Lobophyllia corymbosa	0	0	0	0	10.13
Leptoria phyrgia	3.81	21.38	0	0	0
Symphyllia spp.	6.5	0	0	0	0
Platygyra lamellina	0	4.69	0	0	0
Porites spp.	11.81	33.56	31.63	34.25	0
Montipora sp.	0	0	0	0	0
Hydnophora microconos	0	0	0	0	0
Goniopora minor	0	0	17.19	0	6.5
Heliopora caerulea	0	0	0	0	0
Millipora spp.	0	0	0	0	0
Others	0	0	0	0.13	0.38
Seagrass/weeds	0	0	0	0	0
Coralline algae	0	0	0	0	0
Echinoderms	0	0	0	0	0
Zoanthids/sponges	0	0	0	0	0
Tridacna	1.63	0.75	0.75	0.75	0
Holothurians	0	0	0	0	0

the quadrat area (Fig. 4), while the dead coral rocks and sand cover represented 15.25% and 17.31% respectively. In Station III where the depth was observed as 7.5 m, live coral covered an average 56.56% of the area surveyed and the remaining area was covered with sand (6.25%) and dead coral fragments (36.44%). Live corals constituted 74.56% in Station IV at a depth of 7.48 m while the dead corals and sandy cover made up 17.13% and 7.56% respectively. Porites lutea was the dominant coral fauna recorded in Stations I, II, III and IV constituting 11.81%, 33.56%, 31.63% and 34.25% respectively. To a lesser extent Symphyllia rectan (6.5%) Leptoria phyrgia (3.81%), Diploastrea heliopora (2.81%), Acropora sp. (1.75%), Favia pallida (1.56%) and Favites abdita (1.63%) were recorded in the quadrats in Station I. Leptoria phyrgia represented 21.38% in Station II in addition to the less abundant forms like Platygyra lamellina (4.69%), Diploastrea heliopora (4.63%) and Acropora sp. (2.69%). Goniopora minor was also common (17.19%) in Station III. However, in Station IV Psammacora digitata (43.56%) dominated in the quadrats where live corals covered 74.56% (Table 2) in this area. In Station V 71% of the quadrat was represented by live coral heads mainly dominated by Psammacora digitata (50.75%) while Lobophyllia corymbosa was also recorded in less abundance (10.13%) from this station.

The species diversity index of the coral fauna represented in this zone recorded a highest of 1.6629 from Station I while the least 0.7515 was recorded from Station III. Station II, IV and V recorded a species diversity of 1.2114, 0.7746 and 0.8660 respectively (Table 10).

Zone 3

This zone is located at the north-eastern side of the atoll about 2 km southwest of Kodi Point near the shore (Fig. 2). There is a well developed shoal about 100 metres away from the shore and is the largest observed in the lagoon (Plate II). It measured about 600 metres long and 40 to 60 metres wide at different parts. The lagoon near the shore is hardly a metre and a half deep at high tide, but outwards to the shoal, the depth increases to three of four metres. In Station I, the live coral

Table 3. Percentage cover of live corals, dead corals, sand coralline algae, echinoderms recorded in Zone 3. Values given in each sampling station represent the mean of four quadrat samplings at each station

Species	STATIONS I	II	III	IV	V
Depth (m)	2.3	3.1	2.8	3.1	3.1
Live coral	60.43	35.13	58.11	43.75	29.76
Sandy cover	6.88	0	8.88	0	0
Dead coral cover	30.15	63.3	14.36	55.05	59.55
Psammacora spp.	0	0	0	0	0
Favia spp.	0	1.63	0	5.08	6.64
Favites spp.	8.38	13.88	0	3.75	0
Fungia spp.	0	0	0	0	0
Pocillopora spp.	0	1.25	0	0.75	0
Acropora spp.	0	0	0	0	0
Pavona varians	0	0	0	0	0
Goniastrea retiformis	11.33	0	26.94	0	10.38
Diploastrea heliopora	21.25	9.38	21.45	1.65	0.88
Galaxea fascicularis	0	0.13	0	0	0
Lobophyllia corymbosa	10.13	0	5	14.25	0
Leptoria phyrgia	3.88	3.13	1.58	6.55	1.63
Symphyllia spp.	0	0	0	0	0
Platygyra lamellina	0	2.5	0.88	13.88	10.25
Porites spp.	1.25	0	0	0	0
Montipora sp.	0	0	0	0	0
Hydnophora microconos	2.85	1.63	0	0	0
Goniopora minor	0	1.63	1.63	0	0
Heliopora caerulea	0	0	0	0	0
Millipora spp.	0	0	0	0	0
Others	1.38	0	0	0	0
Seagrass/weeds	0.38	0	0	0	1
Coralline algae	0	0	0	0	5.75
Echinoderms	2.18	0.7	0.58	0.38	1.63
Zoanthids/sponges	0	0	0	0	0
Tridacna	0	0.13	0.08	0.38	0
Holothurians	0	0.75	0	0	0

cover constituted 60.43% and dead coral substrate 30.15% (Fig. 4) while at Station II it was 35.13% and 63.3% respectively. In Station III more than half the area of the quadrat was covered by live coral heads (58.11%) and dead cover constituted 14.36%, while in Station IV, live coral cover recorded 43.78% and dead coral substrate constituted 55.05%. Dead corals dominated in Station V representing 59.55% of the quadrat area while live corals covered 29.76% and Goniastrea retiformis and Diploastrea heliopora were the most predominant coral forms in this zone. Diploastrea heliopora represented 21.25%, 19.38% and 21.45% of the quadrat area respectively in Stations I, II and III while Goniastrea retiformis constituted 11.33%, 26.94% and 10.38% in Stations I, III and V. Most of these colonies of the two species were found growing on the bottom and on the sides of the shoal where they were not exposed even at low tides. To a lesser extent Lobophyllia corymbosa and Favites abdita were also present in this zone (Table 3). The former constituted 10.13%, 5% and 14.25% in Stations I, III and IV while the latter represented 8.38%, 13.88% and 3.75% in the quadrats in Station I, II and IV. Leptoria phyrgia and Platygyra lamellina were present in a few quadrats, the former representing 3.88% and 6.55% in Stations I and IV while the latter constituted 13.88% and 10.25% in Stations IV and V. In addition to the above, other coral species were also recorded in smaller quantities which include Favia pallida, Pocillopora damicornis and Leptastrea bottae.

The indices of species diversity for this zone varied between 1.7411 (Station I) and 1.963 (Station III). The index was 1.6881, 1.6677 and 1.3316 for Stations II, IV and V (Table 10).

One of the most significant fauna associated with the shoals in this zone has been the rock boring sea urchin Echinometra mathei found between the crevices and perforations in the shoal (Plate VI). The density of this species in this zone recorded a maximum of 15 numbers/m^2 while the mean monthly densities varied between 5.3 and 8.8 nos/m^2 The density and size group of the species and its seasonal variation have been dealt in detail in the third chapter. In addition to the common forms, Heterocentrotus mammillatus was also recorded for the first time from this atoll (Plate IX). However, the species was found to be rare in this part of the lagoon.

Zone 4

This zone is situated on the north-eastern side of the lagoon towards the east of Kondi-Ma Channel (Fig. 2) possesses certain shoals at a depth of 5 to 7 metres. The live coral heads represented the major part of the quadrats during sampling in this zone with values recorded between 44.13 and 62.83% for all the stations (Fig. 4). Psammacora contigua, Favites abdita and Porites lutea were the most dominant forms observed in this part of the lagoon. In Station III Psammacora contigua represented 23.38% of the quadrat area while Favites constituted between 7.63 and 13.13% of the live coral cover from Station II to V. Porites dominated in Station I and V representing 25.63 and 24.93% respectively while it in the remaining stations it was less abundant and live cover of this species varied between 0.78 and 8.15%. In addition, Lobophyllia corymbosa, Leptoria phyrgia Goniopora minor, Montipora sp. Favia pallida, Platygyra lamellina, Symphyllia recta and Diploastrea heliopora were also recorded from this zone in lesser abundance. Favia pallida constituted between 3.88 (Station III) and 6.8% (Station II) of live coral cover while Lobophyllia corymbosa constituted between 2.5 (Station II) and 9.63% (Station I). Symphyllia recta varied between 3.63 and 8.38% recorded in the first three stations while Platygyra lamellina recorded 2.38, 9.88 and 1.56% of the quadrat area in Station I, II and IV respectively. Montipora sp. constituted 10.25% of the live coral cover at Station III while it recorded 3.13 and 4.33% in Station IV and II respectively.

The index of species diversity in this zone observed during the survey varied between 1.3609 and 2.1062 (Table 10). The highest index was recorded in Station IV and the least in Station V. The index read 1.6085, 1.8956 and 1.7047 for Station I, II and III respectively.

Table 4. Percentage cover of live corals, dead corals, sand coralline, algae and echinoderms recorded in Zone 4. Values given in each sampling station represent the mean of four quadrat samplings at each station

Species	STATIONS				
	I	II	III	IV	V
Depth (m)	6.16	6.25	6.15	5.95	4.55
Live coral	60.5	62.83	59.44	60.33	44.13
Sandy cover	15.5	10	13.63	11.13	25.63
Dead coral cover	22.13	26.54	26.19	28.25	29.75
Psammacora spp.	8.13	0	23.38	0	0
Favia spp.	0	6.8	3.88	5.35	0
Favites spp.	0	11.31	10.34	13.13	7.63
Fungia spp.	1.63	0	0	0	0
Pocillopora spp.	0	0	0	0.48	0.25
Acropora spp.	0	0.88	0	0	1.63
Pavona varians	0	0	0	0	0
Goniastrea retiformis	0	7.9	0	0	0
Diploastrea heliopora	0	0	0	8.88	0
Galaxea fascicularis	0	0	0	0	0
Lobophyllia corymbosa	9.63	2.5	5.33	4.13	7.5
Leptoria phyrgia	0	1.63	0	5	0
Symphyllia spp.	8.38	4.13	3.63	0	0
Platygyra lamellina	2.38	9.88	0	1.56	0
Porites spp.	25.63	3.13	0.78	8.15	24.93
Montipora sp.	0	4.33	10.25	3.13	0
Hydnophora microconos	0	0	0	0	0
Goniopora minor	3.13	0	0	13.04	0
Heliopora caerulea	0	0	0	0	3.88
Millipora spp.	0	0	0	0	0
Others	0.38	0	1.88	0	0.75
Seagrass/weeds	0	0	0	0	0.13
Coralline algae	0	0	0	0	0
Echinoderms	0	0.63	0.75	0.3	0
Zoanthids/sponges	0	0	0	0	0
Tridacna	1.31	0	0	0	0.38
Holothurians	0	0.06	0	0	0

Zone 5

The zone is situated on the lagoon reef extending from Tunda Point to Wiringili Island (Fig. 2). The zone has a well developed boulder zone and a flat that is exposed at low water (Plate III). The major part of reef was covered by dead coral rubbles and rocks and it constituted 68.2, 42.71, 48.71, 53.68 and 64.71% of the quadrat area in Stations I, II, III, IV and V respectively (Table 5). Live corals recorded a low between 5.65 and 11.94% in all the sampling stations. Most of the coral forms recorded in the reef were flattened and often freshly budding forms. By far, the most common species recorded in the reef is Porites, Platygyra lamellina and Galaxea fascicularis while non-seleractinian forms were dominated by Heliopora caerulea and Millipora. Porites lutea varied between 1.13 and 2.06% on the reef while Platygyra lamellina recorded between 0.75 and 2.13%. The non-scleractinian Heliopora caerulea and Millipora was more common than any other species recording a maximum cover of 4.81 and 5.94% respectively. The index of species diversity recorded a maximum of 2.0453 in Station III while the least was 1.0591 in Station V (Table 10). In the other Stations, the index was 1.7563, 1.7069 and 1.2779 for Stations I, II and IV respectively.

Among the reef associated flora, the coralline algae was abundant in some areas mainly constituted by Lithophyllum and Lithothamnion. In Station II, III and IV, the coraline algae constituted 11.75, 14.38 and 10.63% of the substrate. Another reef associated fauna found in abundance along the reef was the Diademid sea urchin Echinothrix sp. The sea urchin Echinothrix was commonly found in sheltered perforations of the reef flat feeding on coralline and non-coralline algae (Plate VI). The density of Echinothrix diadema, the most abundant species varied between 2 and 16 numbers/m^2 with seasons. A detailed seasonal variation studies was carried out for this species and the results have been discussed in chapter three. In the present survey the density of the species varied between 2.5 and 4.68% among the reef flat. Beside the sea urchins, many others such as ophiuroids, sea-cucumbers, zoanthids and Tridacnid clams abounded in the coral reefs in this zone.

Table 5. Percentage cover of live corals, dead corals, sand, coralline algae and echinoderms recorded in Zone 5. Values given in each sampling station represent the mean of four quadrat samplings at each station

Species	STATIONS				
	I	II	III	IV	V
Depth (m)	0	0	0	0	0
Live coral	7.69	11.94	7.06	5.65	9.88
Sandy cover	16.31	25	18.5	15.94	17.73
Dead coral cover	68.2	42.71	48.19	53.68	64.71
Psammacora spp.	1.75	1	0.5	0.65	0.88
Favia spp.	0	0.25	0	0	0
Favites spp.	0	0	0	0	0
Fungia spp.	0	0	0	0	0
Pocillopora spp.	0.38	0.13	0.88	0	0
Acropora spp.	1	0.63	0.44	0	0
Pavona varians	0.25	0	0.25	0	0
Goniastrea retiformis	0	0	0	0	0
Diploastrea heliopora	0	0	0	0	0
Galaxea fascicularis	0.5	0.13	0.5	0	0.75
Lobophyllia corymbosa	0	0	0	0	0
Leptoria phyrgia	0	0	0	1.63	0
Symphyllia spp.	0	0	0	0	0
Platygyra lamellina	0	2.13	0.75	0	0
Porites spp.	2	2.06	1.13	0	0
Montipora sp.	0	0	0	0	0
llydnophora microconos	0	0	0	0	0
Goniopora minor	0	0	0	0	0
Heliopora caerulea	0	4.81	1.88	2.38	2.38
Millipora spp.	1.94	0.88	0.75	1	5.94
Others	0	0	0	0	0
Seagrass/weeds	1	3.38	5.5	9.88	0
Coralline algae	2.75	11.75	14.38	10.63	4.38
Echinoderms	3.43	3.2	4.68	3.24	2.5
Zoanthids/sponges	0	1	1.13	0.88	0
Tridacna	0.25	0.38	0.38	0	0.81
Holothurians	0.38	0.65	0.2	0.12	0

Zone 6

The zone extended between Wiringli Island and Ragandi with a reef flat of about 50 metres wide separated by the boulder zone from the lagoon (Fig. 2). The boulder zone is about 30 metres in width with dead loose colonies of corals. The live coral cover in this zone was very poor, fluctuating between 3.88 and 15.75% (Fig. 4). In Station I the dead loose coral colonies constituted 67.13% while it was 62.06% in Station II. In Station III, the area covered by the dead coral colonies represented 67.43 while it recorded 38.7 and 36.82% for Station IV and V respectively. Porites was one of the common encrusting forms of coral recorded in this zone representing 4.56, 2.85 and 1.63% in Station I, III and IV respectively. Goniopora was also present in a few quadrats recording 2.03 and 2.63% in Station III and IV while Psammacora was also encountered representing 1.81 and 2.94% of the live coral cover in Station I and V respectively. The non-scleractinian forms Heliopora caerulea and Millipora were by far the most common species in this zone. Heliopora caerulea constituted 2.92 and 3.13% in Stations III and V while Millipora represented 2.31, 1.13 and 2.75% in Stations I, IV and V respectively. Favites recorded 2.56% in Station V while Symphyllia represented 2.38% and Goniastrea retiformis 1.13% (Station I) of the live coral cover in this zone.

The index of species diversity of coral species in this zone was calculated to vary between 0.6674 observed in Station II and 2.0613 in Station I (Table 10). The index was 1.6661, 1,2449 and 1.9249 in Station III, IV and V respectively.

The reef associated flora and fauna of this zone was similar to that recorded in Zone 5. Coralline algae Lithophyllun and Lithothamnion covered the reef substrate varying between 5.45 and 11.75% in stations III and IV while it represented 11.43% and 10.38% in Station II and V respectively. The diademid echinoid Echinothrix was also found in large numbers in the crevices along the reef flat and between 1.13 and 4.58% the area of the quadrat in some stations.

Table 6. Percentage cover of live corals, dead corals, sand, coralline algae and echinoderms recorded in Zone 6. Values given in each sampling station represent the mean of four quadrat samplings at each station

Species	STATIONS I	II	III	IV	V
Depth (m)	0	0	0	0	0
Live coral	15.75	3.88	10.08	11.25	15.13
Sandy cover	16	16.56	10.9	24.06	25.81
Dead coral cover	67.13	62.06	67.43	38.7	36.81
Psammacora spp.	1.81	0	0.38	0.75	2.94
Favia spp.	0	1.5	0	0	0.13
Favites spp.	0	0	0	0	2.56
Fungia spp.	0	0	0	0	0
Pocillopora spp.	1.13	0	0	0	0.5
Acropora spp.	0	0	0	0	0
Pavona varians	0.88	0	0.98	0	0.5
Goniastrea retiformis	1.13	0	0	0	0
Diploastrea heliopora	0	0	0	0	0
Galaxea fascicularis	0.13	0	0.33	0	0.5
Lobophyllia corymbosa	0	0	0	0	1
Leptoria phyrgia	1.06	0	0	0	0
Symphyllia spp.	0	2.38	0	0	0
Platygyra lamellina	1.88	0	0.6	1	0.5
Porites spp.	4.56	0	2.85	1.63	0
Montipora sp.	0	0	0	0	0
Hydnophora microconos	0	0	0	0	0
Goniopora minor	0	0	2.03	2.63	0
Heliopora caerulea	0	0	2.93	0	3.13
Millipora spp.	2.31	0	0	1.12	2.75
Others	0	0	0	0	0
Seagrass/weeds	0	2.25	0.75	6.63	4.63
Coralline algae	0	11.44	5.45	11.75	10.38
Echinoderms	1.13	0	4.58	3.68	1.88
Zoanthids/sponges	0	3.38	0.83	3.94	5.25
Tridacna	0	0	0	0	0
Holothurians	0	0.38	0	0	0.13

Zone 7

The zone is characterized by the dominance of live corals cover over the dead ones. The average live coral heads constituted 70.31% in Station I (Fig. 4) while the dead corals represented only 14.81% of the quadrat area. In Station II, the live coral heads covered 53.88% while the dead coral rubbles represented only 32%. The live corals covered 77.5, 52.5 and 64% in the Stations III, IV and V respectively. In Station I the branching Acropora sp. constituted 46% of the live coral cover while the rest was contributed by Platygyra lamellina (11.13%), Porites (5.56%) and Diploastrea heliopora (7.63%). Similarly in Station II the dominant coral fauna included Porites (16.63%), Diploastrea heliopora (14.2%) Psammacora (12%), Favites (4.69%) and Lobophyllia corymbosa (3.88%). Dead broken Acropora branches constituted 32% of the dead loose colonies in this Station. However, in Station III Psammacora contigua was by and for the most prevalent form representing 33.57% of the live corals while to a lesser extent, the rest was constituted by Porites (21.13%), Platygyra (7.94%), Lobophyllia (7.63%) and Leptoria phyrgia (4.63%). Porites was also the most common coral species both in Station IV and V representing 25.56 and 13%. In Station IV the other species recorded include. Favia pallida (4.81%), Goniastrea retiformis (5.38%), Lobophyllia corymbosa (7.81%), Leptoria phyrgia (4.006%) and Symphyllia sp. (2.38%) while in Station V the species included Lobophyllia corymbosa (11.56%) Diploastrea heliopora (11.75%), Psammacore digitata (8.75%) Favites spp. (2.5%) Symphyllia recta (3.5%) and Platygyra lamellina (3.75%).

The index of species diversity recorded in this zone (Table 10) in the decreasing order was 2.0901 (Station V), 1.6069 (Station II), 1.6002 (Station IV), 1.4611 (Station III) and 1.0109 (Station I).

Zone 8

This is one of the deepest zones in the lagoon and has a rich coral fauna. The maximum live coral cover of 91.75% (Fig. 4) was recorded in Station I of this zone and constituted wholly by Psammacora contigua.

Table 7. Percentage cover of live corals, dead corals, sand coralline algae and echinoderms recorded in Zone 7. Values given in each sampling station represent the mean of four quadrat samplings at each station

Species	STATIONS I	II	III	IV	V
Depth (m)	8.4	8.1	9.3	8.6	8.1
Live coral	70.31	53.89	77.5	52.5	64
Sandy cover	13.38	13.24	6.13	26.13	14.75
Dead coral cover	14.81	32	15.63	22.25	20.5
Psammacora spp.	0	12	33.56	1.63	8.75
Favia spp.	0	0	0	4.81	0
Favites spp.	0	4.69	0	0	2.5
Fungia spp.	0	0	0	0	0
Pocillopora spp.	0	0	0	0	0
Acropora spp.	46	0	0	0.88	1.75
Pavona varians	0	0	0	0	0
Goniastrea retiformis	0	0	0	5.38	5
Diploastrea heliopora	7.63	14.2	0	0	11.75
Galaxea fascicularis	0	0	0	0	0
Lobophyllia corymbosa	0	3.88	7.63	7.81	11.56
Leptoria phyrgia	0	0	4.63	4.06	2.44
Symphyllia spp.	0	0	2.63	2.38	3.5
Platygyra lamellina	11.13	2.5	7.94	0	3.75
Porites spp.	5.56	16.63	21.13	25.56	13
Montipora sp.	0	0	0	0	0
Hydnophora microconos	0	0	0	0	0
Goniopora minor	0	0	0	0	0
Heliopora caerulea	0	0	0	0	0
Millipora spp.	0	0	0	0	0
Others	0	0.13	0	0	0
Seagrass/weeds	0	0.5	0	0	0
Coralline algae	1.5	0	0	0	0
Echinoderms	0	0	0	0	0
Zoanthids/sponges	0	0.25	0	0	0
Tridacna	0	0.13	0.75	0.38	0
Holothurians	0	0	0	0	0.38

Table 8. Percentage cover of live corals, dead corals, sand, coralline algae and echinoderms recorded in Zone 8. Values given in each sampling station represent the mean of four quadrat samplings at each station

Species	STATIONS I	II	III	IV	V
Depth (m)	11.2	13.4	13.1	12.5	12.7
Live coral	91.75	68.76	54.83	55.33	57.38
Sandy cover	3.75	9.13	26.13	21	26.13
Dead coral cover	3.75	19.69	16	22.55	15.63
Psammacora spp.	91.75	0	54.83	10.08	30.63
Favia spp.	0	0	0	2.63	0
Favites spp.	0	0	0	8.56	0
Fungia spp.	0	0	0	0	0
Pocillopora spp.	0	0	0	0	0.38
Acropora spp.	0	9.7	0	0	0
Pavona varians	0	0	0	0	2.25
Goniastrea retiformis	0	0	0	0	0
Diploastrea heliopora	0	39.81	0	7.81	0
Galaxea fascicularis	0	0	0	0	0
Lobophyllia corymbosa	0	9.25	0	0	0
Leptoria phyrgia	0	0	0	0	0
Symphyllia spp.	0	0	0	0	0
Platygyra lamellina	0	10	0	0	3.75
Porites spp.	0	0	0	9	20.38
Montipora sp.	0	0	0	0	0
Hydnophora microconos	0	0	0	2.5	0
Goniopora minor	0	0	0	14.25	0
Heliopora caerulea	0	1.25	0	0	0
Millipora spp.	0	0	0	0	0
Others	0	0	0	0.5	0
Seagrass/weeds	0.13	0	0.13	0	0
Coralline algae	0	0	0.38	0	0
Echinoderms	0	0	0	0	0
Zoanthids/sponges	0.63	0	0.88	0	0
Tridacna	0	0.88	0	0.5	0
Holothurians	0	0	0.13	0	0

In Station II, out of the total live coral cover of 68.76%, 39.81% was contributed by Diploastrea heliopora while the rest was constituted by Acropora sp. (9.7%) and Lobophyllia corymbosa (9.25%). In Station III the coral fauna was similar to that in Station I, where in Psammacora contigua constituted 54.83% live coral cover. The average live coral cover was 55.33 and 57.38% (Fig. 4) while the dead colonies made up 22.55 and 15.63% in Stations IV and V respectively. Goniopora was the dominated coral form constituting 14.25% in Station IV while it was Psammacora, having a cover of 30.63% in Station V. In the former, in addition, Psammacora (10.08%), Favites (8.56%) and Diploastrea (7.81%) were also present while in the latter, Porites (20.38%), Symphyllia (3.75%) and Pavona varians (2.25%) were the constituent species.

The index of species diversity was the highest in Station IV (1.8473) while it recorded 1.0409 and 1.2158 in Station V and II respectively (Table 10). The index was zero for Stations I and III where a single species (Psammacora sp.) was present in the quadrat area.

Zone 9

This zone represents the seaward reef flat from the Tunda Point to the Kodi Point facing the open ocean (Fig. 2). The area was surveyed at five sampling Stations by wading 50 to 60 metres away from the shore during the lowest lowtides. Major part of the reef was covered by dead and rockey substratum (Table 9). The dead coral cover varied between 62.69 and 75% in the different stations. The live coral cover was very poorly represented in the quadrats recording 9.81, 9.31, 11.05, 3.63 and 7.25% from Station I to V respectively (Fig. 4). The common forms encountered in the seaward reef include Psammacora contigua, Pocillopora eydouxi, P. verrucosa, Acropora palifera, Pavona varians, Platygyra lamellina and Porites Non-scleractinian Heliopora caerulea and Millipora were also present in some areas of the reef.

Table 9. Percentage cover of live corals, dead corals, sand, coralline algae and echinoderms recorded in Zone 9. Values gives in each sampling station represents the mean of four quadrat samplings at each station

Species	STATIONS I	II	III	IV	V
Depth (m)	0	0	0	0	0
Live coral	9.81	9.31	11.05	3.63	7.25
Sandy cover	4	6.63	3.88	10.25	4.74
Dead coral cover	66.75	75	74.93	62.69	65.14
Psammacora spp.	2.19	3.25	0.63	0.75	0.38
Favia spp.	0.50	0	0	0	0.50
Favites spp.	0	0	0	0	0
Fungia spp.	0	0	0	0	0
Pocillopora spp.	1	2.06	2.38	0	0.63
Acropora spp.	0.50	1.25	0	1.38	1
Pavona varians	0.50	0.63	0.88	0	0.75
Goniastrea retiformis	0	0	0	0	0
Diploastrea heliopora	0	0	0	0	0
Galaxea fascicularis	0	0	0	0	0
Lobophyllia corymbosa	0	0	0	0	0
Leptoria phyrgia	0	0	0	0	0
Symphyllia spp.	0	0	0	0	0
Platygyra lamellina	0.50	0	1.63	0	0
Porites spp.	0	1.25	0	0	0.75
Montipora sp.	4	0	2.93	0	0
Hydnophora microconos	0	0	0	0	0
Goniopora minor	0.50	0	1.25	0	0
Heliopora caerulea	0	1.88	1.25	1.50	0
Millipora spp.	0	1.63	2.25	0	3.25
Others	0.13	0	0	0	0
Seagrass/weeds	3.88	0.88	1.63	9.19	8.63
Coralline algae	9.75	3.13	11.88	13.13	8
Echinoderms	0.38	0.38	0.38	0	0
Zoanthids/sponges	2.50	1.88	1.63	1	5
Tridacna	0	0	0	0	0
Holothurians	0	0.19	0	0.13	0

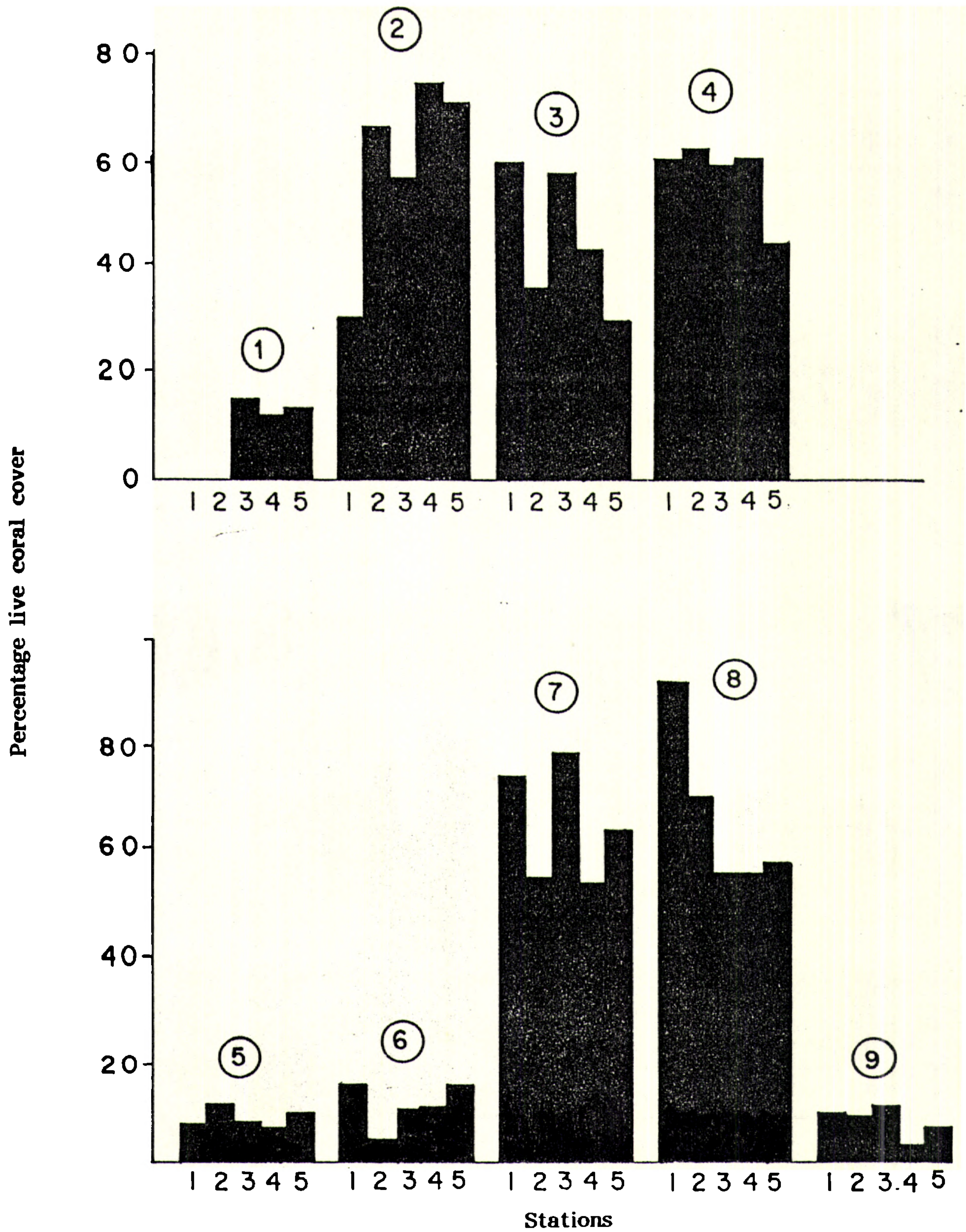


Fig. 4. The percentage of live coral cover observed for the different sampling stations in each zone during the survey.

Table 10. Index of Species Diversity of corals at different stations recorded from the lagoon and reef during the survey in Minicoy.

Zone	Habitats	Depth (m)	STATION I	II	III	IV	V
Zone 1	Sandy flat	0.5 - 1.0	0	0	1.6498	1.2208	1.7521
Zone 2	Lagoon	5.6 - 8.10	1.2114	1.2114	0.7515	0.7746	0.8666
Zone 3	Lagoon	2.3 - 3.1	1.7411	1.6881	1.1963	1.6677	1.3316
Zone 4	Lagoon	4.55 - 6.25	1.6085	1.8956	1.7047	2.1062	1.3609
Zone 5	Lagoon reef flat	-	1.7363	1.7069	2.0453	1.2779	1.0591
Zone 6	Lagoon reef flat	-	2.0613	0.6674	1.6661	1.2449	1.9249
Zone 7	Lagoon	8.1 - 9.3	1.0190	1.6069	1.4611	1.6002	2.0901
Zone 8	Lagoon	11.2 - 13.4	0	1.2158	0	1.8473	1.0409
Zone 9	Seaward reef flat		1.7471	2.0489	2.1446	1.0588	1.6512

Table 11. Check-list of species of corals reported from coral reefs of Minicoy

Phylum COELENTERATA

Subphylum CNIDARIA

Class ANTHOZOA

Subclass ZOANTHARIA

Order Scleractinia

(Classification after Wells, 1956)

Suborder Astrocoeniina

Family Thamnasteriidae

1. Psammocora contigua (Esper, 1797).
2. P. (Stephanaria) exesa Dana, 1846.
3. P. (Plesioseris) haimeana Milne-Edwards and Haime, 1851.
4. P. digitata Milne Edwards and Haime, 1851.
5. P. profundacella Gardiner, 1898.

Family Pocilloporidae

6. Stylophora mordax Dana, 1846.
7. S. pistillata (Esper, 1897)
8. Pocillopora damicornis (Linnaeus), 1758.
9. P. verrucosa (Ellis and Solander), 1786.
10. P. ligulata Dana, 1846.
11. P. eydouxi Milne-Edwards and Haime, 1860.

Family Acroporidae

12. Acropora abrotanoides (Lamarck), 1816.
13. A. conferta (Quelch), 1886.
14. A. corymbosa (Lamarck), 1816.
15. A. echinata (Dana), 1816.
16. A. efflorescens (Dana), 1846.
17. A. formosa (Dana), 1846.
18. A. forskali (Ehrenberg), 1836.

Table 11. contd..

19. A. haimei (Milne-Edwards and Haime), 1860.
20. A. hemprichi (Ehrenberg), 1834.
21. A. humilis (Dana), 1846.
22. A. hyacinthus (Dana), 1846.
23. A. indica (Brook), 1893.
24. A. intermedia (Brook), 1893.
25. A. monticulosa (Bruggemann), 1879.
26. A. palifera (Lamarck), 1816.
27. A. pharaonis forma arabioa (Brook), 1893.
28. A. rambleri (Basset-Smith), 1890.
29. A. reticulata (Brook), 1892.
30. A. squarrosa (Ehrenberg), 1834.
31. Acropora sp.
32. A. teres (Verrill, 1866).
33. A. nasuta (Dana, 1846).
34. A. granulosa (Milne Edwards and Haime, 1860).
35. A. aspera Dana, 1846.
36. Asteopora myriophthalma Lamarck, 1816.
37. A. listeri (Bernard, 1896).
38. Montipora tuberculosa (Lamarck, 1816).
39. Montipora sp.

Suborder Fungiine

Family Agariciidae

40. Pavona maldivensis (Gardiner), 1905.
41. P. varians Verrill, 1864.
42. P. duerdeni Vaughan, 1907.

Family Fungiidae

43. Gardineroseris planulata (Dana, 1846).
44. Cycloseris sp. of somervilli (Gardiner), 1909.
45. C. cyclolithis
46. Fungia (Danofungia) danai Milne-Edwards and Haime, 1851.

Table 11. Contd...

47. F. (Fungia) fungites (Linnaeus), 1758.
48. F. (Pleuractis) scutaria Lamarck, 1801.
49. Fungia somervillei Gardiner, 1901.
50. Podabacia crustacea (Pallas), 1766.

Family Poritidae

51. Goniopora sp. of minor Crossland, 1952.
52. G. stokesi Milne-Edwards and Haime, 1851.
53. Porites andrewsi Vaughan, 1918.
54. P. lutea Mile-Edwards and Haime, 1851.
55. P. minicoiensis Pillai
56. P. palmata Dana, 1846.
57. P. solida (Forskal), 1775.
58. P. somaliensis Gravier, 1910.
59. P. rus
60. P. lichen Dana, 1846
61. P. andrewsi Vaughan, 1918.
62. P. minicoiensis Pillai, 1969.
63. Porites (Synarea) convexa Verrill, 1864.
64. Plesiastrea versipora (Lamarck), 1816.
65. Favia favus (Forskal), 1834.
66. F. pallida (Dana), 1846.
67. F. speciosa (Dana), 1846.
68. Favites abdita (Ellis and Solander), 1786.
69. F. ehrenbergi (Klunzinger), 1879.
70. F. halicora (Ehrenberg), 1834.
71. F. melicerum (Ehrenberg), 1834.
72. F. pentagona (Esper), 1794.
73. F. complanata (Ehrenberg, 1834)
74. Favia stelligera
75. G. retiformis (Lamarck), 1816.
76. Platygyra lamellina (Ehrenberg), 1834.
77. P. daedalae (Ellis and Solander, 1786)
78. Leptoria phrygia (Ellis and Solander), 1786.
79. Hydnophora microconos (Lamarck), 1816.

Table 11. Contd..

Subfamily Montastreinae

80. *Diploastrea heliopora* (Lamarck), 1816.
81. *Leptastrea purpurea* (Lamarck), 1816.
82. *L. transversa* Klunzinger, 1879.
83. *L. bottae* (Milne-Edwards and Haime, 1849).
84. *Cyphastrea seralia* (Forskal, 1775).

Family Oculinidae

Subfamily Galaxeinae

85. *Galaxea fascicularis* (Linnaeus), 1759.
86. *G. hexagonalis* (Milne-Edwards and Haime), 1848

Family Merulinidae

87. *Merulina ampliata* (Ellis and Solander), 1786.

Family Mussidae

88. *Acanthastrea echinata* (Dana), 1846.
89. *Symphyllia radians* Milne-Edwards and Haime, 1849.
90. *S. recta* Dana, 1846.
91. *S. nobilis* (Dana, 1846).
92. *Lobophyllia corymbosa* (Forskal), 1775.

Suborder *Caryophylliina*

Family Caryophylliidae

Subfamily Eusmiliinae

93. *Euphyllia glabrescens* (Chamisso and Eysenhardt), 1821.

Suborder Denerophyllina

Family Dendrophyllidae

94. *Turbinaria mesenterina* (Lamarck, 1816).
95. *Dendrophyllia microcanthus*

Subclass ALCYONARIA

Order *Coenothecalia*

Family Helipooridae

96. *Heliopora coerulea* (Pallas), 1766.

Table 11. Contd..

Class Hydrozoa

Order Milleporina

Family Milleporidae

97. *Millepora platyphyllia* Hemprich and Ehrenberg, 1834.
98. *M. dichotoma* (Forskal), 1775.
99. *M. tenera* Boschma, 1949.
100. *M. exessa* (Forskal, 1775).

Plate 1

A. The large scale destruction of the branching Acropora sp. in the lagoon is mainly attributed to the sensitivity of the species to excessive silting.

B. Dead coral colonies in the lagoon.

C. Acropora spp. was the most dominant coral in the outer reef flat of Kalpeni lagoon with extensive colonies of the species.

PLATE I

A

B

C

Plate II

A. The well developed shoal located at the north-eastern side of the lagoon in Minicoy is about 600 metres long and 40 to 60 metres wide at different parts. It is about 100 metres away from the shore and is the largest observed in the lagoon.

B. Removal of coral stones from the intertidal area on the seaward reef flat resulted in the exposure of the loose beach sand beneath and led to increased removal of beach sand.

C. The eroded beach sediments along the lagoon beach formed a major share of the transported sediments in the lagoon.

PLATE II

A

B

C

Plate III

A. The highly eroded lagoon shoal in the northeastern side of the atoll had a higher density of boring bivalves.

B. Sedimentation and siltation has been a major factor in the mass mortality of corals in the lagoon.

C. Sediments transported by the water currents have no further escape into the open sea because of the presence of the elevated reef flat which remains exposed most of the time acting as an effective barrier against sediment transport.

PLATE III

A

B

C

Plate IV

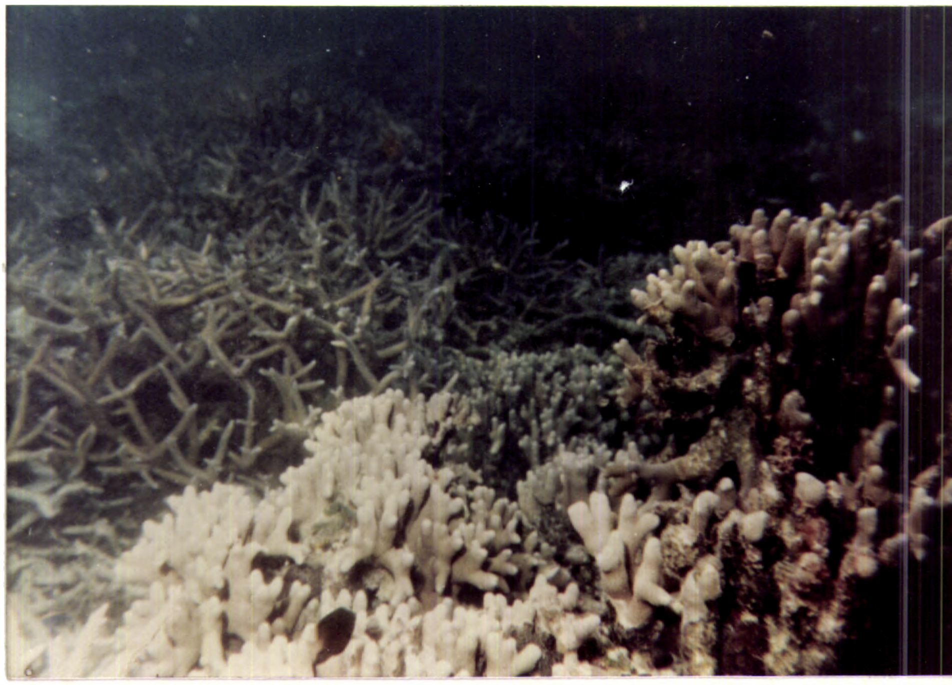
A. Live coral cover of Porites sp. and Acropora sp. in the Kavaratti lagoon.

B. Extensive colonies of branching Acropora in the Kalpeni lagoon.

C. Recolonization of encrusting forms of corals were observed along the sides of the numerous shoals in the lagoon.

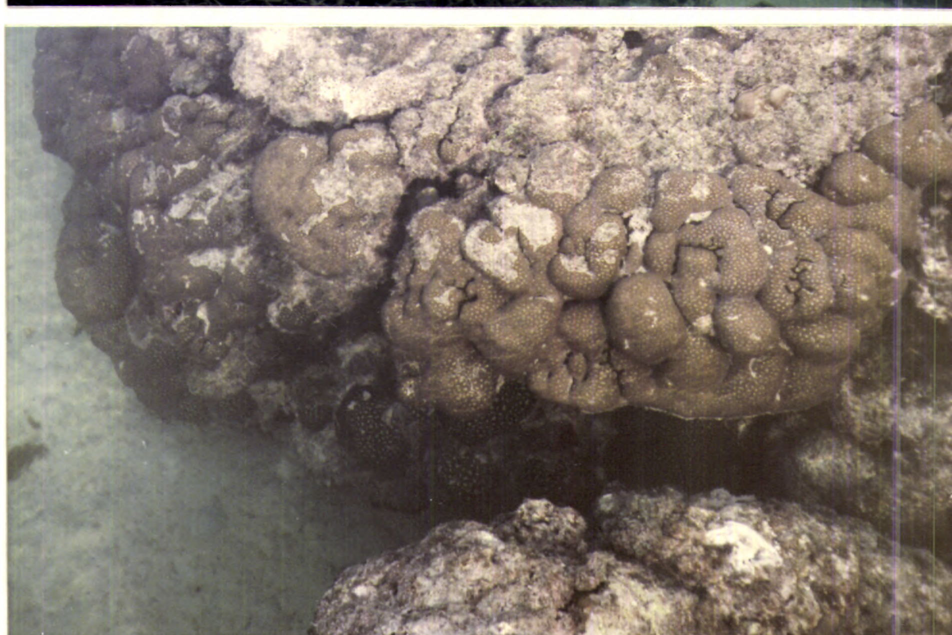
PLATE IV

A



B

C



The index of species diversity for corals recorded the highest of 2.1446 in Station III while it was 1.7471, 2.0489, 1.0558 and 1.6512 in Stations I, II, IV and V respectively (Table 10).

One of the major coral reef associated flora in this zone is the coralline algae and seaweeds. The major seaweeds encountered included Acanthophora, Geliedella, Dictiurus purpurea Turbinaria sp. and Lobophora variegata. Seaweeds cover varied between 0.8 and 9.19% of the quadrat along the reef. Coralline algae was also predominant with a cover area varying between 3.13 and 13.13% in the reef during the survey. The echinoid Echinothrix diadema was also recorded in this reef found in the crevices of raised substrates. However, their density was less than that observed for the species on the lagoon reef flat in zone 5 and 6.

DISCUSSION

The lagoon habitats in Minicoy Atoll, just like any other inhabited atolls in the Lakshadweep, has undergone drastic changes and have come under increasing pressure of interference both natural as well as man made (James et al., 1989). However, lack of systematically conducted earlier surveys for quantitative documentation of the fauna, the extent of damage and the paucity of continuous observations are major handicaps in assessing the recent changes in the deterioration of the corals in this lagoon and hence a comparison of the results obtained in the present study with those of the earlier ones is not fully possible.

Some conclusions on the progressive coral degradation in Minicoy had been made in the past based on the earlier studies,(Pillai, 1971, 1975, 1983, 1986 and 1990). During late sixties and early seventies this atoll had a luxuriant growth of corals of both massive and ramose types, with a rich and varied fauna of the reef associated invertebrates. No significant death of corals was reported in the lagoon during this period. A few years later, Pillai (1986) brought to the notice of the scientific community the

the damages caused to corals in the lagoon especially in the south-western and north-eastern parts where large scale death of both massive and ramose coral colonies were observed.

In the present study it was found that in all the areas except the deeper zones, the percentage of live coral cover was poor (Fig. 4). In the deepest part of the lagoon (Zone 8) the average live coral cover in the different sampling stations ranged between 54.83 and 91.75% (Fig. 4) while in the adjacent zone it varied between 52.5 and 77.5%. In the shallow water area, the live coral cover recorded was between 11.75 and 14.95%. The lagoon reef flat as well as the seaward reef flat recorded dead coral cover in most of the quadrats. In an attempt to estimate quantitatively the percentage coverage of live and dead coral cover in sample plots of 25 sq.m. in the Minicoy lagoon, James et al. (1989) reported that the coverage of corals in the plots ranged from 5 to 10% of the bottom area and 50 to 80% of them was dead. In view of the lack of site specification in the former study the results obtained in the present survey cannot be compared with the results reported by James et al. (1989). However, all these results indicate progressive and continuous process of coral deterioration which has been taking place for the past few years.

According to Pillai (1971) Minicoy lagoon had a luxuriant growth of Acropora teres, A. aspera, A. corymbosa and A. humilis along with large thickets of A. formosa. Victor et al. (1989) have also reported the branching Acropora spp. as the dominant coral fauna in the south western part of the lagoon (Zone 1). In the present survey, Acropora spp. were very poorly represented (2.5%) in the quadrats in Zone 1 (Table 1) indicating that corals of this genus might have vastly deteriorated and become dead. The distal branches of the dead colonies of this genus projecting out from the sand, observed during the present study (Plate I) is a bearing testimony to the existence of a once flourishing ramose corals in this zone. Pillai (1975) has attributed the large scale death and disintegration of Acropora spp. in the recent past to the fact that this was one of the most sensitive species to silting. Enquiries with the local fishermen during this study has revealed that the scanty distribution of this species in the lagoon is due to the intensive interference (hand picking) of the people in the island habitats in the recent past. The branching ramose forms are often the most soughted after ornamental and decorative corals. Moreover local fishermen during the collection of live-baits in the lagoon put small nets over the coral colonies and break the branches in the process, thus leading to large scale destruction of the species.

During early seventies, Pillai (1971) and Nair and Pillai (1972) have observed huge colonies of Goniastrea retiformis, Diploastrea heliopora, Lobophyllia corymbosa, Platygyra lamellina and Porites spp. in the shoal located in the north-eastern side of the lagoon (Plate II). in the present survey it was observed that the average live coral cover in this zone varied between 35.13 and 60.43% (Fig. 4) with majority of the living coral cover confined to the sides and undersides of the shoal (Plate IV). Goniastrea retiformis and Diploastrea heliopora still remained as the dominant form in the shoal (Table 3). Massive dead poritids and faviids partly buried in the sand were also observed during the survey.

One probable reason for the large scale deterioration of corals in Zone 1 to 5 is the effect of excessive silting as a result of dredging activities (and the subsequent sea erosion) carried out in the lagoon between the early and middle seventies. Pillai (1990) has opined that 75% of the damage of the corals in the lagoon was due to excessive siltation as a result of these dredging activities. According to Bak (1978) dredging and the subsequent churning up of enormous quantities of sediments result in reduced coral growth or death in some cases. As a result of the increased siltation (due to churning up of sediments) the drastic reduction in the light values, suppresses calcification rates (in some cases upto 33%) in corals. Besides siltation also influences corals adversely through stimulation of the energy consuming rejection behaviour of the polyps and in the case of colonies of coral species which are inefficient in sediment rejection

(Porites spp.) expulsion of zooxanthellae and subsequent death of the species occur. In his studies on the effect of dredging on two species namely Montastrea annularis and Agaricia agaricites Bak (1978) observed that a reduction of 33% in calcification rates was not just due to the effect of reduced light values but rather from sub-lethal effects (eg. on reproduction) from a 'metabolic shock' which had long term consequences.

In the present survey it was observed that Porites spp. by far was the most prevalent species in the deeper areas of the lagoon dominating in the four zones (Table 7) and in one case contributing to a maximum of 80.5% of the area of the quadrat. Psammacora sp. also was the richest coral fauna in the deepest part of the lagoon (Zone 8) recording a maximum live coral cover of 91.75% (Table 8). According to Marshall and Orr (1931) the colonies of Porites are more as less dome shaped and the small calices provide little holding place for sediment so that much of cleansing is done by water movements. Further Mayer (1924) observed that Porites withstood unfavourable conditions more than Acropora, Fungia and Pocillopora and that water movement is more important as cleansing than ciliary action. A similar observation was also made in Psammacora sp. which is considered hardy coral and being a small polypoid form, it depends to a large extent on the water movements for the removal of the sediments (Marshall and Orr, 1931). In the present study the water currents were recorded at higher velocities ranging between 0.300 and 0.633 knots/hr in the deeper areas in comparison with the low velocity currents experienced in shallow regions (Table 16). Hence the observation made in the present study of increased survival of the coral fauna mainly Porites and Psammacora in the deeper areas, against the excessive siltation due to dredging can be explained on the basis of the increased current velocities (water movements) experienced in these regions. A similar observation was also made at Low Isles of the Great Barrier Reef, where there were live flat topped Porites colonies on the reef. The centre portions of these flat topped colonies were dead which indicated that they have been killed by the exposure to unfavourable conditions at low tide during periods of less water movements and was confirmed by the fact that such flat tops were seldom found in deeper waters. (Marshall and Orr, 1931). However, the above assumption of better survival of Porites colonies as a direct result of increased water movements could not explain the low live coral cover of this species recorded in Zone 1 during the survey (Table 1) and also as reported by Pillai and Jasmine (1989).

Sedimentation studies carried out during the period from 1990 to 1992 revealed that sedimentation rate was the highest in the south-western part of the lagoon (Fig. 8). This means that the southern portion of the lagoon is fast getting filled up with sediments. These sediments would have been transported by the water currents from the lagoon as a result of erosion but these sediments have no further escape into the open ocean because of the presence of the elevated reef flat which remains exposed most of the time acting as an effective barrier against sediment transport (Plate III).

On the reef flat in zone 5 and 6, during low tides, the reef flat gets exposed. Some of the colonies thus exposed resulted in the mortality due to dessication. These colonies were found fouled upon by algae like Jania capillacea, Zoonaria variegata and Gellidiella spp. on the exposed coral skeleton and later got covered by calcareous algae which penetrated the corallites causing erosion to the reef substrate. Such disintegrating process was also commonly observed on the exposed seaward reef flat.

In the present study, it was also observed that in some species namely Acropora palifera, Porites spp. Pocillopora damicornis and Psammacora contigua found growing on the lower areas of reef flat, where a part of the colony would always remain intact (submerged), reorganization and reactivation of the peripheral soft tissues took place along the line of destruction and advanced on the adjacent parts of the dead skeleton secreting a new layer of calcium carbonate. On a few occasions, this new layer was found to expand and cover the fouled algal layer.

According to Fishelson (1973) coral species namely Platygyra lamellina and Faviids were able to preserve water in their 1.0 to 2.0 cm deep corallites and thus maintain some living tissues even when exposed during low tides. During the survey on the reef flats it was observed in the case of Platygyra lamellina and faviids that the colonies not only regenerated from those parts that remained intact but also a few were observed to be regenerated from isolated corallites found within the denuded zone. The better survival of Platygyra lamellina observed on the reef flats in Zone 5 and 6 can be explained on the basis of Fishelson (1973) findings.

Besides Platygyra lamellina, branching forms like Psammacora contigua and Pocillopora damicornis also occurred on reef flat. These species are usually spread by swimming planulae; the larvae move around and settle and thus repopulate these reef flat areas. Thus it can be concluded from the above observations that reproductive reinvasion and partial regeneration of the corals accounted for the presence of coral fauna on the reef flats.

In the lagoon recolonization of corals by settlement of the planulae will largely depend on the physiographic conditions, since they can settle only on hard substrata. According to Pillai (1990) restoration of coral fauna will take a minimum of 15 to 20 years with regard to fast growing species like Acropora. The chances of recolonization of corals in the areas where coral mortality is very significant is very remote since the substrate is covered by moving sand that will prevent the settlement of fresh planulae. However, recolonisation of the coral forms like Platygyra lamellina, Porites, Favia, Favites and Lobophyllia along the sides of numerous shoals in the lagoon was observed during the survey (Plate IV). In some cases the corals began to recolonise themselves not only from the dead parts of the shoal but also from isolated corallites found in these areas. The tissue thus regenerated was observed to extend not only over the sides of these dead substrates, but also established contact with the polyps of adjacent corallites and united forming a continuous living layer.

Species Diversity

The hermatypic scleractinian corals of Minicoy so far as known at present include 104 species in 37 genera and the records are mostly from the shallow waters (Pillai and Jasmine, 1989). This can be considered a relatively poor representation of the coral fauna when compared to a total of 241 species in 75 genera (Pillai and Scheer, 1976) reported from the adjacent Maldive Archipelago. In the present study several common Indo-Pacific genera and species of Cyphastrea seralia, Cycloceris cyclolitis, Favia laxa and Porites rus have been encountered and are reported for the first time from Minicoy (Plate XI).

The relatively low number of genera reported from Minicoy is not altogether a clear reflection of the paucity of the fauna but can be due to less intense collection. Pillai and Jasmine (1989) reported that significant difference in the occurrence and composition of the fauna at generic level seemed to occur between Minicoy and rest of the islands. The authors considered that the genera namely Cyphastrea and Echinopora were never present in the shallow waters of Minicoy. The non detection of Cyphastrea seralia from Minicoy until the present survey strengthens the view that the coral fauna in Lakshadweep was not studied intensively. The limited extent of areas surveyed and the low intensity of collection might have been the reasons for the unrealistic conclusions in the past on the number of species. Further investigations in the deeper waters of Minicoy and other islands would certainly add to the present faunal list.

Several species namely Leptastrea bottae and Dendrophyllia microanthus recorded by Gardiner (1903) from Minicoy, but could not be seen by the later workers have been encountered during the present survey. In the present study it was observed that even though Minicoy harboured a fairly good number of species and genera, the degree of their dominance differed considerably with respect to the other islands of the Archipelago. Acropora spp. the most dominant coral species in the Kalpeni lagoon (Plate IV) with extensive colonies of the species, exhibited only a patchy distribution that too over a negligible area in the Minicoy lagoon. According to Grigg (1983) the difference in dominance as well as patchy nature of distribution were due to either natural or manmade causes. The various dominant coral forms in the lagoon and the extent of such dominance have already been described.

In the literature one come across strong evidences to suggest predictable patterns of species diversity existing along a depth gradient which appears to be associated with the gradient of light energy and also a variety of biotic and abiotic factors (Hudson, 1985). Based on the studies carried out on the reefs near Eilat in the Red Sea, Loya (1972) reported that species richness increased in diversity from the surface to a depth of 8-12 m. In the reef slopes of Chagos Atolls, Sheppard (1980) observed an increase in species richness from the surface to around 20 m where it reached a maximum and then declined gradually to the deepest site. Numerous other studies made on reefs have also reported an increase in diversity with increased depth (Lewis, 1974 and Glynn, 1976). In the present study a strong predictable pattern of species diversity was not observed as the depth of water increased (Table 10). In the shallow region of depth less than 1.5 m the index of species diversity varied between nil and 1.7521. A similar index was also obtained in the deepest areas of the lagoon, where the depth was about 13.0 m. Though better survival and live coral cover was observed at the deeper zones in the lagoon, species diversity did not follow a similar trend. Porter (1972) in his studies on the Caribbean reef corals has also reported a similar observation and concluded that there was no strong pattern of species diversity with increasing depth. However, further investigations in the deeper outer reef are necessary which would certainly throw light on the pattern of species diversity existing along a depth gradient as reported by Loya (1972), Lewis (1974), Glynn (1976) and Sheppard (1980).

In the present study the species diversity values were generally higher on the reef flats (Table 10). Although the reef flat was dominated by one or two species, the index of species diversity was 2.0453 in one station while in others it varied between 1.0591 and 1.7563, and on the seaward reef flat the species 'diversity varied between 1.0588 and 2.1446. There are similar reports of increased diversity existing on reef flats that are periodically exposed at low tides or subjected to other disturbances that cause mortality (Connell, 1978; Ditler, 1978). At Discovery Bay, Ohlhorst (1980) obtained the highest diversity (H' = 2.34) under conditions apparently unfavourable for coral growth (high temperatures and reduced water circulation). According to Fishelson (1973) the high diversity of coral species recorded on the reef flat at Eilat in Red Sea was due to the unpredicted extreme low tides, that occurred sporadically in the reef flat which killed a part or all of the coral population occurring and in this way prevented the rapidly growing species from attaining a space monopoly and competition. Glynn (1976) observed a similar effect on reef flats on the Pacific side of Panama, where extreme tidal exposure killed 40-60% of the dominant Pocillopora spp. which had a diversifying effect on the reef flat. According to Grigg and Maragos (1974) the degree of exposure to waves and swells affected coral cover and diversity and in general diversity was highest and live coral cover lowest at most of the exposed areas which indicated that disturbance from chronic wave action can also act to maintain diversity. A similar observation was made in the present study also.

The above study concludes that is general the Minicoy reef is characterized by low species diversity and low live coral cover except for a few monospecific species in the deeper zones of the lagoon which exhibited better coverage. The large scale destruction and patchy distribution of the once dominant Acropora spp. in the lagoon are attributed to the sensitivity of this species to excessive silting and human interferences in the lagoon. Excessive siltation as a result of the dredging activities carried out in the lagoon is suggested a major causative factor for the large scale degradation of corals in the lagoon. On the reef flats, reproductive reinvation and partial regeneration of corals accounted for the presence of coral fauna while in the lagoon, coral colonies were observed to recolonize not only from the dead parts of the shoal but also from isolated corallites. The present study provided no evidence for a direct correlation between species diversity and 'reef health'. There was no significant change in the species diversity although there was considerable change in the pattern of live and dead coral cover; thus implying that factors other than live coral cover was responsible to bring about a high species diversity. The study also provides conclusive evidence that Minicoy Atoll may be considered as a model of reef under stress. The trends discussed in this chapter may become an useful tool in reef management and for early identification of the factors of stress.

CHAPTER - II

ECOLOGICAL CHARACTERISTICS OF THE ENVIRONMENT

INTRODUCTION

Studies on the ecology of a coral reef lagoon is of great significance as the environment influences not only the fauna and flora associated with the coral heads, but also the high sea resources to a great extent (Pillai and Mohan, 1986). A knowledge of the physico-chemical and biological parameters is essential because corals which form the structural frame work of the reefs, are highly specific in their requirements for light, temperature, salinity and dissolved oxygen. Besides, the studies on environmental parameters in a lagoon, is important because coral reef atolls, generally lack large buffer zones around them and so any change in the environment is very conspicously manifested in the lagoon, thus resulting to ecological stress very easily.

The most important pre-requisite for the study of relationship between a coral reef environment and the reef destroying agents, is an understanding of the various physical, chemical and biological factors of the environment. Parameters such as temperature, light and salinity in a reef ecosystem interact to produce numerous distinctive habitats for the reef destroying organisms. Although we are able to isolate each of these factors and consider its influence on the corals, the behaviour of a species at any time is determined, not by a single exogenous factor, but by several of them working simultaneously.

The present chapter deals with some of the major physical, chemical and biological parameters acting in the Minicoy lagoon and the objectives of this study are as follows.

1. to compare the ecological processes on the windward and leeward side of the lagoon.
2. to study the variation of ecological processes in the different areas (live coral, dead coral, sandy bed and seagrass bed) and

3. to study the influence of ecological processes on the distribution of the bio-eroding agents in the lagoon.

REVIEW OF LITERATURE

In the past, major ecological studies in Lakshadweep have been carried out around Kavaratti, Kalpeni and Amini group of islands. Jayaraman et al. (1959) studied the vertical distribution of dissolved oxygen in the deeper waters of the Arabian Sea. Later Patil and Ramamirtham (1963) compared the chemical characteristics of Lakshadweep offshore waters during winter and summer conditions. Qasim and Sankaranarayanan (1970) studied the production of particulate organic matter by the reef of Kavaratti Atoll while the primary productivity of seagrass bed of this atoll was studied by Qasim and Bhattathiri (1971). There are several reports on the zooplankton community structure in the lagoon and surrounding sea of Kavaratti Atoll (Tranter and George, 1972; Goswamy, 1973, 1979, 1983; Madhupratap et al., 1977). Studies on the chemical characteristics of waters around Kavaratti and Kalpeni Atolls are well documented (Qasim et al., 1972; Sankaranarayanan, 1973; Sengupta et al., 1979). Nair et al. (1986a,b) have studied the environmental features of the sea around Lakshadweep. Recently Suresh (unpublished) carried out a detailed study of the various ecological processes acting in Kavaratti lagoon and its influence on coral growth.

However, in contrast, there are only very few reports on the ecological aspects of Minicoy Atoll (Rao and Jayaraman, 1966; Nair and Pillai, 1972; Jagtap and Untawale, 1984). These reports were based on studies carried out for shorter durations. One major reason, that has been responsible for the limited literature on the ecological characteristics of the environment of Minicoy atoll has been the remoteness of this Atoll. Till date, there has been no effort to study the various physico-chemical parameters acting in the lagoon on a long term basis. The current pattern and forces of dynamics acting inside the lagoon remains to be uninvestigated. The magnitude of sedimentation in the lagoon and its role on coral destruction has also not been studied eventhough sedimentation as a result of

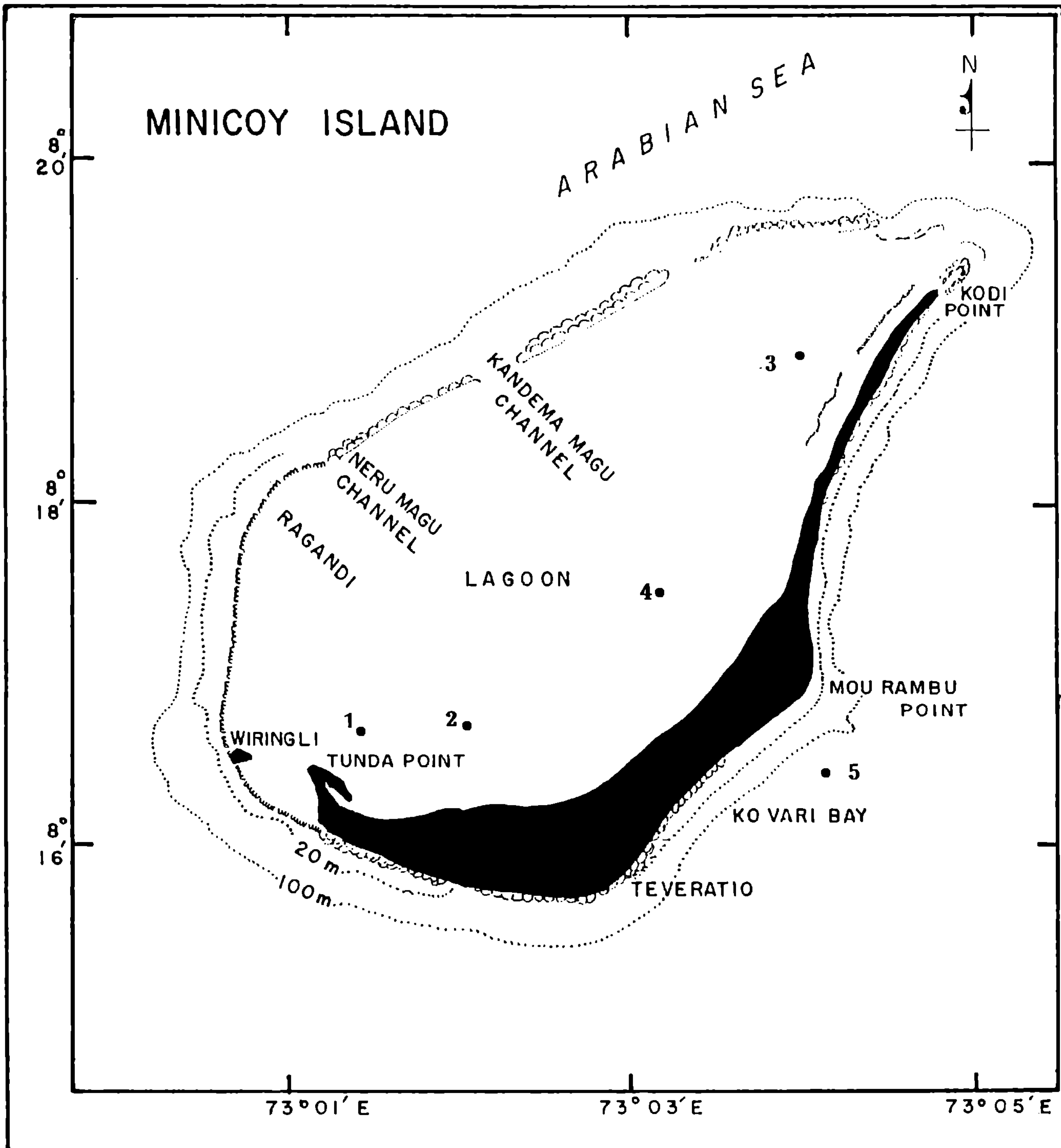


Fig. 5. The different stations in Minicoy lagoon where ecological studies were conducted.

dredging activities in the lagoon, was considered a major reason for the mass mortality of corals in the lagoon (Pillai, 1990).

In view of the lack of information on the subject under consideration, a detailed study of the ecological parameters was proposed to be carried out in the lagoon of Minicoy Atoll for a period of two years, and the results are presented.

MATERIAL AND METHODS

For monitoring the ecological parameters on a regular basis, fortnighly sampling was carried out at 4 fixed stations in the lagoon which represented live coral area, dead coral area, seagrass bed and sandy bed respectively (Fig. 5). In order to make comparisons of ecological processes on the windward and leeward side of the lagoon, one station was selected on the leeward side of atoll (Fig. 5).

Sampling was carried out for a period of two years from 23.1.1990 till 26.12.1991.

a) Physical Parameters

1. Temperature: Atmospheric temperature and temperature of water was measured using a 0 to 50°C high precision thermometer. Water was collected from the surface in a plastic bucket for measuring the surface temperature.

2. Salinity: Water samples were collected from 5 cms below the surface into a 100 ml clear, air tight polythene bottles. The samples were stored in an insulated box till they were analysed. Analysis was done using 'Mohr' titration method (Strickland and Parsons, 1968). Ten millilitre of the sample was titrated against silver nitrate solution using potassium chromate as indicator. Silver nitrate solution was standardised

using standard sea water procured from the Oceanography Laboratory Copenhagen. Titration was repeated for concordant values.

3. Sedimentation: The sediment particles setling down on the reef surface, collected in a vertically oriented sediment trap was taken as a measure of the gross sedimentation (Cortes and Risk, 1985).

For studying the gross sedimentation 4 sampling stations were selected in the lagoon (Fig. 5) from 23.1.1990 till 23.12.1991. These stations were located at a distance of 1.6 km, 4.1 km, 5.1 km and 5.7 km away from the main entrance. These stations were selected in such a manner that the rate of sedimentation in the lagoon could be studied with the knowledge of the current pattern in the lagoon.

Plastic containers with a height to diameter ratio of 3:1 was considered ideal for estimating vertical fluxes (Gardiner 1980a,b) and used as sediment traps. These sediment traps were tied to a pole fixed securedly to the substratum with the mouth of these sediment traps raised about 40 cms above the lagoon bed (Charuchinda and Hylleberg, 1984). The sediment traps were suspended for a period of 24 hours before they were recovered carefully by closing the mouth underneath the water with a lid so as to prevent the loss of sediments from these traps at the time of recovery.

In the laboratory the water and sediment mixture in the traps were filtered through a dried weighed Whatman No.41 filter paper. The sediments were poisoned with 0.001 M sodium azide and then dried at 105°C and weighed accurately. The weight of this "Resuspended sediments" traped for a given period of time is expressed as Gross sedimentation in terms of $g/m^2/24$ hrs .

Water currents

The study of current pattern inside the lagoon was necessary to determine the path of transportation of sediments inside the lagoon. This was considered significant because coral growth and its recolonization are influenced by sediments (Dodge et al., 1974).

Current pattern in the lagoon was studied using drift technique (Fig. 5a). Drift techniques has been reported satisfactory for preliminary observations on the current characteristics (Maragos, 1978). Details of the dimensions of the floating devise are given in Fig. 5a. The floating device was positioned low enough in the water, between 2 and 4 metres (depending upon the depth of water). The value obtained is considered as the mean velocity of the existing vertical gradient in current velocity. By using the compass surveying method, the position of the floats, the distance covered by the floats and the direction of movement of the floating device were measured accurately. The current velocity was calculated based on the distance travelled by the float and the time taken. The nature of the tide was also noted.

Chemical Parameters of the Environment

1) **Dissolved oxygen**

For estimation of dissolved oxygen, the samples were collected using a plastic bucket causing least agitation. The water from the bucket was then siphoned through a piece of plastic tubing into a glass stoppered BOD bottle of 125 ml capacity (Marsh and Smith, 1978) with no trapped gas. The siphoned water was allowed to overflow and flush the BOD bottle for 30 seconds. Care was taken to exclude bubbles from the siphon tube as well as the sample bottle.

Samples collected were fixed immediately using 1.0 ml Winkler-A and Winkler-B solution. The bottles were shielded from direct sunlight

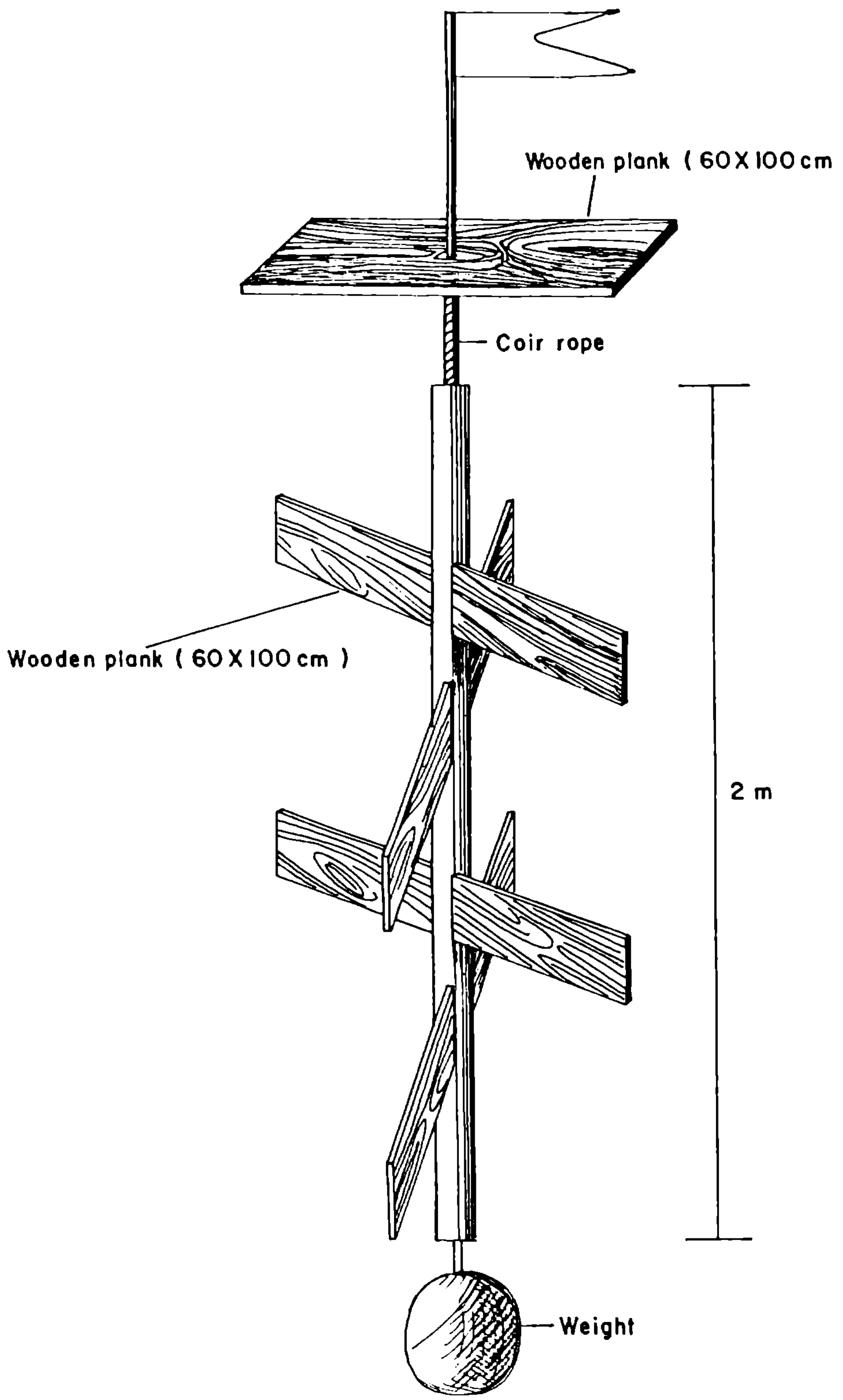


Fig. 5a. The floating devise used for studying current pattern of Minicoy lagoon.

and protected from drastic temperature changes by storing them in insulated box. Samples were taken to the laboratory and analysed within 6 hours of sampling. Analysis of the samples was done using 'Winkler method' modified by Carritt and Carpenter as given in FAO (1975) using 0.02 N sodium thiosulphate with starch as indicator.

Nutrients

Water samples were collected from the different stations in a 500 ml polythene bottle and stored in an insulated box. A standard graph was prepared for each nutrient factor using known concentrations of standards. The absorbance of the sample was measured using a spectrophotometer and the concentration was determined from the standard graph accordingly. Nutrient values are expressed in international units of microgram atom per litre (ug at/L).

Nitrite (NO_2^- N)

Estimation of nitrite (NO_2-N) was carried out using modified Bendschneider and Robinson method as given in FAO (1975).

25 ml of the sample was transferred to a volumetric flask. Another 25 ml was also transferred to a second container for a turbidity blank. Added 0.5 ml of sulphanilamide solution to the sample and turbidity blank and mixed well. After not less than three minutes and not longer than 8 minutes, 0.5 ml of the diamine solution was added to the sample only (not to the turbidity blank) and mixed well. After 10 minutes the absorbance of the sample and the turbidity blank were measured in a spectrophotometer at 545 nm. The concentration of nitrite in the sample was calibrated from the standard graph after subtracting the absorbance of the turbidity blank from that of the sample.

Nitrate (NO_3-N)

Estimation of nitrate was done using Mullin and Riley (1955) method.

50 ml of the sample was taken in a volumetric flask and 2.0 ml buffer reagent was added followed by 1.0 ml reducing agent on gentle mixing. The sample was then kept in the dark for 20 hours. Then 2.0 ml acetone solution and after 2 minutes, 1.0 ml of sulphanilamide solution were added. After not less than 2 minutes and not longer than 8 minutes, 1.0 ml N-(1-napthyl) ethylene diamine dihydrochloride (N.N.E.D.) solution was added to the sample. The absorbance of the sample was determined after 10 minutes at 550 nm. The procedure was repeated for a turbidity blank without adding 1.0 ml N-(1-napthyl) ethylene diamine dihydrochloride (N.N.E.D.). The concentration of nitrate in the sample was calibrated from a standard graph after subtracting the absorbance of the turbidity blank from that of the sample.

Silicate (SiO_4)

Reactive silicate was determined as described in FAO (1975).

35 ml of sample was taken in a 50 ml plastic jar and 1.0 ml molybdate reagent was added. After 10 minutes, 1.0 ml of 0.7 m oxalic acid solution was added followed immediately by 1.0 ml of 0.1 m ascorbic acid solution, by gentle stirring. The absorbance of the sample was measured against distilled water in a cell after 30 minutes at a wave length of 810 nm. The absorbance measured was corrected using a reagent blank. The reagent blank was prepared using 35 ml distilled water and adding only 0.5 ml of molybdate reagent and the absorbance was measured after one hour.

Phosphate (PO_4-P)

Phosphorus was estimated using Murphy and Riley (1962) method as described in FAO (1975).

To 35 ml of the sample in a volumetric flask, 1.0 ml of acid-molybdate solution (prepared fresh by adding 5 ml of 0.1 m potassium antimony tartarate solution to acid-molybdate reagent) was added followed by the addition of 1.0 ml of 0.4 m ascorbic acid solution, mixed thoroughly between the additions. After five minutes the absorbance of the sample was measured at 882 nm and was corrected using a reagent blank prepared with 35 ml distilled water but without adding 1.0 ml of 0.4 m ascorbic acid.

Chlorophyll

Primary productivity studies are relevant in the context of investigating coral erosion since recruitment of planulae larvae of corals is reported to be influenced by primary productivity and moreover bioerosional damage by boring bivalves is also correlated with primary productivity (Highsmith, 1980a).

In the present study, water samples were collected from different parts of the lagoon representing live coral area, dead coral area, seagrass bed and sandy bed respectively. Three litres of the water sample were filtered through a GFC filter paper using a suction pump. The filter paper was then carefully folded and dipped in 7.0 ml of 90% acetone and kept in the dark for two hours. It was then mascerated throughly using a glass tube and centrifuged. The chlorophyll content (ug/L) was read at 665 nm using a uv/vis spectrophotometer JASCO MODEL 7800. The phaeo concentration of the sample was obtained using 3 drops of 10% HCl.

Diurnal studies

In order to evaluate the diurnal variation of ecological parameters in the lagoon a round the clock observation was made in the lagoon. Diurnal studies were found to be relevant in the context of investigating coral mortality since there are reports of coral colonies being damaged due to extreme temperature conditions (Fishelson, 1973). Hence it was suggested to study the diurnal variation in ecological parameter in a shallow part of the lagoon so as to evaluate the extent to which these variations would contribute to ecological stress, leading to the mortality of corals.

Diurnal studies were conducted at two stations in the lagoon.

Station I — It was situated about 4.1 km away from the main entrance and about 250 m away from the nearest shore. The average depth of water at this station was 2.0 m at low tide and the bottom was characterised by a luxuriant growth of sea grass mainly Syringodium isoetifolia and Thalassia hemprichii.

Station II — It was fixed in front of the helipad in the southwestern part of the lagoon sand flat. A part of this area gets exposed during low tide. The bottom of this station is characterised by the absence of any luxuriant coral growth.

RESULTS

Data collected for ecological studies were pooled and grouped into three seasons namely Pre-monsoon (January to April), Monsoon (May to August) and Post-monsoon (September to December). Since Minicoy Island received early monsoon showers from the month of May onwards (Fig.10) the grouping for seasons in the present study was done taking this fact into consideration.

Temperature (°C)

The variations of air and water temperature recorded in the lagoon and on the seaward reef flat are given in Fig. 6.

In the lagoon, during the period from January 1990 and December 1991 the air temperature varied between 29.7 and 31.6°C at Station I while it varied between 29.3 and 31.6°C at stations II, III and IV. On the seaward

Table 12. Pre-monsoon, Monsoon and Post-monsoon seasonal averages of hydrographic parameters for stations 1 to 4 on the windward side and Station 5 on the Leeward side of Minicoy Island.

a) Air temperature (°C)

Year	Seasons	Lagoon (windward)				Leeward
		Station I	Station II	Station III	Station IV	Station V
	Pre-monsoon	29.8	29.8	29.8	29.8	30.0
	Monsoon	29.6	29.6	29.9	29.7	29.7
1990	Post-monsoon	31.6	31.6	31.6	31.6	31.7
	Average	30.32	30.32	30.42	30.42	30.45
	Pre-monsoon	29.7	29.7	29.7	29.7	30.0
	Monsoon	29.8	29.8	29.8	29.8	30.1
1991	Post-monsoon	29.3	29.3	29.3	29.3	29.3
	Average	29.58	29.58	29.58	29.58	29.80

b) Water temperature (°C)

	Pre-monsoon	29.5	29.4	29.6	29.8	29.6
	Monsoon	29.5	29.5	29.2	29.0	29.4
1990	Post-monsoon	30.1	30.2	29.8	29.3	29.8
	Average	29.72	29.67	29.52	29.35	29.58
	Pre-monsoon	29.6	29.1	29.8	30.1	29.7
	Monsoon	28.8	29.4	29.5	29.4	29.2
1991	Post-monsoon	29.9	29.9	29.6	29.0	29.4
	Average	29.43	29.48	29.60	29.51	29.40

Table 12. Contd..

c) Dissolved oxygen (mg/l)

Year	Seaons	Lagoon (windward)				Leeward
		Station I	Station II	Station III	Station IV	Station V
	Pre-monsoon	4.3	4.2	4.4	4.5	5.5
	Monsoon	5.4	5.4	5.0	4.6	5.6
1990	Post-monsoon	6.3	5.6	5.8	4.5	5.7
	Average	5.30	5.11	5.05	4.57	5.61
	Pre-monsoon	4.9	5.2	5.1	4.9	5.6
	Monsoon	4.7	5.6	5.6	4.8	5.6
1991	Post-monsoon	5.8	6.0	4.8	4.7	5.7
	Average	5.13	5.59	5.13	4.81	5.62

d) Salinity (ppt)

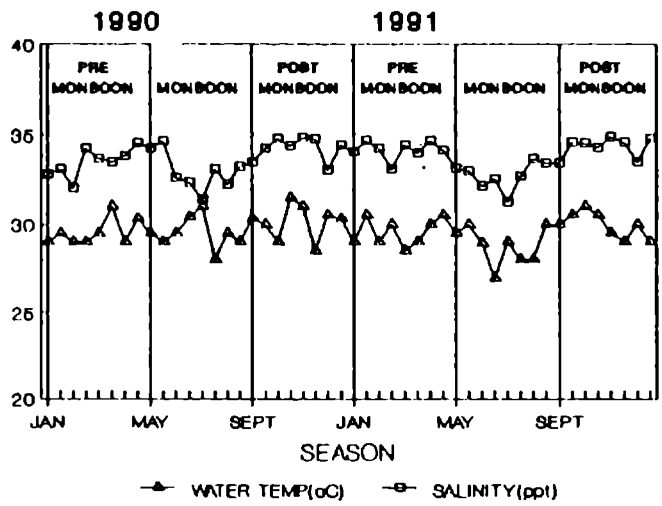
	Pre-monsoon	33.5	33.6	33.9	33.7	34.6
	Monsoon	33.0	32.8	32.6	32.6	33.7
1990	Post-monsoon	34.3	34.5	34.4	34.0	34.4
	Average	33.57	33.66	33.65	33.44	34.23
	Pre-monsoon	34.2	34.2	34.3	34.0	34.4
	Monsoon	32.7	32.9	32.8	32.8	34.0
1991	Post-monsoon	34.3	34.0	34.3	33.8	34.6
	Average	33.74	33.70	33.79	33.53	34.34

Table 13. Analysis of variance (ANOVA) tables, showing the levels of significance in the variation of different hydrographic parameters between stations and over seasons in Minicoy Island

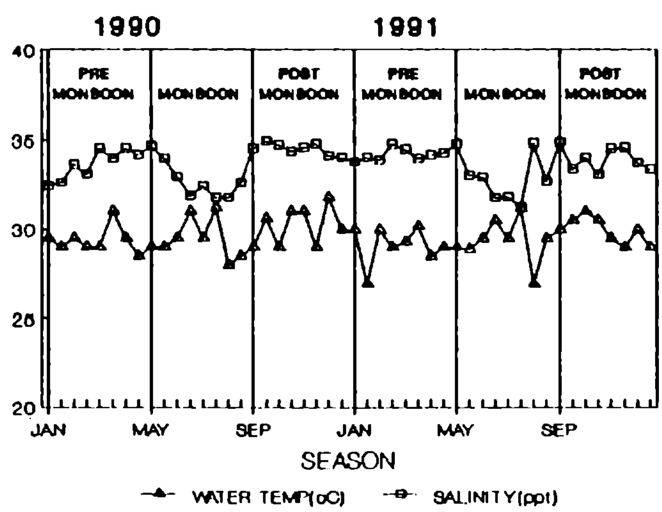
Source of variation	d.o.f.	Sum of squares	Mean sum of squares	F value	Remarks
a) Air Temperature					
Between stations	4	1	0.25	0.04	$P \geq 0.05$
Between year/station	5	35	6.97	1.49	$P \geq 0.05$
Between season/y/st.	20	94	4.68	6.17	$P \leq 0.01$
Error	210	159	0.76		
b) Water Temperature					
Between stations	4	1	0.20	0.46	$P \geq 0.05$
Between year/station	5	2	0.43	0.36	$P \geq 0.05$
Between season/y/st.	20	24	1.22	1.37	$P \geq 0.05$
Error	210	186	0.89		
c) Dissolved oxygen					
Between stations	4	22	5.55	6.92	$P \leq 0.01$
Between year/station	5	4	0.80	0.35	$P \geq 0.05$
Between season/y/st.	20	46	2.29	2.95	$P \geq 0.05$
Error	210	163	0.78		
d) Salinity					
Between stations	4	18	4.46	25.07	$P \leq 0.01$
Between year/station	5	1	0.18	0.04	$P \geq 0.05$
Between season/y/st.	20	83	4.15	6.05	$P \leq 0.01$
Error	210	144	0.69		

Table 14. Seasonal average of gross sedimentation (g/m^2/24 hr) recorded in various stations in the lagoon of Minicoy Island

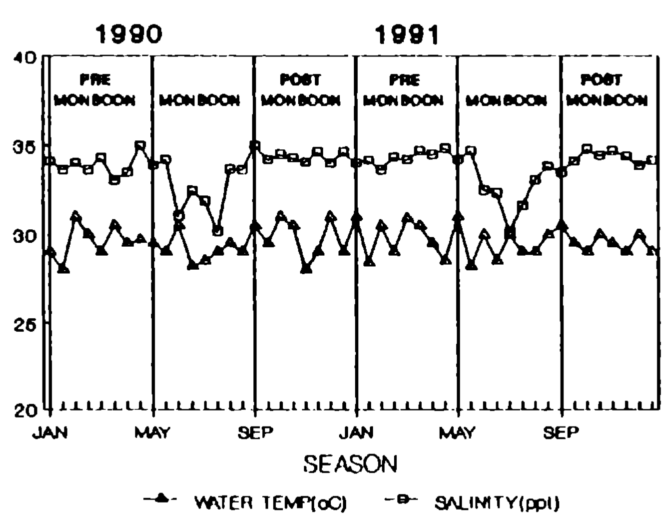
Year	Season	Lagoon			
		Station I	Station II	Station III	Station IV
	Pre-monsoon	144.7	172.0	93.9	71.7
1990	Monsoon	97.8	124.5	76.4	38.1
	Post-monsoon	80.9	125.3	53.6	53.0
	Average	107.79	140.60	74.64	54.28
	Pre-monsoon	101.8	146.4	91.3	75.9
1991	Monsoon	131.8	152.5	71.6	82.7
	Post-monsoon	127.4	136.1	64.2	64.9
	Average	120.33	145.03	75.69	74.48



STATION I

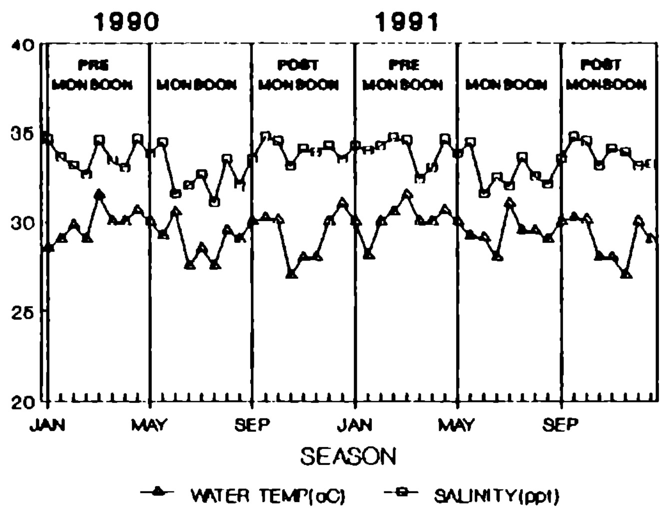


STATION II

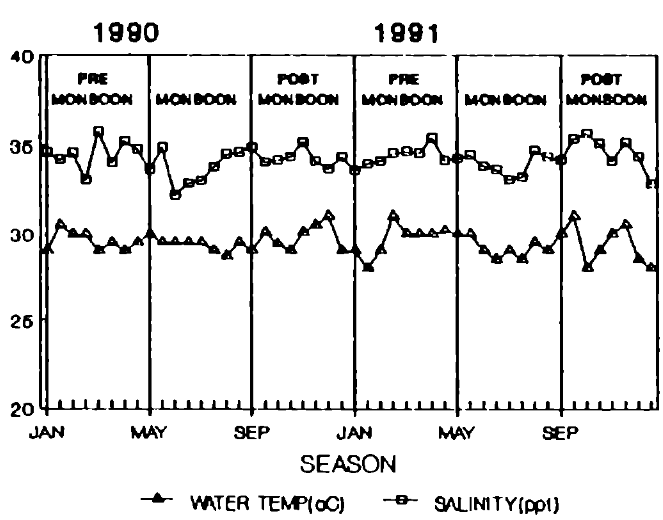


STATION III

Fig. 6. Variation in temperature and salinity in the different stations during the various seasons.



STATION IV



STATION V

Fig. 6. Variation in temperature and salinity in the different stations during the various seasons.

reef flat at Station V, the temperature of air varied between 29.3 and 31.7°C during the different seasons.

Analysis of variance of the pooled data (Table 13) did not show any significiant variation in the temperature between the different stations ($P \geq 0.05$) while the variation recorded over the different seasons was significant ($P < 0.05$).

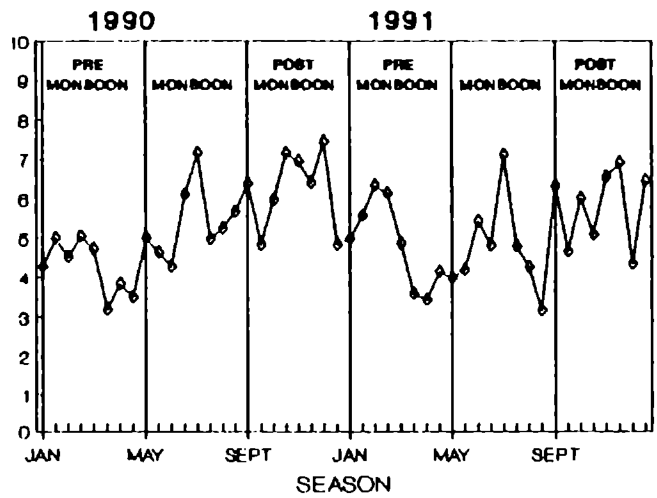
The temperature of water in the lagoon varied between 28.8 and 30.1°C during different seasons at Station I while the variation was between 29.1 and 30.2°C at Station II. At Station III the temperature of water varied slightly between 29.2 and 29.8°C while the values ranged between 29.0 and 30.1°C at Station IV in the lagoon. On the seaward reef flat (Station V), the temperature of water varied between 29.2 and 29.8°C.

Analysis of variance of the data (Table 13) showed that the variation in the temperature of water recorded at the different stations and over the different seasons were not statistically significant ($P \geq 0.05$).

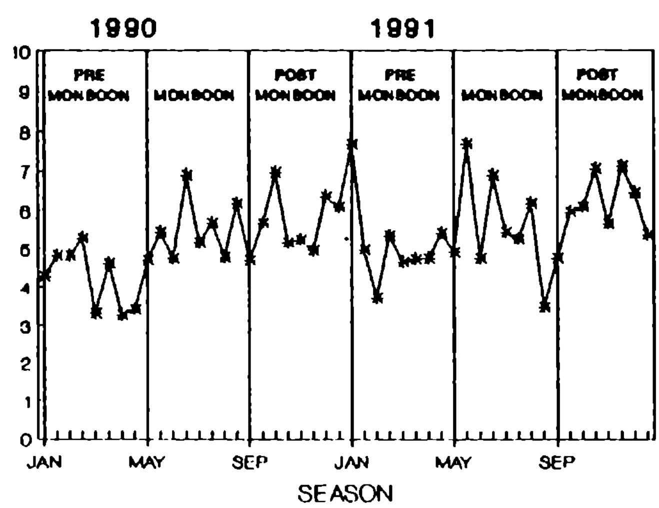
Dissolved oxygen (mg/l)

The variations in dissolved oxygen in the lagoon and on the seaward reef flat recorded during the period from January 1990 till December 1991 are given in Fig. 7.

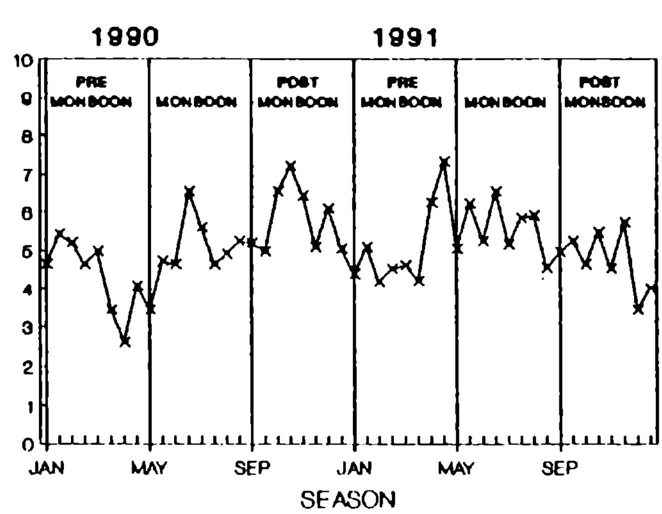
In the lagoon, the dissolved oxygen varied between 4.3 and 6.3 mg/l at Station I while it varied between 4.2 and 6.0 mg/l at Station II. At Station III, the dissolved oxygen over the different seasons varied between 4.4 and 5.8 mg/l while at Station IV a narrow variation was observed during the different seasons, with values ranging between 4.5 and 4.9 mg/l. On the seaward reef flat correspondingly higher dissolved oxygen values were recorded during the study with values ranging between 5.5 and 5.7 mg/l over different seasons. In general higher dissolved oxygen concentration was recorded in the lagoon during the post-monsoon season.



STATION I

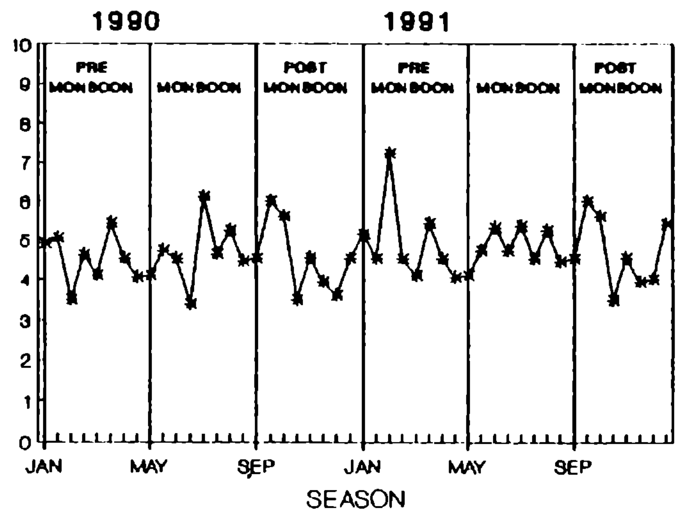


STATION II

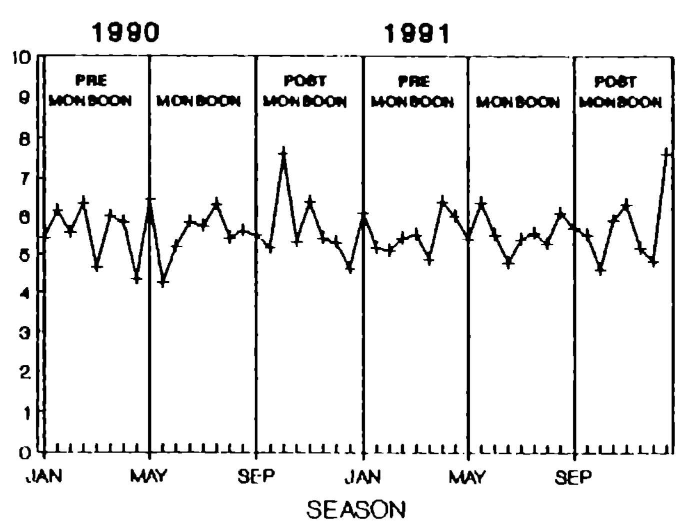


STATION III

Fig. 7. Variation in dissolved oxygen in the different stations during the various seasons.



STATION IV



STATION V

Fig. 7. Variation in dissolved oxygen in the different stations during the various seasons.

Analysis of variance of the data (Table 13) showed that, the variation in dissolved oxygen recorded at different stations and over different seasons was significant ($P \angle 0.05$).

Salinity (ppt)

The variation in salinity from January 1990 till December 1991 recorded in the lagoon and on the seaward reef flat is given in Fig. 6.

During the period from January 1990 till December 1991, in the lagoon, the salinity varied between 32.7 and 34.3 ppt at Station I, while it varied between 32.8 and 34.5 ppt at Station II. At Station III, the values recorded varied between 32.6 and 34.4 ppt and at Station IV the salinity varied between 32.6 and 34.0 ppt over the seasons. On the seaward reef flat salinity values were slightly higher with values ranging between 33.7 and 34.6 ppt. In general, lower salinity values were recorded in all the stations during the monsoon.

Analysis of variance (Table 13) to test the significance of variation in salinity between the different stations was highly significant ($P \angle 0.01$).

Sedimentation ($g/m^2/24$ hr)

The seasonal averages of Gross Sedimentation ($g/m^2/24$ hr) recorded in various stations over seasons is given in Fig. 8.

Gross sedimentation was highest at Station II, followed by Station I and II while the least was recorded at Station IV, over the different seasons. At Station II, during 1990, the gross sedimentation recorded 172.0 during pre-monsoon, decreased to 124.5 recorded in monsoon and later increased to 125. 3 during the post-monsoon season, the average for the year being 140.6 During 1991 an initial gross sedimentation of 146.4 (pre-monsoon) increased to 152.5 (monsoon) and later decreased to 136.1

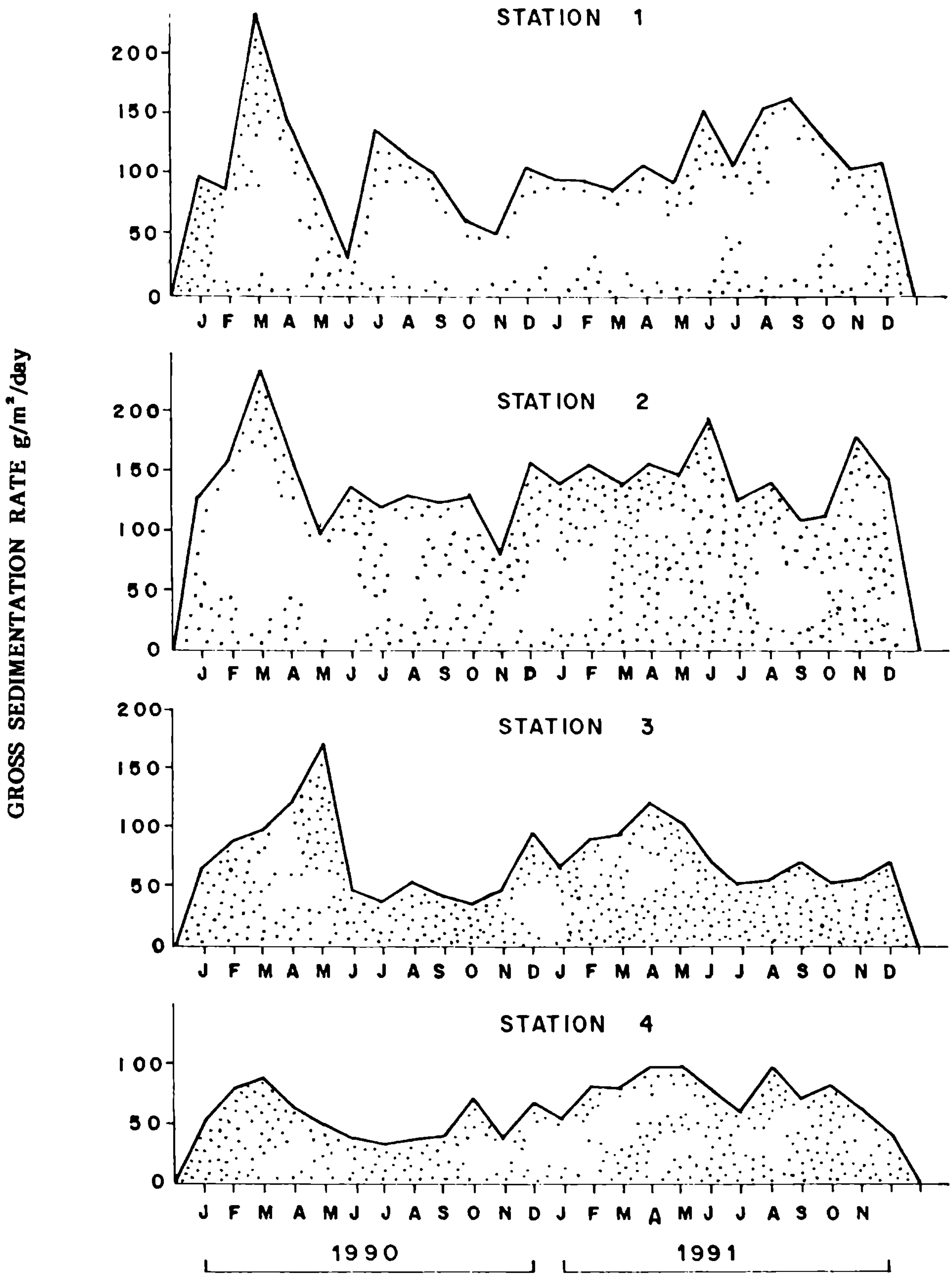


Fig. 8. The Gross Sedimentation recorded in the different stations during the period from January 1990 to December 1991.

Table 15. Analysis of variance (ANOVA), table, showing the level of significance in variation of gross sedimentation ($g/m^2/24$ hr) in the various stations

Source of variation	d.o.f.	Sum of squares	Mean sum of squares	F value	Remarks
Between stations	3	93926	31308.69	35.62	$P \leq 0.001$
Between year/station	4	3516	879.07	0.56	$P \geq 0.05$
Between season/y/ station	16	25093	1568.30	1.64	$P \geq 0.05$
Error	72	68956	957.72		

(post-monsoon) the average for the year being 145.03. At Station I, from an initial 144.7 (pre-monsoon) the gross sedimentation decreased to 97.8 (monsoon) and 80.9 (post-monsoon), the average for the year 1990 was 107.79. During 1991, at this station the gross sedimentation values were 101.8, 131.8 and 127.4 during pre-monsoon, monsoon and post-monsoon respectively and the average was 120.33. During 1990 at Station III the initial gross sedimentation of 93.9 (pre-monsoon) decreased to 76.4 (monsoon) and 53.6 (post-monsoon), the average recorded being 74.64. During 1991 gross sedimentation decreased from 91.3 recorded during pre-monsoon to 71.6 in monsoon and further decreased to 64.2 during post-monsoon. The average gross sedimentation observed for 1991 was 75.69. At Station IV, during 1990, the gross sedimentation was 71.7, 38.1 and 53.0 for pre-monsoon, monsoon and post-monsoon respectively while during 1992 the corresponding values were 75.9, 82.7 and 64.9 respectively. The average gross sedimentation was 54.28 in 1990 and 74.48 in 1991 at this station.

Analysis of variance to test the significance in variation of gross sedimentation (Table 15) at the various stations was highly significant ($P < 0.001$).

Water currents

The dominant currents and their velocities (knots/hour) observed in the Minicoy lagoon over the different seasons is given in Table 16.

In the lagoon, during pre-monsoon season the westerly flowing south-west and north-west currents dominated. During early pre-monsoon (January), the south-west currents dominated (58% of observations) with their velocities ranging between 0.115 and 0.380 knots per hour. As pre-monsoon season advanced (February), south-west current constituted 50% (with velocities between 0.054 and 0.244 knots) and north-west currents constituted 23% (0.088 and 0.498 knots/hour). During March, as pre-monsoon advanced further, the dominant currents in the lagoon were the south-west (53%) and north-west (47%) with velocities ranging between 0.074 and 0.147 knots/

Table 16. The dominant currents in the lagoon of Minicoy coral reefs. The range of velocities of the current expressed in knots/hour is given in brackets

	Directions of currents						
	South-West	South-East	North-West	North-East	West	North	East
Pre-monsoon							
January	58% (0.115-0.380)	8% (0.104-0.577)	19% (0.125-0.440)	11% (0.154-0.731)	4% (0.135)		
February	50% (0.054-0.244)	5% (0.213-0.351)	23% (0.088-0.498)	5% (0.466-0.692)		17% (0.133-0.276)	
March	53% (0.074-0.147)	47% (0.032-0.083)					
April	8% (0.075)	8% (0.079)	60% (0.045-0.168)	12% (0.076)	8% (0.066)	4% (0.146)	
Monsoon							
May		25% (0.083-0.942)	55% (0.189-0.400)	7% (0.229)			13% (0.12)
June			80% (0.011-0.633)				20% (0.162-0.38)
July			100% (0.300-0.427)				
August							
Post-monsoon							
September		44% (0.021-0.178)	44% (0.031-0.252)				12% (0.144)
October			100% (0.300-0.427)				
November	50% (0.008-0.288)	50% (0.089-0.172)					
December							

Study carried with the help of Lakshadweep Harbour Works Department, Minicoy.

hour 0.032 and 0.083 knots/hour respectively. Just before the onset of the south-west monsoon (April) the north-west currents dominated (60%) in the lagoon with current velocities ranging between 0.045 and 0.168 knots/ hour.

During the monsoon season, the north-east currents predominated in the lagoon (55%) and its predominance increased as monsoon advanced. In comparison with pre-monsoon values, higher current velocities were observed during the monsoon. During early monsoon (May) the current velocities varies from 0.189 to 0.400 knots/hour while as monsoon advanced, the velocities varied from 0.011 to 0.633 knots/hour. During July, in the lagoon, north-east currents dominated with current velocities ranging between 0.300 and 0.427 knots/hour.

Towards the beginning of post-monsoon (September) south-east and north-east currents equally dominated (44%) in the lagoon, with current velocities ranging between 0.021 and 0.178 knots/hour 0.031 and 0.252 knots/ hour respectively. As the post-monsoon advanced (October) only the north-east currents were predominant in the lagoon and their velocities ranged between 0.011 and 0.319 knots/hour. Towards November it was the south-west (50%) and south-east (50%) currents that was dominant in the lagoon. Their respective velocities ranged from 0.008 to 0.288 knots/hour and from 0.089 to 0.172 knots/hour.

Chlorophyll (µg at/l)

The average concentration of chlorophyll (µg at/l) in the water samples collected from live coral areas, dead coral areas, seagrass bed and sandy patch is given in the Fig.9.

In general the chlorophyll concentration in the seawater samples collected from live coral areas were comparatively higher than those collected from dead coral cover, seagrass bed and sandy patch. The average chlorophyll

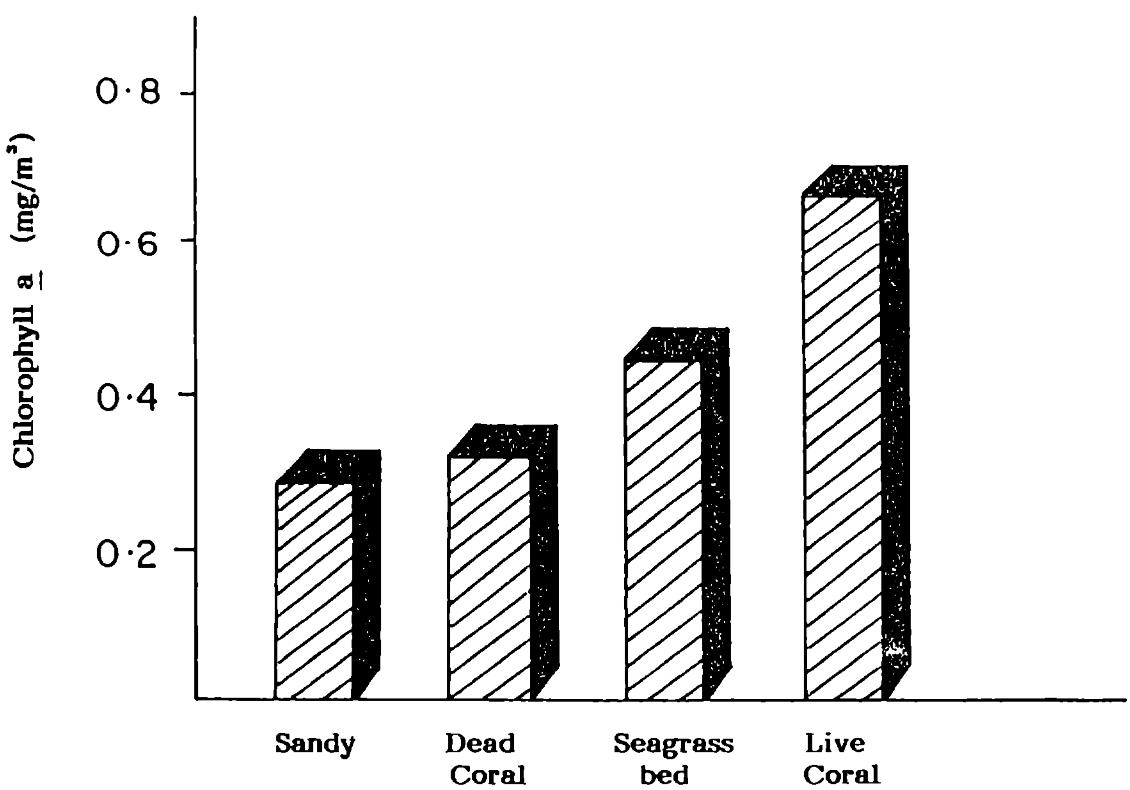


Fig. 9. The average concentration of chlorophyll a in water samples collected from the different coral reef habitats in the Kalpeni lagoon.

Table 17. Analysis of variance (ANOVA) table, showing the level of significance in variation of chlorophyll a in water samples from sea grass bed, sandy area, live and dead coral cover in the Kalpeni lagoon

Source	d.o.f.	M.S.S.	F ratio	Remarks
Between	3	0.5341	6.55	$P \angle 0.001$
Error	64	0.0818		

concentration of the samples collected from areas dominated by live coral heads was 0.668 with the values ranging between 0.124 and 1.682. For samples collected from area dominated by luxuriant growth of seagrass in the lagoon, the average chlorophyll concentration was 0.442 and the values ranged between 0.124 and 0.935. Chlorophyll concentration in water samples collected from dead coral heads varied between 0.124 and 0.510 while those collected from sandy areas had their values varied between 0.124 and 0.748. The average chlorophyll concentration was 0.306 and 0.281 for samples collected from dead coral areas and sandy patch.

Analysis of variation (Table 17) showed that the variation in the chlorophyll concentration in the different areas was highly significant ($P \angle 0.001$).

Diurnal Studies

The variation in the physico-chemical parameters observed at Station I and Station II during the study is given in Table 18.

During the study in Station I the temperature of air varied between 27 and 30.5°C, with the minimum temperature recorded at 0600 hrs and maximum between 1200 hrs and 1500 hrs. The temperature of water in the lagoon at this station varied from 29 to 33.5°C with the minimum and maximum temperature recorded at 0600 hrs and 1500 hrs respectively. Dissolved oxygen fluctuated widely between 2.54 (0600 hrs) and 11.41 mg/l (1500 hrs). Dissolved oxygen increased with increasing intensity of day light recording a maximum at 1500 hrs and then recorded a decrease. However salinity did not show any marked fluctuation during the study and the values varied only between 33.46 and 34.31 ppt. Nitrite varied between 0.05 and 0.13 µg at/l with the maximum recorded at 2100 hrs and the minimum recorded at 0600 hrs
Nitrate concentration at this station fluctuated between 0.025 and 0.175 µg at/l recorded at 0900 hrs and 2100 hrs respectively. Phosphate values recorded a minimum of 0.025 between 0600 and 0900 hrs and a maximum

Table 18. Diurnal variation in the various physico-chemical parameters recorded in stations I and II in Minicoy Island

STATION I (23.1.1990)

Hours	Air temp. °C	Water temp. °C	Dissolved Oxygen mg/L	Salinity ppt	Nitrite	Nitrite	Silicate	Phosphate
						µg at/l		
0900	28	29.8	4.52	33.46	0.06	0.025	2.45	0.025
1200	30.5	31	8.93	34.03	0.08	0.100	2.90	0.055
1500	30.5	33.5	11.41	34.22	0.12	0.05	2.90	0.025
1800	30.5	32.5	8.59	34.12	0.08	0.175	3.45	0.055
2100	28.2	30.5	6.50	34.31	0.05	0.025	3.0	0.105
2400	27.8	30	5.42	34.22	0.08	0.100	3.0	0.13
0300	27.2	29.8	3.62	34.31	0.12	0.125	2.60	0.055
0600	27	29	2.54	34.31	0.13	0.175	2.90	0.025

STATION II (2.2.1990)

0900	28	27	4.52	33.46	0.203	0.375	2.15	0.027
1200	30	32.3	7.80	34.03	0.265	0.310	1.75	0.054
1500	30.5	36.5	11.07	34.22	0.307	0.135	5.0	0.042
1800	30.0	34.5	9.04	34.12	0.410	0.110	3.15	0.015
2100	28	28.2	2.83	34.31	0.203	0.252	2.30	0.081
2400	27.5	28	2.03	34.22	0.115	0.354	2.30	0.015
0300	29	28	1.36	34.31	0.135	0.411	1.45	0.150
0600	27	26.5	1.58	34.22	0.165	0.346	1.90	0.150

of 0.155 observed at 0300 hr. Silicate concentration during the study at this station varied from 2.45 (0900 hrs) to 3.45 µg at/l (1800 hrs).

In Station II, the temperature of air varied between 27 and 30.5°C. There was wide fluctuations in the temperature of water in this station with values ranging between 26.5 and 36.5°C, the lowest recorded during early morning hours while the highest was observed at 1500 hrs. During the post noon period the temperature of water varied between 32 and 36°C. Dissolved oxygen recorded 4.52 mg/l in the morning and as the intensity of daylight increased the concentration increased recording 7.8 and 11.07 mg/l at 1200 and 1500 hrs respectively. Thereafter the concentration of dissolved oxygen decreased to 9.04 at 1800 hrs and recorded a least of 1.58 mg/l during early dawn hours. Salinity did not show marked variations during the study, the values recorded between 33.46 and 34.46 ppt. Nitrite concentration in this station varied between 0.115 and 0.410 µg at/l recorded at 2400 hr and 1800 hrs respectively while nitrate content varied between 0.110 (recorded at 1800 hrs) and 0.411 µg al/l (at 0300 hrs). Phosphate concentration in this station recorded a lowest of 0.015 between 1800 and 2400 hrs while the highest concentration of 015 µg at/l was observed between 0300 and 0600 during the early down hours. In the present study, silicate concentration varied between 1.45 and 5.0 µg at/l observed at 0300 hrs and 1500 hrs respectively.

Results

Rainfall

During the year 1990 the maximum period of precipitation prevailed from May to August, coinciding with the south-west monsoon which accounted for about 73% of the annual rainfall (1517.0 mm) as given in Fig.10. The highest monthly rainfall was recorded during June (689.0 mm). The island also received considerable rainfall during the north-east monsoon which accounted for about 23% of the annual total rainfall. The grouping of May in the monsoon season in the present study can be justified on the

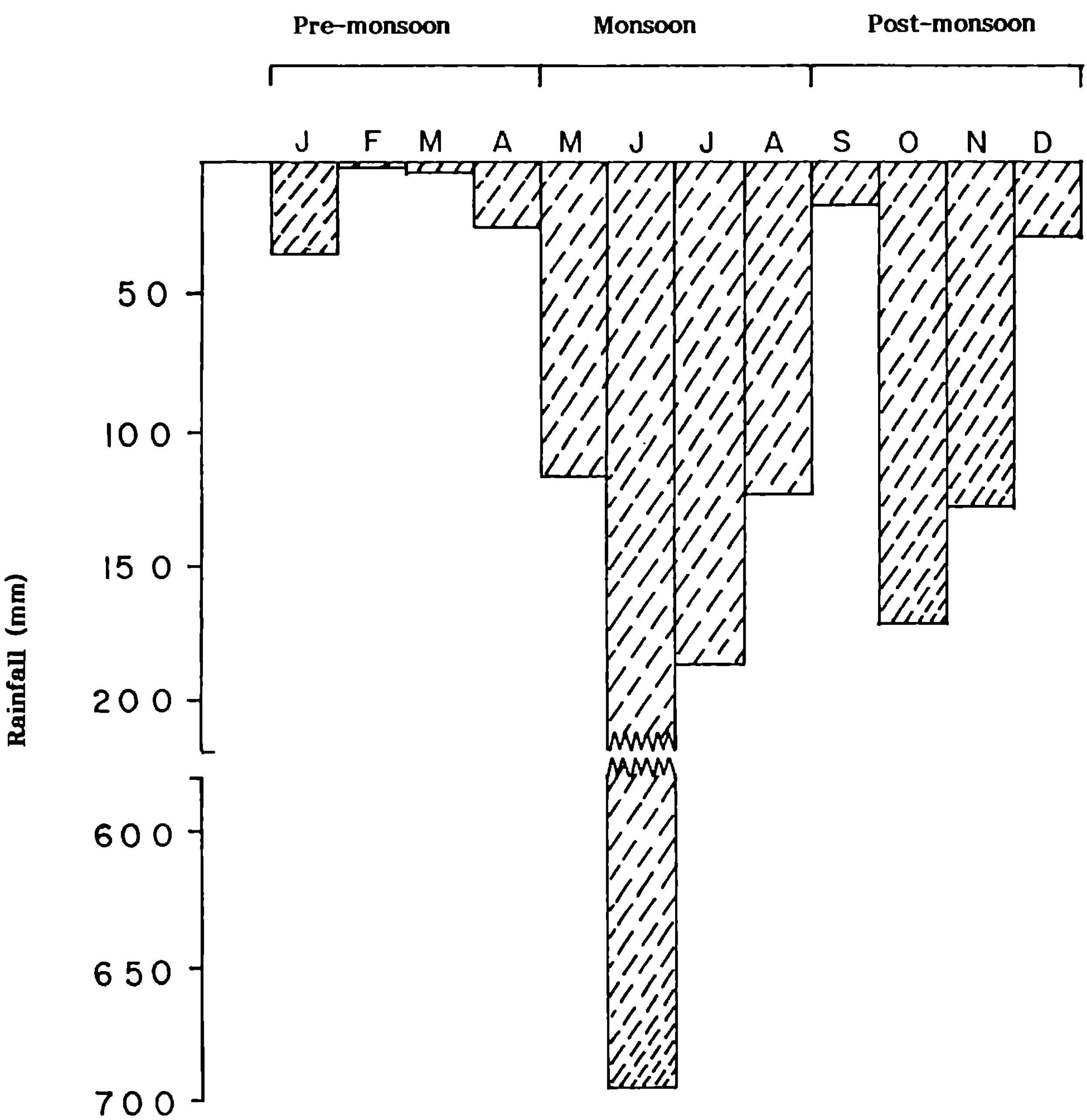


Fig. 10. Rainfall data for Minicoy Island for the year 1990. Data compiled from the Indian Meteorological Department, Minicoy.

Table 19. Wind directions and percentage frequency observations at Minicoy island for 1990. (Compiled from the Minicoy Weather Station, India Meteorological Department)

	N	NNE	NE	ENE	E	SE	S	SW	WSW	W	WNW	NW	Variable
January	40	20	13.3		3.3								23.3
February	35.7	3.57	32.14		3.57								25
March	41.9	19.3	12.9			3.2							22.6
April	10		6.6								10	50	23.3
May										25.8	12.9	54.8	6.45
June								6.6	3.3	53.3	6.6	23.3	6.6
July								9.68	3.2	70.97		16.13	
August										74.2	19.35	6.45	
September	3.33									16.6	16.6	63	
October	29.03						6.45	3.2	3.2	19.3	9.7	19.3	9.7
November	20	6.7	20		10	6.7		3.3	3.3	3.3	6.7	13.7	6.7
December	12.9	22.59	64.52										
Average	16.07	6.01	12.46		1.41	0.83	0.54	1.90	1.08	21.96	6.82	20.52	10.30

Table 20. Meteorological data recorded for one year at Minicoy Island (X ± S.D.)

Months 1990	Pressure (Milli bar)	Air temperature °C	Relative humidity (%)	Wind speed (Knots/hr)	Number of day with cloud cover					Rainfall (mm)
					0	1-2	3-5	6-7	8	
January	1012.64 ± 1.075	27.68 ± 1.01	79.2 ± 6.77	3.84 ± 3.67		6	14	7	3	36.8
February	1013.53 ± 0.72	26.95 ± 0.897	76.74 ± 5.35	2.33 ± 1.19	1	22	5			2.6
March	1012.67 ± 1.08	27.06 ± 0.99	78.57 ± 6.09	3.84 ± 3.67		6	14	7	4	4.6
April	1010.37 ± 1.22	29.86 ± 1.33	74.06 ± 14.75	2.84 ± 1.14	4	10	12	4		25.6
May	1008.79 ± 2.16	29.82 ± 1.23	82.04 ± 5.65	4.84 ± 1.43		6	15	9	1	115.96
June	1008.74 ± 2.17	28.14 ± 1.35	84.76 ± 5.55	6.75 ± 2.78		3	4	7	16	689.8
July	1009.69 ± 1.31	27.99 ± 1.24	83.75 ± 4.73	5.82 ± 3.18		3	12	6	10	186.4
August	1011.33 ± 0.65	28.30 ± 0.76	79.70 ± 2.52	5.78 ± 1.64		4	12	6	9	110.2
September	1011.21 ± 1.42	27.52 ± 0.98	81.42 ± 6.09	5.11 ± 1.16		5	11	4	10	56.3
October	1012.10 ± 1.07	28.20 ± 1.20	80.25 ± 4.20	5.65 ± 2.06		2	16	10	3	134.0
November	1012.47 ± 1.21	27.93 ± 1.68	78.05 ± 4.14	2.61 ±		12	14	4		126.8
December	1012.83 ± 2.05	27.79 ± 1.02	73.22 ± 13.94	3.4 ± 1.78	3	7	12	9		28.9

basis of the rainfall data (Fig.10) which showed that Minicoy island received 115.96 mm of rainfall during this month, thus supporting the view that the island starts receiving early south-west monsoon showers from the month of May onwards.

Winds

The wind directions and percentage frequencies observed at Minicoy island for 1990 is given in Table 19 and wind speed in Table 20 The wind records disclosed a strong combined frequencies of, W, WNW and NW components during the monsoon season. The combined components constituted about 94, 83, 87 and 100% frequencies of May, June, July and August respectively. During the post-monsoon the combined frequencies of the N, NNE and NE components dominated representing 66, 64, 60 and 100% frequencies of September, October, November and December respectively while the combined percentage frequencies of N, NNE and NE components recorded 73, 71 and 74% for September, October and November respectively.

The mean wind velocities (Table 20) showed that the strongest winds occured during the south-west monsoon and early post-monsoon. The mean monthly velocities of the winds during these season recorded between 4.85 and 6.75 knots hr^{-1}.

DISCUSSION

1. Temperature

In the present study it was observed that the annual mean temperatures of the surface water in the different regions of the lagoon were more or less same with minor variations between 29.4°C and 29.6°C. Neither the seasons nor the situations at the different stations were significant statistically (Table 13).

Results of the diurnal studies revealed that in the shallow habitats in the lagoon the instantaneous daily temperature ranged from 26.5°C to 36.5°C as observed at 0530 and 1430 hrs., respectively. The range of instantaneous day time temperature of the lagoon in the shallow habitats recorded in the present study conforms well with the results obtained from the atoll (30°C to 35°C) as well as from Kalpeni Atoll (30°C to 38°C) as reported by Girijavallabhan et al. (1989).

The increase in instantaneous day time temperature recorded in the shallow habitats can be explained on the basis of direct solar heating insitu and the advection of warmer water from the reef flat. Moreover the shallow nature of the habitat which gets exposed during low tides and the relative absence of any water movements in this area are likely to affect the temperature, locally due to less mixing. In view of the shallowness of the habitat, it may be exposed to the vagaries of local weather conditions for long periods during low tides. According to Potts and Swart (1984) small scale temporal and spatial thermal variation is likely to be marked on any reef with extensive shallow habitats heated by insolation during the day and cooled by evaporation and radiation at night. Wells (1952) reported that on the coral reefs of Arno Atoll, Marshall Islands, the instantaneous day time temperatures on the inner flats ranged from 27°C to 36.5°C, while the mean oceanic temperature was 28°C ± 1°C all the year round. Mayer (1918) in his studies at Maer Island, noted a 12.5°C range over 24 days, based on instantaneous day time readings. The daily variations observed in the present study in the shallow habitats are similar to those observed in habitats at Low Isles (Moorhouse, 1933; Orr, 1933).

It is unlikely that such fluctuations would occur in the lagoon where the water depth is more and sufficient mixing of water is present. In other areas of the lagoon the instantaneous day time temperature ranged between 29°C and 33.3°C. Only in the absence of any pronounced spatial variation in temperature of water in the remaining areas of the lagoon, it can be implied that in general, most areas of the lagoon are equally benigh. Potts and Swart (1984) could not attribute thermal extremes to extensive mortality of corals although there was relatively unfavourable habitats in the Heron reefs. Besides there are also indications that corals in the Oman coast have adapted to a much wider range of temperature (16°C to 40°C) than that normally encountered elsewhere by corals (Kinsman, 1964). Johannes (1970) also reported that even at sublethal temperature, when normal behaviour and metabolic processes are affected, it is unlikely that temperature fluctuations apart from fluctuations occurring on a geological time scale are in any way responsible for large scale coral mortality.

The present study clearly draws conclusive evidence that variations in water temperature is not a major factor that causes mortality to corals in the Minicoy lagoon and that except in the sand flat (where no coral colonies exist) the range of daily fluctuations recorded in the lagoon is well within the limit of the lethal temperatures determined for corals. The surface temperature recorded in the different parts of the lagoon can also be considered to reflect the bottom temperature since in an atoll lagoon, the vertical variations of water temperature appear to be non-significant (Andrews and Pickard, 1990). The series of observations made in the present study also reveal that occurrence of short period (diel) variations in water temperature of the lagoon and the reasons for variations were typical for what was observed in similar habitats of the other Lakshadweep Islands.

Salinity

In the present study it was observed that the average salinities varied between 32.6 and 34.5 ppt in the lagoon while on the seaward reef flat the variation was between 33.7 and 34.6 ppt. In both lagoon and reef flat, lower salinities were recorded in monsoon (May to August) during the period of maximum precipitation.

Most species of corals have been shown to have little tolerance to exposure to seawater of 50% salinity for longer periods (Mayer, 1918; Vaughan, 1919; Edmondson, 1928). There are numerous reports on the destruction of branching and massive coral fauna by heavy rains and associated low salinity in Jamaican reefs (Goodbody as given in Endean, 1976) in Kaneohe Bay, Hawaii (Bathen, 1968) and in Fiji (Cooper, 1966). Bathen (1968) stated that in Kaneohe Bay Hawaii, the seasonal variation of salinity was (inversely) related to the rainfall pattern. In the present study, a similar observation was made where the seasonal variations in salinity mainly due to the monsoon rains was highly significant ($P < 0.01$), statistically.

In the present study it was observed that in the lagoon as well as on the reef flat, corals were not subjected to salinities appreciably lower than lethal limits as given by Edmondson (1928). According to Andrews and Pickard (1990) a fall of 100 mm of rain when mixed with 1.0 m depth of seawater would reduce the salinity from 35 ppt to 31.5 ppt (which is well above the lethal limits for corals). However, this reduction would be less for greater depths and moreover the likely flow of deeper water over the reef flat would always help to maintain the salinity near to normal levels. This view has been upheld by the observations quoted by Stoddart (1966) for Addu Atoll, Maldives and Cloud (1952) for the reef flat on Onotoa Atoll, Gilbert Islands. The Minicoy Island received a total annual rainfall of 1517.0 mm during 1990 (Fig. 10) but it is unlikely that the rain water would get into lagoon by sub-surface seepage since in most areas the land area of atolls are at a lower level that the necessary hydraulic head to force water into the lagoon against sea pressure does not exist. Instead the precipitation would sink immediately into the ground and remain as underground water. Buddemeier (1981) has pointed out that as the water level in an atoll lagoon is generally higher than that of the ocean outside, the resulting head would tend to drive lagoon water towards the ocean.

The series of observation made for a period of two years, in the present study reveals that the occurrence of seasonal variations in salinity of the Atoll were typical of other islands in Lakshadweep (Girijavallabhan et al., 1989) where there is a flourishing growth of corals as observed in the Kalpeni and Chetlat lagoons. Results of this study also suggest that salinity variations in the lagoon were well within the range of lethal levels and that salinity variation cannot be considered a factor causing significant coral mortality in the Minicoy Atoll.

Gross Sedimentation

The impact of increased sedimentation is probably considered the most common and serious anthropogenic influence on coral reefs (Grigg and Dollar, 1990) and in modern reefs it is a controlling factor of reef growth (Hubbard, 1986). There are conclusive evidences of the deleterious effect of increased sedimentation on live corals. Corals remove sediments by tentacular and ciliary action, body extension and mucus sheet entanglement (Hubbard, 1973; Bak and Elgershuizen, 1976; Lewis and Price, 1976) all of which represents an energy drain on the coral. Corals which depend on light for growth (Goreau, 1959; Muscatine et al., 1979) are also influenced by turbidity as a result of increased sedimentation since it reduces light penetration. Rogers (1979) showed experimentally that reduction of incident light by suspended sediments has a greater effect on some coral species than the sediment itself. Besides, the normal feeding activities of corals would also be interfered with, especially those corals which are suspension feeders (Lewis, 1976). There are reports of decreased coral growth rates associated with high sediment (Aller and Dodge, 1974), cellular damage (Rogers, 1983; Peters and Pilson, 1985), depressed spat recruitment (Sammarco, 1980), expulsion of zooxanthellae (Rogers, 1983) and even mortality of corals (Rogers, 1979; Thompson, 1979). Eventhough there are numerous other reports reviewing the effect of sediment stress on corals (Lewis, 1974; Johannes, 1975) data on the spatial or temporal quantitative as well as the lethal levels of sedimentation to evoke a response on growth or mortality is still lacking (Dodge and Vaisnys, 1977).

In the present study based on the two year long series of observation, it was found that the average sedimentation rate in the lagoon varied from 64.38 to 172.0 $g/m^2/24$ hr. In general gross sedimentation was higher on the southwestern part of the lagoon and the higher rates of sedimentation also coincided with the pre-monsoon period in most areas. This is in sharp contrast to the observation made in Kavaratti atoll by Suresh (unpublished) where higher values were recorded in the monsoon. The higher rates of sedimentation observed during the pre-monsoon can be attributed to the presence of a definite and dominant south westerly current flowing through the lagoon during this season (Table 16). The flood tide travel faster than the ebb tide and hence the same is the chief carrier of sediments. As a rule the velocity of the tidal currents is reduced as the currents approach the shore. In this process a qualitative differentiation takes place in the grain size of the sediments deposited between low and high water marks. Thus a decrease in grain size from the low to the high water mark is resulted. The sediments thus brought by the flood tide is largely trapped in the lagoon floor. In the Minicoy lagoon during flood tide, water is observed to flow in from the northeastern entrance on the reef into the lagoon and flows through the southwestern part of the lagoon into the open sea over the reef flat at zone 5, thus creating an unidirectional water movement. Hence it is likely that the sediment particles are transported into the lagoon by the predominating south western currents during the pre-monsoon and get deposited in the protected, shallow habitats where there is relatively less water movements due to the peculiar topographic nature of the atoll. During the monsoon and post-monsoon it is likely that the predominant north-west currents would confront the incoming flood tide from the opposite direction, and thus account for a less uniform pattern of sedimentation. Hence eventhough Minicoy and Kavaratti Atolls are considered as typical tropical habitats, these two atolls differ considerably in their extent of area of the lagoon as well as current patterns and water movements and differ largely on the sedimentation pattern also.

Eventhough the exact source of these sediments cannot be defined in the absence of any indepth study, it is likely that the eroded beach sediments from the seaward reef flat (Plate II) as well as from the lagoon beach along the north eastern end of the island (Bodothiri and Aoumagu villages) which has been undergoing a continuous process of erosion since long, form the major share of these transported sediments into the lagoon. The wide stretch of beach present about fifty years ago along the Bodothiri and Aoumagu Villages has been reduced to a narrow strip as observed today (local enquiry).

Lower rates of sedimentation was observed in Station 4 in comparison with other stations. The lagoon floor at this station has a dense vegetation of seagrass dominated by Thalassia hemprichii in the shallow region near to the shore and Syringodinium isotoefolia in the deeper areas. Seagrass community plays a significant role in reducing sedimentation by traping and stabilizing the resuspended sediment in the water column (Anon 1983). Hence the reduced suspended sediments observed in this region can be attributed to the thick growth of the seagrass vegetation.

The values reported in this study are within the proximity of the normal rates as reported by several workers. Rogers (1990) observed that the normal sedimentation rate for coral reefs was of the order of 100 $g/m^2/day$ and observed that at Puerto Rico the sediment suspension rate ranged from 10 to 210 $g/m^2/day$. The values observed in the present study were much higher than 4.5 to 11.0 $g/m^2/day$ as reported in Discovery Bay, Jamaica (Aller and Dodge, 1974). Suresh (unpublished) observed that in Kavaratti Atoll, the monthly average gross sedimentation varied between 26.9 and 64.5 $g/m^2/day$ in the pre-monsoon while in the post-monsoon it varied from 22.6 to 153.2 $g/m^2/day$. The value recorded during monsoon in Kavaratti Atoll is 1033.5 $g/m^2/day$ which is very high as compared to the monsoon gross sedimentation recorded in Minicoy Atoll in the present study. Cortes and Risk (1985) observed that at Cahuita, which was effected by large scale coastal sedimentation, the sedimentation rate varied between 200 and 10000 $g/m^2/day$ which is much higher than in Discovery Bay, Jamaica (Aller and Dodge, 1974) or Puerto Rico (Rogers, 1990).

Eventhough the values observed in the present study are in conformity with the values reported at Puerto Rico (Rogers, 1990) and far less than the levels recorded at the reefs at Cahuita (Cortes and Risk, 1985), sedimentation has been considered a significant factor causing coral mortality in the Minicoy lagoon (Pillai, 1990). The series of dredging activities undertaken during the early seventies for deepening of the entrance channel at the north eastern reef and the lagoon for navigational purpose led to the churning up of enormous load of silt and sediments and burried many coral colonies (James et al., 1989). A similar observation was also recorded from the reefs at Cahuita where coral colonies were frequently seen buried in sediments with bleaching at colony fringes (Cortes and Risk, 1985). Considering the prolonged effect of excessive siltation and sedimentation in the Minicoy during early seventies when dredging activities were in progress, it would naturally had a bearing on coral growth and this would have hampered the ability of the coral to overcome sediment accumulation. Under high sediment loading environmental conditions associated with dredging activities, recovery of the corals from injury would be unlikely.

Previous identification of the reefs at Minicoy Atoll under the stress of siltation had usually involved the description of the areas that had undergone considerable damage due to dredging activities (Pillai, 1975; 1986 and 1990; James et al., 1989). The poor documentation and the lacking of quantitative data on the spatial and temporal variations of suspended sediments in the past (more relevantly early seventies) make it difficult to derive definite conclusions. The present study points out that eventhough in strict terms of definition (Cortes and Risk, 1985) Minicoy Atoll cannot be considered a model of reef under stress of siltation and sedimentation since the gross sedimentation rate is less than 300 $g/m^2/day$ sedimentation in the past had been a factor contributing to coral mortality.

One interesting observation made in the study was the complete absence of coral colonies or recruitment in the south western part of the lagoon in Minicoy where a sand flat already exists. Increased sedimentation which is not directly harmful to adult colonies can significantly reduce larval recruitment by inhibiting settlement (Hodgson, 1990; Babcock and

Davies, 1991). According to Harrigan (1972), sediments inhibit the settlement of Pocillopora planulae since the larvae cannot attach or anchor firmly to fine sand grains. Prior to laying down, a primary corallite planula has to attach itself to the settlement surface with a mucus stand and then flattens down on the substrate. Moreover the pattern of sediment distribution also affects the orientation of settlement (Hodgson, 1990). Since sediment tends to lodge in depressions on a horizontal surface, sedimentation could prevent planulae from settling in these sites. But sedimentation can be expected to have less effect on larval settlement on vertical surfaces and underside of shoals in the lagoon. This finding is relevant to interpretation of a number of studies of coral recruitments which have demonstrated a proportionately greater number of recruits on vertical or under surfaces than uppersurface of the many shoals in the lagoon (Birkeland, 1977; Bak and Engels, 1979; Neudecker, 1981; Wallace and Bull, 1981; Harriott, 1985). The existence of this phenomenon was earlier reported by Cortes and Risk (1985) and Fisk and Harriott (1989) who observed recruitment of coral planulae after two weeks on clean substratum raised above the Great Barrier Reef at Queensland while recruitment onto the reef itself was a rare event. A similar observation of coral recruitment on the sides and undersides of the numerous shoals in the lagoon was observed during the survey, as discussed elsewhere.

To predict the response of coral reef community to sedimentation, it will be important to know the sediment tolerance of adult corals. Results of the present study suggests the need to test the effects of sediments on a wide variety of coral larvae. If larval settlement is inhibited by sediment settlement, the long term coral reproduction would also be affected and this would eventually lead to a decreased generic diversity of corals in such reefs compared to reefs exposed to less sedimentation.

It can be summarized from the above discussion that the rate of sedimentation values reported in the present study corroborates with the normal sedimentation rates as reported from other coral reefs and that at present the Minicoy coral reef cannot be considered a model of reef under stress of siltation and sedimentation. Previous identification of the reefs at Minicoy under sedimentation stress was based on visual observation of the areas that had already undergone considerable damage due to dredging. Therefore the absence of quantitative documentation on the spatial and temporal variation of sedimentation in the past makes it difficult to make comparison with the present results. However, in the past when sedimentation was high, it was considered a major factor contributing to coral mortality. The present study has also highlighted how the increased sedimentation had inhibited planulae settlement and recruitment in the south western part of the lagoon and restricted the recruitment of planulae to vertical and undersurfaces of many areas in the lagoon. The study also suggests the need to test the effects of sediments on a wide variety of coral planulae. The trends described in this study may become useful in reef management allowing early identification of the factors of stress.

Dissolved oxygen

In the lagoon it was observed that dissolved oxygen content varied with the vegetative nature of the substratum and that the effect of both the site as well as the season on the dissolved oxygen was statistically significant ($P \angle 0.05$). The average dissolved oxygen in the lagoon varied between 4.69 and 5.35 mg/l while on the seaward reef it was slightly higher at 5.61 mg/l. The higher values recorded on the seaward reef flat, in-comparison with the lagoon can be explained in terms of severe wave action and the subsequent aeration of seawater.

Diurnal studies revealed that dissolved oxygen exhibited marked fluctuations in the lagoon and the values ranged from 2.54 to 11.41 mg/l. The maximum concentration was recorded at 1500 hr, reflecting the highest rate of photosynthesis during the daytime in the vegetative cover and the consequent release of dissolved oxygen while the minimum was recorded in the early dawn hours, due to intense respiration coupled with non-release of oxygen. The pattern of diel variation observed in the present study at Minicoy island was also similar to that reported by Qasim et al. (1972), Sankaranarayanan (1973) and Goswamy (1973, 1979) in Kavaratti Island. The range of dissolved oxygen observed in the present study is in conformity with results from other islands of Lakshadweep as given by Girijavallabhan et al. (1989). In view of the least significance of dissolved oxygen concentration as a limiting factor for coral reefs ecosystem it is unlikely that the variation in dissolved oxygen in the atoll observed in the study is a significant factor contributing to the mortality of corals.

Nutrients

Diel variations of nitrite concentration exhibited uniform patterns in both shallow waters as well as deep water lagoon habitats. Higher values were observed during reduced light intensity hours and lower values during periods of increased light intensity. Since the fixation of nitrite into nitrate is a strong light dependent process (Qasim et al., 1972; Mc Carthy, 1972; Webb et al., 1975; Wiebe, 1976) the process would result in decrease in nitrite concentration during the day time. The results obtained during the present studies in regard to nitrite are in full agreement with those of others. According to D'Elia and Webb (1977) the nitrate is assimilated from the solution even at low concentrations. The low values of nitrate observed during increased light intensity period in the present study can be explained on the basis of increased uptake of the nutrient by photosynthetic organisms.

The lagoon habitats of Minicoy was found to contain very low nitrite and nitrate concentration in the present study. This is in agreement with the general observation of reduced levels of inorganic nitrogen commonly encountered in coral reefs as reported by Webb et al. (1975); Wiebe et al. (1975) and Atkinson (1988); while in some cases the concentration has been reported to be too low to detect (Andrews, 1983). The relatively higher concentration of nitrite and nitrate recorded in the shallow habitats can be attributed to the effect of leaching and surface run off of nitrients from the nearby mangrove ecosystem found in the southwestern tip of the island.

Similarly in the case of phosphates, lower values were recorded in the lagoon and shallow habitats during increased light intensity period while their levels increased during night time in the study. Johannes et al. (1983) have reported that the net uptake of phosphate was highest around midday when the photosynthetic activity was maximum. Qasim et al. (1972) and Goswamy (1979) have also expressed similar views of relating diel variation in phosphate in the Lakshadweep lagoon with photosynthetic activities. Hence the relatively lower values for phosphate recorded in the present study during increased light intensity periods can be attributed to its increased uptake during photosynthesis which is maximum at increased light intensity periods.

Diel variations of silicates did not show any definite pattern during the present study indicating the less significant role for this nutrient factor in the metabolic activity of coral reefs, a view also shared by Smith and Jokiel (1975).

From the above study it is evident that levels of nutrients and diel pattern of variation observed in the Minicoy lagoon are in conformity with similar studies reported from other atolls like Kavaratti of the Lakshadweep as well as from similar habitats elsewhere as stated above. Hence it is unlikely that nutrients are a significant factor influencing the destruction of corals in Minicoy.

Chlorophyll a

Eventhough coral reefs are highly productive communities (Odum and Odum, 1955; Kohn and Helfrich, 1957) the chlorophyll a concentration in the reefs waters is very low. Sournia and Ricard (1976) attributed the less abundant tropical phytoplankton population in the open sea as the reason for the chlorphyll a concentration.

In the Laurel reef at Puerto Rico, Glynn (1973) observed the chlorophyll a concentration between 0.1 and 0.95 mg/m^3 while in La Parguera reefs at Puerto Rico, the concentration varied between 0.2 and 1.86 mg/m^3 (Gonzales, 1965; Burkholder et al., 1967). In Takapoto atoll at Tuamotu, Sournia and Ricard (1975) observed the concentration of the pigment between 0.26 and 0.77 mg/m^3 and in Fanning atoll at Line Islands, Gordon et al. (1971) recorded chlorophyll a values between 0.23 and 0.62 mg/m^3. In Bikini Atoll, Marshall Islands the values ranged from 0.16 to 0.60 mg/m^3 (Marshall, 1965) while in Lakeba reefs, Fiji, the chlorophyll a concentration was found between 0.08 and 0.11 mg/m^3 (Ricard, 1976). Low photosynthetic pigment values were also observed in Tahiti reefs (0.06-0.17 mg/m^3) by Ricard (1977) and Lizard Islands, Great Barrier Reef (0.13-0.20 mg/m^3) by Griffiths (1976). The very low values of chlorophyll a values between 0.23 and 0.62 mg/m^3. In Bikini Atoll, Marshall Islands the values ranged from 0.16 to 0.60 mg/m^3 (Marshall, 1965) while in Lakeba reefs, Fiji, the chlorophyll a concentration was found between 0.08 and 0.11 mg/m^3 (Ricard 1976). Low photosynthetic pigment values were also observed in Tahiti reefs (0.06-0.17 mg/m^3) by Ricard (1977) and Lizard Islands, Great Barrier Reef (0.13-0.20 mg/m^3) by Griffiths (1976). The very low values of chlorophyll a in the coral reefs probably denote that the contribution of phytoplankton to the overall productivity of the reefs is not significant (Balasubramanian and Wafar, 1974) and it represents only the production rate of the surrounding waters.

In the present study it was observed that the chlorophyll a concentration ranged from 0.13 to 1.68 mg/m^3 in the lagoon of Kalpeni. The values recorded were comparatively lower in the sandy patch of the lagoon while higher in areas dominated by dense live corals and seagrass beds (Fig. 9). Since the seagrass beds in Kalpeni lagoon are situated very close to the beach where water movements are minimum, the reduction in the tidal flushing of phytoplankton populations as well as the increased availability of dissolved nitrients, particularly inorganic nitrogen released by nitrogen fixing benthic communities (Webb and Wiebe, 1975; Corredor et al.,

1988) would contribute to the comparatively higher chlorophyll a concentration in these habitats.

During the period of study it was observed that the chlorophyll a concentration was relatively low in a few samples collected from shallow areas with dense living coral colonies of Acropora spp. (Plate I). According to Sorokin (1990) grazing by filtering benthic animals including corals would cause the depletion of phytoplankton population in shallow areas of reef flat and patchy reef zones especially above live corals. The depletion of phytoplankton over the shallow reef areas could also be caused by inhibition of fine and fragile oceanic phytoplankton during their contact with solid surfaces of the reefs and of the suspended sand particles in shallow turbulent areas (Sorokin, 1990). Hence the reduced chlorophyll a concentration recorded in the reef areas and shallow areas above live corals observed in the present study can be explained on the basis of the findings of Sorokin (1990).

Further Sorokin (1990) has observed that in shallow areas the depletion of phytoplankton could be caused by the change of the environmental conditions such as increase of temperature and excess of light especially over white coral sand area. A similar observation was also made in the present study where the chlorophyll a concentration was relatively very low (0.13 to 0.73 mg/m^3) in the shallow sandy patch in the southwestern part of the lagoon. Excess of light over the sandy substratum and the subsequent change of the environmental conditions would have caused a reduction in the phytoplankton concentration in this region.

The vertical distribution of phytoplankton in lagoon water is usually more or less even (Sorokin et al., 1982). Sometimes, phytoplankton concentration can increase in the bottom waters of the lagoon, during low tides when the surface layer is occupied by warm waters from the reef flat which are depleted of phytoplankton or during hightide when the surface layer is occupied by oceanic waters, arriving through the reef passes (Sournia and Ricard, 1976). Hence it can be seen that the levels of phytoplankton biomass within the lagoon is largely related to the degree of lagoon closure, nutrient input rates, mixing rates within the lagoon (Wolanski, 1987) and the residence time of lagoonal waters (Pickard, 1986). Hence an indepth study on the above aspects that influence the levels of chlorophyll a concentration within the lagoon would provide conclusive evidence for the results obtained in the present study.

CHAPTER - III

BIOLOGICAL DESTRUCTION OF CORAL REEFS

INTRODUCTION

The structure of modern coral reefs is the result of interaction between reef growth and reef destruction. In the past, reef growth received much attention particularly in terms of physical characteristics and patterns of coral zonation, however, in contrast, reef destruction has received only very little attention. The boulder tracts, eroded reef flats and lagoonal sediments are indicative of the destructive processes which are continually operating and affecting reef growth.

The agents of destruction of coral reefs can be dealt under the heads namely physical, chemical and biological. Though these forces act separately upon the reefs, they are intimately interrelated. The biological agents of destruction weaken the substrate and make it more susceptible to physical and chemical erosion. The reverse situation also occurs where damage caused by physical or chemical erosion facilitates bioerosion.

The biological agents of coral reef destruction includes the boring organisms that attack both living and dead corals which form the structural framework of the reefs. The major groups that cause erosion to coral skeleton include algae, sponges, polychaetes, sipunculids, bivalves and echinoderms (Hutchings, 1986). The borers make extensive galleries inside the coral substrate rendering it more susceptible to disintegration. The sediments that are produced by the boring activities also contribute to filling up of the lagoon. The destructive effect of these boring organisms on the mechanical stability of the reef framework assumes considerable significance in view of the increasing value of corals for industrial purposes and also of the protection given by the reefs to the islands from sea erosion. Besides, studies on the biological destruction of coral reef are relevant today since a world wide recession of reef building and reef dwelling organisms have been recently reported by many workers (Gardiner, 1936; Stoddart, 1969; Banner, 1974; Nishihira and Yamazato, 1974; Endean, 1976).

The Lakshadweep atolls are no exception to this global phenomenon of deterioration of reefs and their environment. Of all the islands of Lakshadweep, this problem of coral bioerosion and degradation is most pronounced in Minicoy Atoll (James et al., 1989; Pillai, 1990). There was a luxuriant growth of corals of both massive and ramose types in Minicoy, with a rich and varied fauna of reef associated invertebrates during the early seventies (Pillay, 1971). However, during the early eighties, the situation changed markedly, and both massive and ramose corals met with large scale death, and majority of the shoals in the lagoon harboured comparatively very few living corals (Pillay, 1990). Though many of the corals were undergoing destruction on the reefs as well as in the lagoon, to date no study has been carried out to investigate qualitatively and quantitatively the agents of destruction and their role in the breakdown and erosion of calcareous materials in Minicoy atoll. Hence a study was taken up with the following objectives.

1. to determine the faunal groups which are responsible for bioerosion of reefs in Minicoy.
2. to deduce time dependent changes in some of the faunal composition in the reefs of Minicoy.
3. to study the distribution pattern of the bioeroding agents in the Minicoy atoll.
4. to estimate the nature and quantum of coral destruction in the Minicoy Atoll and
5. to understand the relation between coral eroding fauna and the environmental parameters.

REVIEW OF LITERATURE

The literature on biological agents of destruction can be reviewed under three heads namely those responsible for grazing, etching and boring. Although they are treated separately in this review some overlap may occur since the distinction is somewhat artificial.

a) Grazing

The principal grazers of coral reef substrates are echinoids and a wide variety of fish. They graze on live or dead coral substrate, encrusting coralline algae, tufted or filamentous algae growing on hard reef substrates in search of food or to etch a home scar or cavity to which they return after foraging to give them protection from dislodgement by predators or wave action.

The pioneering reports on the erosive effect of parrot fish on coral substrates by Darwin (1845) had been a matter of considerable controversy. However, several studies in the Caribbean (Bardach, 1961; Randall, 1967; Gygi, 1975) and on the Great Barrier Reef (Stephenson and Searle, 1960; Choat, 1966; 1983; and Russ, 1984a,b) on the gut contents and behaviour of scarids have contributed much information on the role of parrot fish in the destruction of corals. The adaptation of parrot fish (Al-Hussaini, 1945; Schultz, 1958; Gohar and Latif, 1963) and surgeon fish (Jones, 1968; Smith and Paulson, 1974; 1975) to carbonate ingestion is well documented. More recently a comprehensive study on several species of parrot fish by Frydl (1977) and Frydl and Stearn (1978) in Barbados confirmed the role of these fishes on eroding the reefs. Scoffin et al. (1980) have estimated the rates of bioerosion by parrot fish in Barbados reef.

Echinoids have also been recognised as important grazing bioeroders in many coral reef habitats especially in the Caribbean region (Sammarco et al., 1974; Hunter, 1977; Stearn and Scoffin, 1977; Scoffin et al., 1980; Carpenter, 1981; 1984; Hutchings, 1986; Morrison, 1988) and some Indo-Pacific coral reefs (Glynn et al., 1979; Russo, 1980; Birkeland and Randall, 1982; Downing and El-Zahr, 1987). There are also several studies correlating echinoid densities on coral reefs with fishing pressure on fish predators of echinoids (Williams, 1979; 1981; Irvine, 1981; Glynn and Wellington, 1983; Hay, 1984; Kamura and Choonhabandit, 1986).

Pearse (1969) studied the abundance of rock boring echinoid Echinometra mathei along the shore of Gulf of Suez, while Khamala (1971) studied the distribution, density and behaviour of the same species on the Kenyan coast.

Branham (1973) reviewed the causes and mechanisms of outbreaks of large populations of the coral feeding star fish Acanthaster planci on coral reefs. Ogden et al. (1973) studied the effect of echinoid grazing on the Caribbean reefs and later estimated the carbonate production by echinoids on the reefs (Ogden, 1977).

In the Great Barrier Reef, Endean and Stablum (1973) monitored the extent of recovery of corals, devastated by Acanthaster planci. In the same year, Endean and Chesher (1973) discussed the temporal and spatial distribution of Acanthaster planci in the Indo-West Pacific region. Later at Okinawa, Nishihira and Yamazato (1974) observed the physical and biological changes in the reefs as a result of infestation with the coral feeding starfish Acanthaster planci.

In the Western North Atlantic, Bauer (1980) reported the geographical variations in population density of Diadema antillarum an echinoid in the Discovery Bay. Sammarco (1982) suggested echinoid grazing as a structural force in the Caribbean reef communities. Sloan (1982) studied the size and structure of Echinoderms associated with the corals at Aldabra Atoll, Seychells. Later, Bak et al. (1984) compared the densities of echinoids before and after mass mortalities of corals on the reefs of Curacao.

In the Great Barrier Reef, Endean and Cameron (1985) observed the effects of population of the coral feeding starfish Acanthaster planci while in the Central Great Barrier Reef, Williams (1986) studied the short term effects of corals destruction as a result of Acanthaster planci infestation. At Iriomote Island, Sano et al. (1987) observed the long-term effects of corals destruction by Acanthaster planci, while Yamaguchi (1986) focussed on the control measures to prevent the outbreak and infestation of Acanthaster planci on the reefs in Japan. In a recent study, Glynn (1988) compared the rates of bioerosion caused by echinoids in the Panama and Galapagos Islands.

In India, there are few reports on the occurrence of the coral feeding starfish, Acanthaster planci in the coral reefs at Andamans (James et al., 1990). There are also reports on the occurrence of this species in the coral reefs of Lakshadweep (Sivadas, 1977) and in Minicoy in particular (Murthy et al., 1979). However, till date, no effort has been made to study the seasonal variation in population densities of the major group of echinoid grazing on the reefs. Such information was found useful to estimate the rate of bioerosion caused by these echinoids in the reefs of Minicoy.

b) Etching

Fungi and algae are the major groups which make use of etching as a means of penetrating coral substrates. Early reports by Duerden (1902) and Gardiner (1930) had suggested endolithic algae as the chief destructive agents of corals. On the other hand, Bertram (1936) could attribute no role for boring algae in the break off of corals in the Red Sea. However, Odum and Odum (1955) in complete contrast to the earlier reports, focussed on the beneficial role for the endolithic algae for coral survival and growth and its contribution to the high rate of photosynthetic activity seen in corals at Enewetak Atoll.

Golubic et al. (1975) observed the distribution of endolithic algae inside the coral while Kobluk and Risk (1977) have investigated experimentally the rate and nature of infestation by endolithic algae using artificial non-marine substrate in the Caribbean Reefs. Kanwisher and Wainwright (1967) have measured the amount of damage caused by algae in the Enewetak Atoll and Risk and Mac Geachy (1978) described the process of algal infestation and occurrence of boring in coral substrates of Caribbean Reefs. The light photosynthetic action spectrum of these endolithic algae in the Great Barrier Reef was studied by Halldal (1968) and Shibata and Haxo (1969). In the Marshall Islands of Enewetak Atoll Highsmith (1981b) was unable to detect any large scale damage caused by the endolithic algae Ostreobium spp. and on the other hand, in the Great Barrier Reef, Bellamy and Risk (1982) reported on the infestation of corals by boring algae.

Till date, there are no reports on the infestation of corals in the Lakshadweep, by the boring endolithic algae Ostreobium sp.

c) Boring

The major groups that bore into coral skeleton include the bivalves, sipunculids, polychaetes and sponges and in addition there are certain minor groups which include crustaceans and gastropods.

Molluscs: The rapid destruction of corals by boring bivalves is important because the rate of growth of corals is very slow. These bivalves bore deep into the corals, to produce honeycomb like structure resulting in quick destruction and dislodgement of the base of the corals where the stress is maximum.

As early as 1903, Stanley Gardiner emphasized on the significance of boring bivalves in the destruction of coral reefs. Otter (1937) in his studies on the destruction of corals in the Great Barrier Reef, described how the coral boring bivalve Lithophaga hanleyana settled on dead coral surface, were later incorporated into live surface by coral growth.

Earlier reports on the boring bivalves have been qualitative (Hunter, 1949; Purchon, 1955a,b; Yonge, 1955; Turner and Boss, 1962). The significance of boring bivalves for the detachment of coral colonies at Al-Ghardaqa was studied by Bertram (1936). While at Phuket, Thailand, Nielsen (1976) recorded very high densities of boring bivalves in corals.

Detailed studies by Goreau et al. (1969, 1970 and 1972) contributed considerable information on the mode of feeding and boring of the bivalve Fungiacava eilatensis. The mode of penetration by Lithophagid bivalve through chemical dissolution of coral substrate (Jaccarini et al., 1968; Ansell and Nair, 1969; Morton and Scott, 1980) and the mechanical boring (Purchon, 1968; Solimon, 1969) are all well documented. Evans (1970) and Warme (1975) dealt on taxonomy and burrow characteristics of boring bivalve. The adaptive significance of the boring bivalve Lithophaga lessepsiana in the coral in the northern Red Sea was discussed by Arnaud and Thomassin (1976) while in the Great Barrier Reef, Kleeman (1977) observed the burrowing activity of Lithophaga kuehnetti.

Highsmith (1981a) correlated the abundance of boring bivalves with the overall bioerosional damage to the corals in the Enewetak Atoll. There are also reports describing damage to corals by boring bivalves as a function of the plankton primary productivity of the surrounding water in Enewetak Atoll (Highsmith, 1980a). However, Loya (1982) has questioned the validity of Highsmiths (1980a) data. At Heron Island, Connell (1973) observed the rate of attack by boring animals as a function of skeletal density of corals. In a recent approach Boaz Lazar and Yossi Loya (1991) measured the total alkalinity changes in the surrounding medium as a direct clue to the rate of chemical and mechanical boring of the bivalve lithophaga sp. in Gulf of Eilat, Red Sea.

In addition to the bivalves, gastropods are also reported to cause destruction to corals as borers. Ward (1965) detected coral tissue in the digestive tract of Coralliophila spp. and it was found responsible for the damage to colonies of Montastrea annularis in Barbados. Other reports (Ott and Lewis, 1973) cite the association of Coralliophila sp. with the living corals, but little damage was noted. At the Discovery Bay reef, J. lang (as given in Brawley and Adey, 1982) attributed the destruction of corals during the post - Hurricane years, to the predation by Coralliophila abbreviata and suggested that feeding by this species attracted other corallivores to the colony, thus accelerating death.

There are several reports on the presence of coral boring bivalves in the Indian region (Melwill, 1909; Hornell, 1922; Gravely, 1941; Satyamurti, 1956; Ganapati and Nagabhushanam, 1958; Kundu, 1965 and Appukuttan, 1972; Pillai and Appukuttan, 1980). Though a few species of boring bivalves have been reported from Lakshadweep and in Minicoy in particular (Appukuttan, 1973) to date, no serious study on their occurrence and role in the breakdown and erosion of calcareous materials in Lakshadweep was taken up.

Polychaetes: Polychaetes are one of the major components of the cryptofauna which are found in live or dead coral substrates. (Mc Closkey, 1970; Kohn and Lloyd, 1973; Peyrot Clausade, 1974; Hutchings and Weate, 1979). Though several polychaete families have boring species, not all have yet been documented. The important boring species belong to the families, Eunicidae, Lumbrineridae, Dorvilleidae, Spionidae, Cirratulidae and Sabellidae (Hutchings, 1986). Marsden (1962) and Ebbs (1966) have discussed the role of benthic polychaetes to the contributions of the calcium carbonate budget of the Northern Florida reefs.

There are also few reports describing the mechanism of boring in polychaetes. Preliminary description of the burrowing process of Nephtys was provided by Clark and Clark (1960) and later Dorsett (1961) explained the mechanical and chemical penetration of rocks by the polychaete, Polydora ciliata. All the data on mechanisms of boring in the genus Polydora (Family Spionidae) have been reviewed by Blake and Evans (1973). Subsequently, Zottoli and Carriker (1974) investigated boring in Polydora websteri into the shells of oysters and mussels. Trevor (1976) on his studies on Nephtys cirrosa, compared the burrowing activity of this species with that of Arenicola and Sipunculus.

The seasonal variation in the pattern of recruitment of boring polychaetes to coral substrates at the different reef areas in the Great Barrier Reef was also reported (Hutchings, 1981, 1984, 1985).

Hutchings and Murray (1982) has also demonstrated the feasibility of experimental technique in studying the factors of bioerosion and explained the variation in rates of bioerosion within different environment. In the Northern Great Barrier Reef, Davis and Hutchings (1983) estimated the annual erosion rates produced by polychaetes in the different regions of the reef.

The contributions of Fauvel (1930a,b and 1932) which culminated in 1953 in the publication of his comprehensive account of the polychaetes of India in the 'Fauna of British India' series, has described 283 species from the coast of India, of which 236 are marine forms. More recently, the polychaetes of the Indian Ocean were catalogued by Hartman (1974).

Eventhough there are a few references on the distribution of polychaetes in Lakshadweep Sea, (Fauvel, 1953), to date, there has been no study on the role of boring polychaetes in the breakdown and erosion of coral reefs of this region.

Sipunculids: Sipunculids are prominent endolithic animals in many reef areas, which bore into live and dead corals (Shipley, 1903). They also excavate hard and well cemented limestones both in the intertidal and subtidal areas (Warme, 1975).

Preliminary studies on the importance of sipunculids in boring communities were not considered in detail (Kohn and Lloyd, 1973; Peyrot-Clausade, 1974; Hutchings, 1974.

Vittor and Johnson (1977) studied the dominance of sipunculids over other endolithic animals in Madagascar and Caribbean reefs respectively. Bromley (1978) discussed the distribution of sipunculids in relation to the low energy lagoonal sediments in the Caribbean reefs. In a detailed study, on the abundance of sipunculids in the reef crest at Carrie Bow Rice and Macintyre (1982) recorded eight species of sipunculids, out of which six were borers in coral substrates.

The mechanism by which sipunculids bore into coral substrate is largely speculative (Hutchings, 1986). Rice (1969) and Warme (1975) contributed to the preliminary information on the boring mechanism of sipunculids into coral substrates.

In the Great Barrier Reef, the recruitment pattern of sipunculids on a coral substrate is well documented (Hutchings, 1983a,b, Davies and Hutchings, 1983; Hutchings and Bamber, 1985; Kiene, 1985). In the southern Great Barrier Reef, Trudgill (1983) estimated the rates of erosion by sipunculids on the reef flat.

There are few reports on the occurrence and distribution of sipunculids in the Indian Ocean (Shipley, 1903; Stephen, 1941; Stephen and Edmonds, 1972; Edmonds, 1955; Halder, 1975 and Reddiah, 1975). Eventhough sipunculids have been often referred to as one of the major groups that causes erosion to coral skeleton, in the Lakshadweep (James et al., 1989), till date no study has been taken up in order to evaluate the occurrence of the boring sipunculids and their role in the breakdown and erosion of coral reefs of Lakshadweep.

Sponges: Boring sponges have probably received the most attention of all the groups of boring animals. Although the boring activity of sponges had been known for sometime, it was not until the late 1960's that their importance in the process of coral erosion, sediment production and calcium carbonate dissolution was realised (Neumann, 1966).

Rutzler (1974) made a comprehensive taxonomic study of boring sponges in Bermuda. Futterer (1974) during his investigations on the significance of boring sponge for the origin of the fine grained material of carbonate sediments at Fanning Atoll, calculated the percentage contribution of sponge chips to the fine grained sediment in the lagoon.

The manner in which the sponge penetrates into calcareous objects has also been reported (Warburton, 1958; Rutzler and Rieger, 1973). Later, Pomponi (1977) described the ultrastructure of etching cells of eight species of boring sponges from the reefs at San Salvador, Bahamas and Florida.

There are various reports estimating the amount of clionid bioerosion. Hudson (1977) on his studies on the long term effect of bioerosion on the Florida Reef, estimated rate of clionid bioerosion by direct measurement of paired core slab x-radiographs. Moore and Shedd (1977) estimated the rate of clionid bioerosion on the reefs at St. Croix and Jamaica by utilising the gross silt sedimentation rates which is an index of the amount of sediment being shed by the collective clionid colonies. Scoffin et al. (1980) studied the rates and effect of sponge bioerosion on the reefs of Barbados and established a calcium carbonate budget quantifying erosion and accretion.

In the Barbados, Mac Geachy (1977) studied the factors controlling sponge boring of reef corals and reported the percentage boring of sponges both in the shallow water and deeper reef environment. Tunnicliffe (1979) observed the effect of boring sponges on the strength of the Acropora crevicornis branches while Bromley (1978) characterised the burrows of individual species of sponge borers in Bermuda.

In the Indian waters the occurrence of boring sponges was first reported by Annandale (1915). Later, in a series of studies carried out along the south-west and southeast coast of India, Thomas (1979, 1983) and Thomas et al. (1983a,b) described the role of boring sponges, with an account of the species mainly concerned with boring.

There are also detailed reports on the occurrence of sponge fauna in Lakshadweep and from Minicoy in particular (Thomas, 1979; 1980a,b). In a recent report, Thomas (1989) has described 18 species of boring sponges from the Lakshadweep, giving percentage composition and abundance of each species in the various islands including Minicoy.

Crustaceans: Among the crustaceans, genus Lithotrya (Cirripedia) has been found boring into coral rocks (Borradaile, 1906). Though Darwin as given in Gardiner, 1903, had remarked that 'coral reefs are for some reasons, not favourable to them', a number of species of Lithotrya are characteristically and specially modified for penetrating into coralline substrates (Gardiner, 1903).

As early as 1903, Stanely Gardiner emphasized on the significance of the rock boring barnacle Lithotrya sp. in the destruction of coral reefs in Lakshadweep. Later, Hoek (1907) during the cruise of H.M.S. Siboga, gave a systematic account of the different species of Lithotrya available in the Indian waters and the seas around. In comparison to the literature available on major group of bioeroding agents like algae, sponges, polychaetes, sipunculids, bivalves and echinoderms, studies on the boring activities of Lithotrya into coralline substrates have received very little attention (Ahr and Stanton, 1973; Mc Lean, 1974; Trudgill, 1976).

MATERIAL AND METHODS

1. Faunal studies

a) Fishes

The abundance of the coral grazing fishes associated with each zone was assessed by counting conspicious species visually as given by Sano et al. (1987). Five transects (20 m long and 1 m wide) were laid in each zone. The transect width of 1.0 m rather than a greater width, was found to minimise bias in visual censuses in methodical tests by Sale and Sharp (1983). During sampling, using a mask and snorkel, the candidate slowly approached each transect. The coral feeders which swam across the transect and consistently fled when approached, were first counted for 10 minutes. (Gooding and Magnuson, 1967; Smith and Tyler, 1972). Resident fishes which did not fly on being approached but stayed in the transect were then counted by careful inspection of the entire area while swimming along the transect. Each transect required approximately 60 minutes to count. No effort was made to poison the area to study the concealed species. Large variations in the abundance of coral feeders in relation to the different substrate was observed within each zone. No effort was made to investigate the grazing rates. All census in the present study was carried out only at high tides which occurred between 1000 and 1400 hrs.

b) Echinoiderms

The population density of the two most commonly occurring echinoids was studied. The variation in monthly density of the diademid sea urchin Echinothrix diadema was studied on the lagoon reef flat from January, 1990 to December, 1991 while the variation in population of rock boring sea urchin Echinometra mathei was studied in the lagoon shoal from January 1991 to December 1991. A simple random quadrat sampling method was adopted for the study. For sampling, a 1 m x 1 m quadrat was used and the count of total number of individuals present in each quadrat was made. A total of 34 quadrats were sampled every month. Field observations were also made on the behaviour of the animals in regard to niche preference feeding habits and gregarious nature.

c) Endolithic fauna (Sponge, sipunculids, polychaetes, bivalves and cirripeds)

Coral samples for studying populations of the endolithic bioeroding agents (mainly sipunculids, polychaetes, bivalves and cirripeds) were collected from the different coral reef habitats namely the seaward reef flat, lagoon reef flat and from the lagoon, during the survey. Samples were collected on a fortnightly basis for a period from 21.1.1990 till 28.12.1991. After assessing the percentage live and dead coral cover and habitat, a piece of coral sample was broken off with a hammer, chisel and a crowbar. The characteristic of the substrate and the epigrowth was also noted. The sample was placed immediately into a polythene bag and sealed to prevent the loss of cryptofauna. Wherever it was possible, the polythene bag was put over the sample before it was broken.

After the sample had been collected and taken to the laboratory where it was weighed the coral samples were broken using a hammer and chisel. Before the coral sample was further broken, into smaller pieces, the length and diameter of the burrows and the nature of openings of the burrows were noted. The residue of small coral pieces were observed under a microscope and the visible endo-cryptolithic fauna were sorted out (Hutchings, 1974, Hutchings and Weate, 1978).

The polychaetes collected were segregated and washed through a sieve in a trough of sea water to remove sand. The animals were then narcotised gradually by the addition of small quantities of 5% alcohol into the sea water (Fauvel, 1953) and preserved in 70% alcohol in glass tubes provided with cotton stoppers and labelled. The sipunculids collected were placed in cool sea water and then narcotised in 7% Magnesium chloride. When the animal no longer responded to touch it was transferred to a 5% solution of neutral formalin for 24 hours and then placed in 70% alcohol for storage in glass tubes and labelled. Collection, segregation and fixation of sponges was done using the method given by Rutzler (1978).

The species of various biological groups were identified following the methods given by Jones and Kumaran (1980) for fishes, Hoek (1907) for boring cirripeds, Fauvel (1953) for polychaetes, Stephen and Edmonds (1972) for sipunculids, Appukuttan (1972) for boring bivalves, Thomas (1979) for boring sponges and James (1989) for echinoids. The technical assistance of various experts in the respective fields was also sought for in confirming the identification. The density of endolithic bioeroding agents (sipunculids, polychaetes, bivalves and cirripeds) was determined as number of individuals to fresh wet weight of the coral. The biomass of these endolithic forms (excluding bivalves and sponges) was determined as the preserved weight of the individuals in a unit of fresh wet weight of the coral. In the case of boring sponges, the percentage occurrence of the different species in the 200 samples collected from the different zones during the study was determined.

The length-weight relationship was studied for the commonly occurring sipunculids such as *Phascolosoma dentigerum*, *Aspidosiphon streestrupii*, *A. cumingii* and *Cleosiphon aspergillum* and boring cirripeds such as *Lithotrya dorsalis*, *L. valentiana* and an unidentified group of *Lithotrya* sp.

2. Quantitative estimation of eroded calcium carbonate

In the case of boring sipunculids, cirripeds and molluscs, the volume of calcium carbonate eroded by these animals was determined by estimating the volume of the burrow and the volume of the burrow was determined by measuring its length and diameter. On a few occasions when the length and diameter of the burrow could not be determined since the corals were already broken into rubbles, the volume of the individual animal was considered as the extent of calcium carbonate removed due to boring. The volume of the animal determined by displacement of water method (Kirsteurf, 1972).

In order to make an estimate of the amount of calcareous material eroded by the boring animal (Sipunculids, bivalves, cirripeds) an exponential relationship ($Y = aX^b$) was established between the size of the animal and burrow dimensions and the parameters a and b were estimated by regression analysis after logarithmic transformation of the data. The relationship determined included.

a) between weight of the animal (W) and volume of burrow (BV) excavated by the animal $BV = a\ W^b$

b) between weight of the animal (W) and length of burrow (BL) made by the animal: $BL = a\ W^b$

c) between length of the animal (L) and length of burrow (BL): $BL = a\ L^b$

d) between length of the animal (L) and volume of burrow (BV) $BV = a\ L^b$

In the case of echinoderms (*Echinothrix diadema*, *Echinometra mathei*) the amount of calcium carbonate in the gut and faecal pellets were considered as an estimate of the amount of calcareous materials eroded by the animal (Russo, 1980; Scoffin *et al.*, 1980). Only the two most commonly occurring sea urchins *Echinothrix diadema* and *Echinometra mathei* were considered for the study.

Fourty-five samples of Echinometra mathei ranging from 2.39 to 4.15 cm test diameter and sixty one samples of Echinothrix diadema of test diameter ranging from 7.0 to 9.3 cm were collected at different periods. Immediately after collection the urchins were put in separate polythene bags (to collect the faecal pellets ejected between collection and dissection in the laboratory). In the laboratory each sea urchin was dissected to extract the gut content. The gut materials and faecal pellets were taken out and placed on 10 cm Whatman filter No.41 and rinsed with distilled water. The filter along with the faecal pellets and gut contents were dried in an oven at 80°C for 8 hours. After weighing the sample was dissolved in 0.1 HCl, dried and weighed again. The difference in initial and final weight was taken as the estimate of the calcium carbonate removed per sea urchin.

Statistical Analysis

Data collected for the population studies in the case of fishes and echinoderms were subjected to Analysis of Variance (ANOVA) to test the significance in the variation. The statistical methods followed in the study are that of Snedecor and Cochran (1980). The data was analysed on a computer (WIPRO P.C.).

RESULTS

Fishes

Table 21 gives representative data of the mean abundance of the coral grazing fishes at the different zones in the coral reefs of Minicoy. The analysis of variance of the data set after pooling within each zone is given in Table 22. Fig. 11 gives the percentage occurrence of the various families of coral feeding fishes observed at the different zones. A check list of the coral browsers, grazers and feeders is also given in Table 23.

In the present study, fishes belonging to 6 families, 9 genera and 25 species were identified as coral feeding fishes occurring in the coral reefs of Minicoy (Table 23). The mean density of the coral feeding fishes in the different transects varied between 5.32 and 29.9 individuals. Lower mean densities were observed in Zone 1, 2, 5 and 6 where the live coral cover was very poor and values never exceeded 7.96, while in the deeper areas of the lagoon (Zone 7 and 8) where there was good live coral cover, comparatively higher mean densities of coral feeders were observed and the values were 20.3 and 29.9 respectively. In most of the transects, Acanthurids were the most predominant group and its percentage contribution varied between 32.51 and 65.98 during the survey. However, in the shallow habitats of Zone 5 and 6, near the lagoon reef flats, chaetodontids were the dominant forms constituting 62.81 and 53.62% respectively. During the survey mean densities of other minor groups (Balistidae, Diodontidae and Tetraodontidae) generally never exceeded 11.33. Labriids were dominant in the deeper regions and northeastern part of the lagoon and their mean densities varied between 22.07 and 27.89. Analysis of variance (Table 22) after pooling the abundance of the coral feeders in each zone was not significant ($P \geq 0.05$).

During the survey chaetodontids were frequently observed swimming to isolated coral heads surrounded by patches of sand in the lagoon (Plate V). Smaller fishes (less than 7 cm) were recorded in the shallow habitats between the inner lagoon reef flat and the sand flat in Zone 5 and 6 while larger specimens were seen in the deeper regions of the lagoon in Zone 7 and 8. During the survey, this species was seen nibbling off the small coral polyps extending from the corallites particularly of Acropora spp. and Porites spp. Seven species of chaetodontids were identified in the lagoon during the present study. These include Chaetodon lunula, C. citrinellus, C. auriga, C. melanotus, C. meyeri, C. trifasciatus and C. xanthocephalus.

C. lunula was by far the most common chaetodontid observed in the lagoon. In the lagoon, the species was observed swimming over sandy areas near coral rubble (Zone 1 and 5) rather far from the live coral heads. Some of these species were recorded in the quiet waters of the lagoon

Table 21. Mean density of coral feeding fishes recorded in the different zones in 20 sq.m. quadrat (based on five transects) during survey. The count was based on usual assessment of the area while survey was in progress. The percentage contribution of the different species in each zone is given in brackets.

Zone	Families				
	Chaetodontidae	Acanthuridae	Labridae	Others	Total
1	1.0 (18.79)	3.33 (62.59)	0.66 (12.4)	0.33 (6.20)	5.32
2	1.5 (19.18)	5.16 (65.98)	0.66 (8.4)	0.5 (6.39)	7.82
3	4.16 (29.46)	5.8 (41.07)	3.33 (23.58)	0.83 (5.87)	14.12
4	5.6 (37.61)	6.3 (42.31)	2.16 (14.51)	0.83 (5.87)	14.89
5	5.0 (62.81)	2.3 (30.83)	0.5 (6.28)	0.16 (2.14)	7.96
6	4 (53.62)	1.8 (24.12)	0.83 (11.13)	0.83 (11.13)	7.46
7	5.8 (28.57)	6.6 (32.51)	5.6 (27.59)	2.3 (11.33)	20.3
8	9.5 (31.77)	11.0 (36.79)	6.6 (22.07)	2.8 (9.36)	29.9

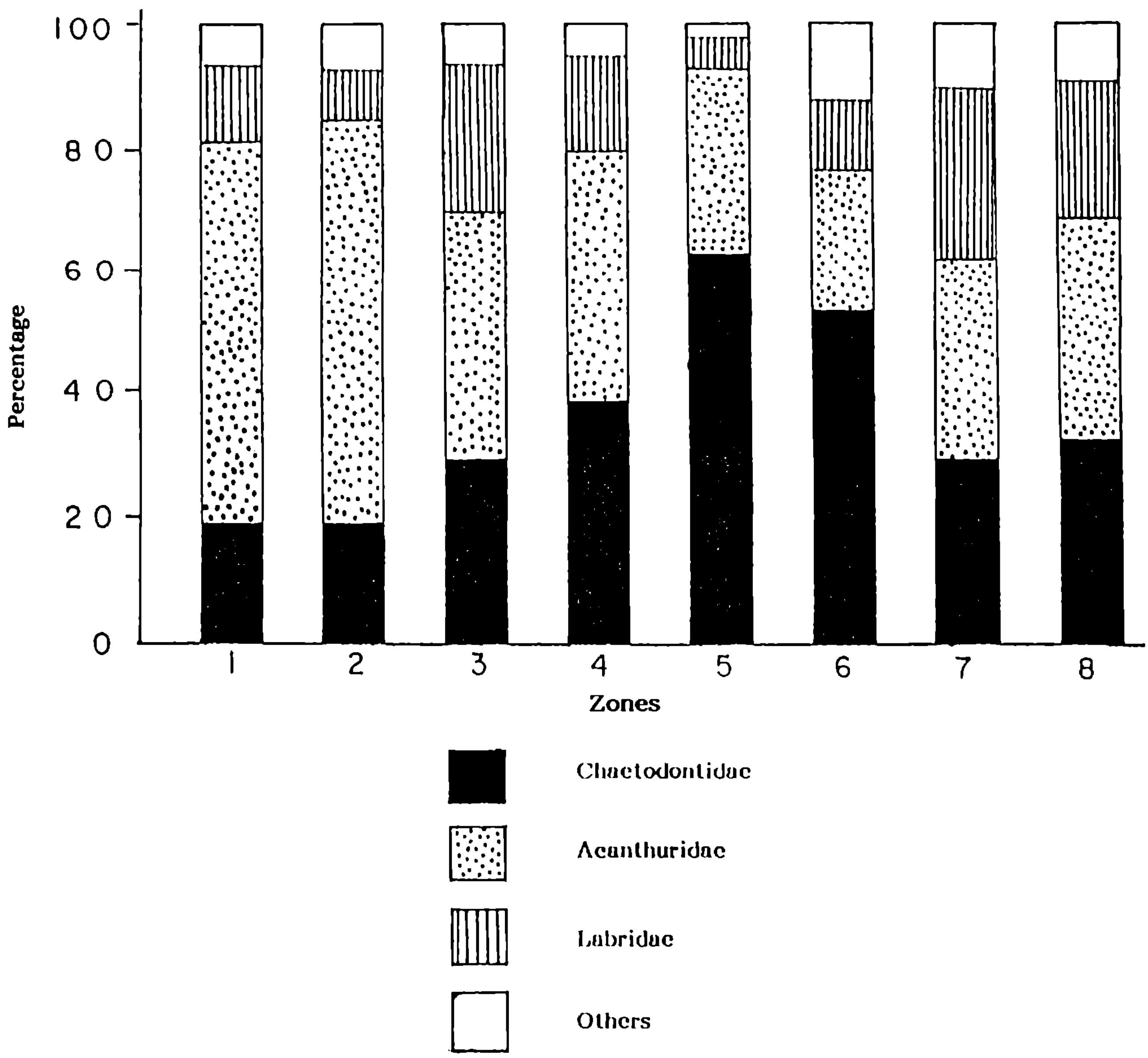


Fig. 11. The percentage contribution of the different groups of coral polyp feeding fishes in 20 sq.m. transect quadrat in the different zones in Minicoy.

Table 22. Analysis of variance (ANOVA) table, showing the level of significance in variation of the mean density of coral polyp feeding fishes per 20 sq.m. transect in each zone

Source	d.o.f.	S.S.	M.S.S.	F. ratio	Remarks
Treat	7	121.087	17.298	3.32	$P \geq 0.05$
Error	24	124.973	5.207		

Table 23. Check list of the coral polyp feeding fishes encountered in the transects during the survey in the coral reef of Minicoy

Fam. Chaetodontidae	1.	Chaetodon lunula
	2.	C. citrinellus
	3.	C. xanthocephalus
	4.	C. auriga
	5.	C. melanotus
	6.	C. meyeri
	7.	C. trifasciatus
Fam. Labridae	8.	Halichoeres scapularis
	9.	H. notopsis
	10.	H. kawarin
	11.	H. centriquadrus
	12.	Thalassoma amblycephalus
	13.	T. hardwicki
	14.	T. quinquivittata
	15.	Cheilinus chlorurus
	16.	C. trilobatus
Fam. Acanthuridae	17.	Acanthurus triostegus
	18.	A. leucosternon
Fam. Balistidae	19.	Rhineacanthus aculeatus
	20.	R. rectangulus
	21.	Ballistoides viridescens
Fam. Diodontidae	22.	Canthigaster margaritotus
Fam. Tetraodontidae	23.	Tetraodon nigropunctatus
	24.	T. meleagris
	25.	T. hispidus

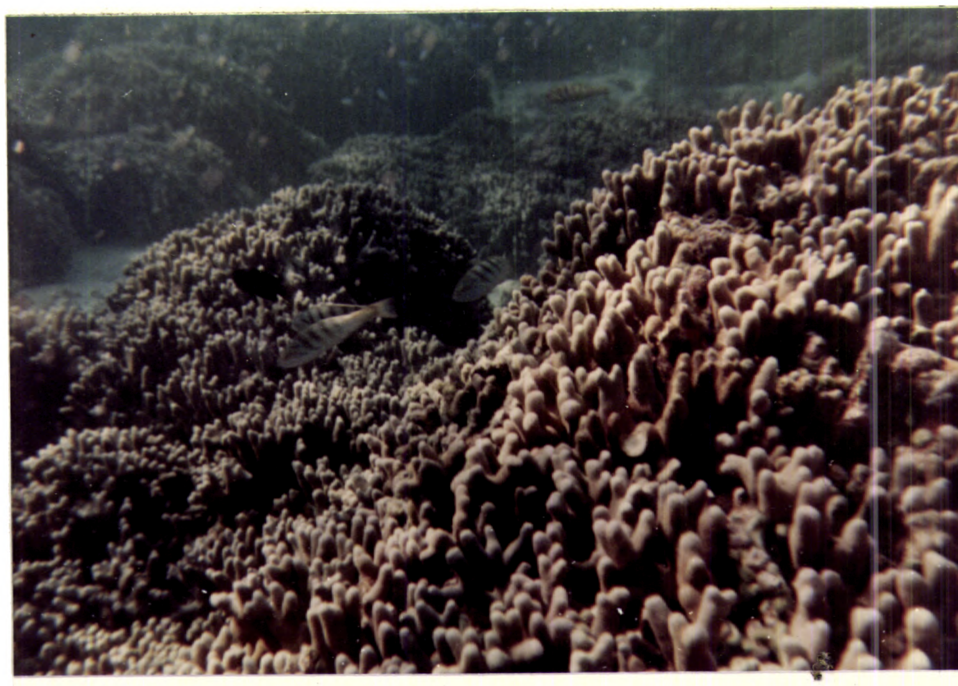
Plate V

A. A greater number of coral polyp feeding fishes were associated in areas of good live coral cover.

B. Coral reef fishes associated with an extensive live coral cover in the Kavaratti reef slope.

C. During the survey Chaetodontids were frequently observed swimming to isolated coral heads surrounded by patches of sand in the lagoon.

PLATE V



A

B

C

rich in live coral cover (Zone 8) and were observed hidden in crevices and holes in the shoals. In most cases, the chaetodontids were recorded in pairs. The Labriids were represented by 9 species belonging to 3 genera during the present survey (Table 23). Halichoeres sp. were generally recorded in the calm areas in the lagoon at depth of 2.10 m. The species was observed to dart about coral heads and usually stayed close to the bases of coral mounds in the lagoon (Plate V). Thalassoma spp. were observed to forage around ramose coral heads and the base of dead corals. On most occasions the species was found solitary in the lagoon. Cheilinus spp. were also solitary on most occasions and found foraging on corals and on sandy and rubble bottom. During the survey, while approaching a transect, most of the species took shelter under rocks in the shoals. Only three species belonging to one genus of Tetraodontids were recorded during the present study (Table 23). This group was not very common in the lagoon except in the deepest zone where the depth of water was between 8 and 13 m. Few of them were also observed in the lagoon shoal situated in the north eastern part of the atoll.

During the present study it was observed that on the inner reef flats and lagoon shoals in the north eastern part of the lagoon (Zone 3) which are always covered at mean sea level and partially exposed only in very low tides, there was very little activity of these coral fishes during low water. However, as soon as high tide inundated these areas and the water level increased, there was a greater activity of the coral fishes which ensued until the water receded and till the next high tide.

Echinoderms

Eight species of echinoids belonging to 7 genera and 5 families associated with grazing and boring of coral reef habitats in Minicoy were identified during the study (Table 26). Diadematidae and Echinometridae were the most dominant families observed during the study while the remaining families Oreasteridae, Stomopneustidae and Toxopneustidae were found only in few samples. The diademid sea urchin Echinothrix diadema (fam. Diadematidae) was the most abundant sea urchin on the seaward and lagoon reef flats where the effect of wave action was pronounced; while in the lagoon shoal, in areas relatively calm, the rock boring urchin Echinometra mathei (fam. Echinometridae) dominated. The present collection includes Heterocentrotus mammillatus (fam. Echinometridae) and Diadema setosum (fam. Diadematidae), which are new records from Minicoy Island. Other echinoids which were directly associated with coral destruction by feeding on coral polyps included Culcita novaeguineae (fam. Oreasteridae) the grazing sea urchins, Echinothrix calamaris (fam. Diadematidae) and rock borers, Tripneustes gratilla (fam. Toxopneustidae) and Stomopneustes variolaris (fam. Stomopneustidae). A very interesting observation was the absence of the much dreaded crown of Thorns starfish Acanthaster planci during the entire study.

The population density (individuals per sq.m.) of the rock boring sea urchin Echinometra mathei for the period from January 1991 till December 1991 is illustrated in Fig. 12 while the population density of the diademid sea urchin Echinothrix diadema on the lagoon reef flat for a period of 2 years from 1990 January till December 1991 is illustrated in Fig. 13.

The density of the rock boring sea urchin Echinometra mathei was higher in the lagoon shoal at the north eastern part of the lagoon (Plate VI) while it was limited on the inner reef flat in Zone 6. Quite unexpectedly the species was not observed on the seaward reef flat and lagoon reef flat which had a pronounced effect of wave action. In the lagoon shoal, the species was found to burrow into pot holes and crevices (Plate VI) and was found to have a preference to inhabit preformed burrows which were already existing. The burrows of the species were extremely irregular and the animal recorded very little movements during the day time and low tide, exhibiting little spine movements even when disturbed. In the shallow regions in Zone 6, the species was found between dead Acropora branches. In general, the specimens collected from the inner reef flat regions of Zone 6 were relatively larger than those collected from the lagoon shoal in Zone 3.

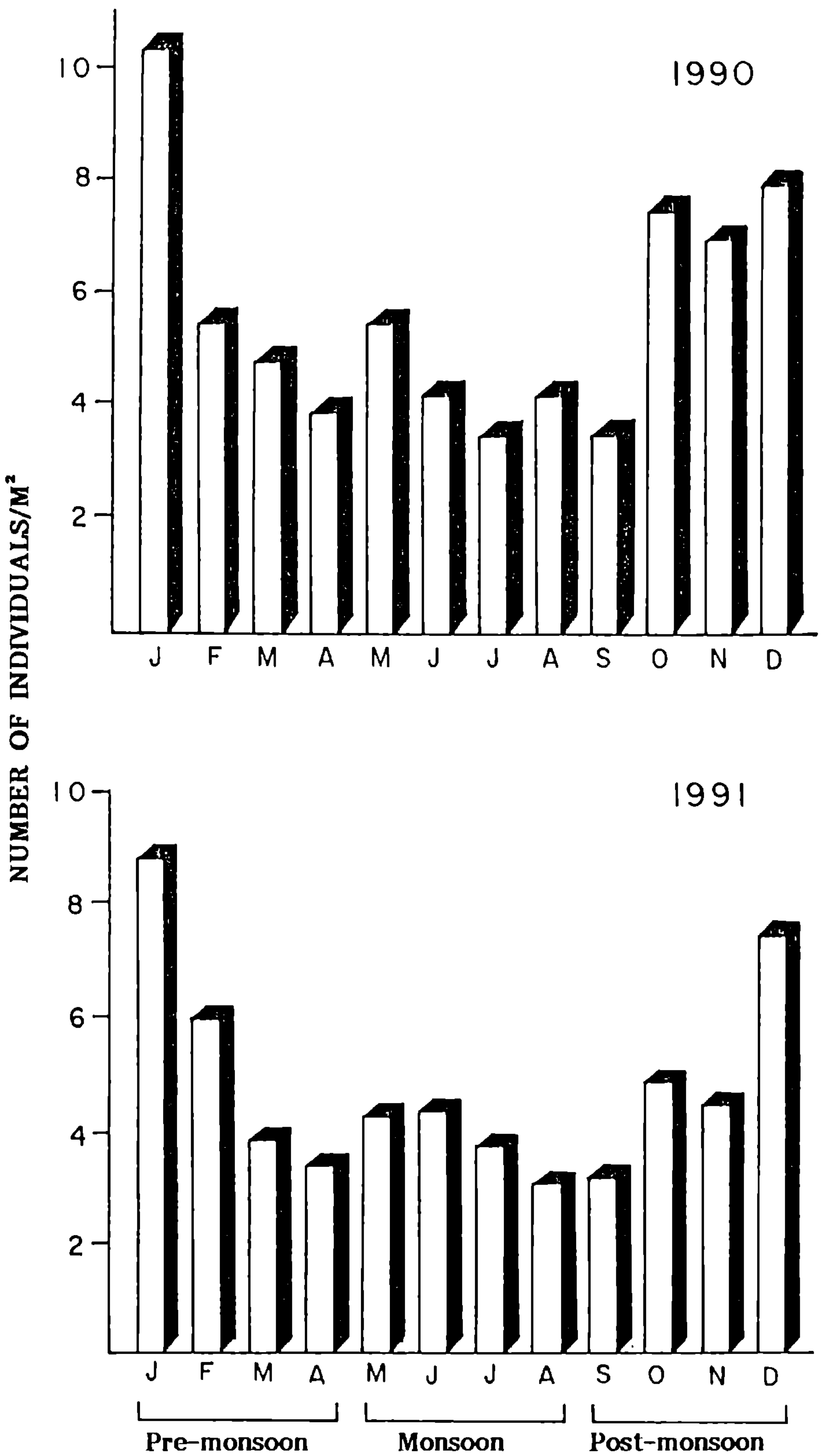


Fig. 12. The variation in population density of the diademid sea urchin Echinothrix diadema on the lagoon reef flat for the period from 1990 January till December 1991.

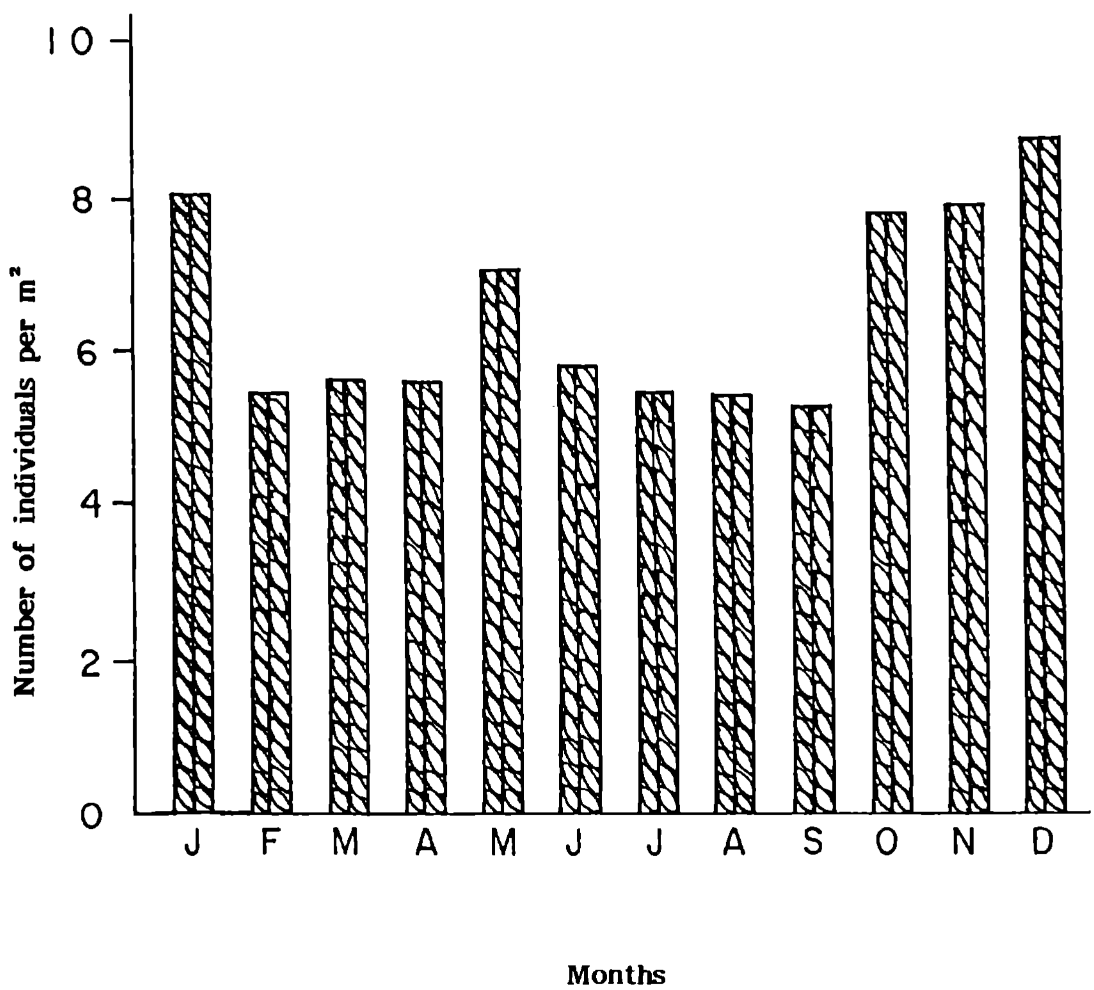


Fig. 13. The variation in population density of the rock boring sea urchin <u>Echinometra mathei</u> in the lagoon shoal for the period from January 1991 till December 1991.

Table 24. Estimated weight of calcium carbonate (grams) sediments particles recovered from the gut and faecal pellets of two species of sea urchins in the coral reefs of Minicoy

Species	No. of samples	Locality	Test diameter	Amount of calcareous particle recovered from gut and faecal pellets (grams)
1. *Echinothrix diadema*	61	Reef flat	7.0 to 9.3 cm	0.125 to 625 g
2. *Echinometra mathei*	45	Lagoon shoal	2.39 to 4.15 cm	0.075 to 0.120 g

Table 25. Analysis of variance (ANOVA) table, showing the level of significance in variation of the population density of (a) the diademid sea urchin Echinothrix diadema on the lagoon reef flat for the period from January 1990 till December 1991 (b) the rock boring sea urchin Echinometra mathei in the lagoon shoal for the period from January 1991 till December 1991

a) Echinothrix diadema

Source	d.o.f.	s.s.	m.s.s.	F. ratio	Remarks
Year	1	3	2.74	0.73	$P \geq 0.05$
Season	4	15	3.73	1.21	$P \geq 0.05$
Error	18	56	3.09		

b) Echinometra mathei

Season	2	5.372	2.686	1.74	$P \geq 0.05$
Error	9	13.928	1.548		

Table 26. The distribution of coral boring and grazing echinoids in the coral reef habitats of Minicoy (* indicates new records from Minicoy)

A Abundant P Present R Rare Not recorded

Zone	Habitats	Depth (m)	*Culcita novaeguineae*	* *Diadema setosum*	*Echinothrix calamaris*	*Echinothrix diadema*	*Stomopneustes variolaris*	*Tripneustes gratilla*	*Echinometra mathei*	* *Heterocentrotus mammillatus*
1	Sandy flat	0.5-1.0								
2	Lagoon	5.9-8.10							R	
3	Lagoon shoal	2.3-3.1							A	R
4	Lagoon	4.55-6.25								R
5	Lagoon reef flat coralline boulders	Exposed during low tide	R	R	P	A	P	R		
6	Inner lagoon reef flat	0.5-1.0							P	
7	Lagoon	8.1-9.3								
8	Lagoon	11.2 to 13.4								
9	Seaward reef flat coralline boulders intertidal	Exposed during low tide			R	A	P			R

Plate VI

A. In the lagoon shoal, in areas relatively calm, the rock boring urchin *Echinometra mathei* dominated. The species was found to have a preference to inhabit preformed burrows which were already existing.

B. The diademid sea-urchin *Echinothrix diadema* was observed only on the reef flats where there was severe wave action. The species was observed in the sheltered crevices along the reef flat.

C. In the case of smaller specimens of boring lithophagids, the burrows were the same length of the bivalve, but the larger ones exceeded the length of the shell.

PLATE VI

A

B

C

The monthly density of E. mathei during 1991 varied between 5.3 and 8.1 in premonsoon, between 5.4 and 7.1 during monsoon, and between 5.3 and 8.8 during post-monsoon (Fig.12). A maximum population density of 16 counts per quadrat was recorded during the study. However, the variation of mean density of the species did not differ significantly between seasons ($P \geq 0.05$; Table 25).

The diademid sea urchin Echinothrix diadema was recorded only on the reef flats (both lagoon and seaward reef flats) where there was severe wave action. The species was observed in sheltered crevices and beneath coral boulders along the reef flat (Plate VI) feeding on coralline and non-coralline algae. During 1990, the monthly density of this species during premonsoon varied between 3.88 and 5.35 while it varied between 3.76 and 5.38, and 3.41 and 7.91 during monsoon and post-monsoon respectively (Fig.13). In the second year, (1991) the montly density varied between 3.44 and 8.76, 3.09 and 4.38 and 3.18 and 10.38 during premonsoon, monsoon and post-monsoon respectively. The maximum individual density recorded for this species was 18 numbers per quadrat. However, the variation in the density observed between the different seasons did not differ significantly ($P \geq 0.05$ Table 25). The density of this species on the inner reef flat ranged between 0.5 and 1.5 per sq.m. based on 25 samples studied (mean 1.0 per sq.m).

In the case of Echinometra mathei the estimated weight of calcium carbonate recovered from the gut (Table 24) varied between 0.072 and 0.120 g for the animals of test diameter ranging from 2.39 to 4.15 cm (number of animals examined = 45). The amount of calcium carbonate recovered from the gut of Echinothrix diadema varied between 0.125 and 0.625 g for size group between 7.0 and 9.3 cm test diameter (Table 24).

Molluscs

The boring bivalves collected from the coral reefs in Minicoy were represented by 12 species belonging to 6 genera (Table 31). Lithophaga was by far the commonest while the remaining genera Botula, Petricola, Gastrochaena and Tridacna were represented only in a few samples. Out of a total of 193 specimens of lithophagids collected during the study L. nigra was the largest group representing about 46% while L. gracilis and L. teres constituted about 36 and 12% respectively (Table 27). An unidentified species of Lithophaga was represented by 11 specimens. One specimen of L. laevigata was collected from the coral boulders on the lagoon reef flat (Plate XII). L. teres and L. laevigata are new records from Lakshadweep (Plate XII). Jonannetia cumingii and J. globosa which were earlier reported from Lakshadweep were not obtained in the present collection.

The shell length of Lithophaga nigra varied between 31.3 and 63.2 mm, while its height and depth varied between 8.3 and 16.7 mm; 6.6 and 14.3 mm respectively (Table 27). In the case of L. gracilis the shell length, height and depth varied from 25.3 to 44.7 mm 8.8 to 14.0 mm and 7.1 to 11.8 mm respectively (Table 27) while in L. teres the corresponding dimensions ranged from 22.9 to 46.3 mm 6.6 to 14.5 mm and 5.2 to 12.6 mm for shell length, height and depth respectively. The unidentified Lithophaga sp. had a length ranging from 22.9 to 44.7 mm, height from 7.9 to 14.4 mm and depth ranging from 6.7 to 12.8 mm.

The regression equation for the relationship between length and height of the shell (based on 89 pairs of shell) for L. nigra was $y = -0.1776 + 0.2684\ x$ ($r = 0.98$) while the regression equation was $y = 2.1459 + 0.2651\ x$ ($r = 0.89$) for L. gracilis (based on 70 pairs of shells). The equation for L. teres was $y = 0.1563 + 0.320\ x$ ($r = 0.98$) based on a study of 23 pairs of shells.

The borings of Lithophaga nigra, L. gracilis and L. teres were long, almost cylindrical and scarcely any space existed between the shell and the wall of the burrow (Plate VI). The openings of the burrow was generally slit like. Internally the burrows were lined by a calcareous coating. In the case of smaller specimens, the burrows were of the same length of the animal, but the larger ones exceeded the length of the shell (Plate IX). The length of the burrows (74 numbers) of L. nigra ranged from 51.0 to 91.0 mm while the diameter ranged from 9.7 to 17.7 mm (Table 28). The burrows made by L. gracilis (65 numbers) ranged from 39.0 to 71.0 mm in length while the diameter never exceeded 15.0 mm. In the case of L. teres, 23 numbers of burrows were examined in which the length ranged from 33.0 to 65.0 mm, while the diameter ranged from 8.0 to 15.4 mm. The burrows which were badly damaged during extraction of the bivalve and were beyond the scope of measurements were discarded in the present study. Based on the shell length and burrow dimensions and exponential relationship for the relationship between length of the shell (L) and length of burrow (BL), length of the shell (L) and volume of the burrow (BV) was calculated for L. nigra, L. gracilis and L. teres (Table 28). According to the equation the relationship between length of burrow (BL) and length of shell (L) for L. nigra was $BL = 2.2363\ L^{0.8862}$ ($r = 0.9490$) and for L. gracilis the relationship was $BL = 0.7570\ L^{1.1845}$ ($r = 0.9503$). The relationship worked out for L. teres was $BL = 3.8380\ L^{0.6952}$ ($r = 0.7974$). The relation between length of the shell (L) and volume of burrow (BV) for L. nigra was $BV = 0.3132\ L^{2.6815}$ ($r = 0.9263$). For L. teres it was $BV = 0.4791\ L^{2.6169}$ ($r = 0.9716$).

In addition to lithophagids, the tridacnid clams were also seen associated with live and dead corals. The valves were observed to project out from the substrate while some completely embedded into the substrate. Three species namely Tridacna gigas, T. maxima and T. squamosa were observed during the survey in the lagoon and on the reef flats. The tridacnid clams were more abundant in the lagoon and were associated with areas of live coral cover. They were relatively less on the reef flats dominated by dead coral substrate. The maximum percentage cover of this bivalve in the quadrat during the survey was 0.13 and 1.63 in Zones 1 and 2 while it was 0.63 in Zone 3 (Table 3). The maximum cover recorded for the

Table 27. Indices of length (L), height (H) and depth (D) and their relationship in the common boring bivalve Lithophaga spp. found in the coral reefs of Minicoy Island

Name of species	No. of bivalve	Length (mm)	Height (mm)	Depth (mm)	Equation $Y = a + bX$	r
Lithophaga nigra	89	31.3-63.2	8.3-16.7	6.6-14.3	$H = \bar{0}.1776 + 0.2684\ L$	0.9887
					$D = \bar{1}.0209 + 0.2424\ L$	0.9992
					$D = \bar{0}.5972 + 0.8831\ H$	0.9887
Lithophaga teres	23	22.9-46.3	6.6-14.5	5.2-12.6	$H = \bar{0}.1563 + 0.3200\ L$	0.9829
					$D = \bar{1}.099 + 0.2993\ L$	0.9789
					$D = \bar{0}.9818 + 0.9378\ H$	0.9888
Lithophaga gracilis	70	25.3-44.7	8.8-14.0	7.1-11.8	$H = \bar{2}.1459 + 0.2651\ L$	0.8964
					$D = \bar{1}.2945 + 0.2317\ L$	0.9871
					$D = \bar{0}.5294 + 0.9856\ H$	0.8693
Lithophaga sp.	11	22.9-44.7	7.9-14.4	6.7-12.8	$H = 4.9284 + 0.1975\ L$	0.7887
					$D = 1.1685 + 0.2457\ L$	0.9229
					$D = \bar{1}.1102 + 0.9059\ H$	0.8520

Table 28. Exponential relationship ($Y \quad aX^b$) established between length of the bivalve and burrow dimensions (length and volume) for the common boring bivalve *Lithophaga* spp. found in the coral reef of Minicoy Island. The parameters a and b were estimated by regression analysis after logarithmic transformation of the data.

Name of species	No of bivalves	Shell length(L) mm	Burrow length(BL) mm	Burrow volume(BV) cub.mm	Y	aX^b	r
Lithophaga nigra	89	31.3-63.2	51.0-91.0	3988.48-21876.96	BL	$2.2363\ L^{0.8862}$	0.9490
					BV	$0.3132\ L^{2.6815}$	0.9263
Lithophaga gracilis	70	25.3-44.7	39.0-71.0	2880.57-12540.38	BL	$0.7570\ L^{1.1845}$	0.9503
					BL	$0.0025457\ L^{4.1154}$	0.8206
Lithophaga teres	23	22..9-46.3	33.0-65.0	1586.96-12101.69	BL	$3.8380\ L^{0.6952}$	0.7974
					BV	$0.4791\ L^{2.6169}$	0.9716
Lithophaga sp.	11	22.9-44.7	38.0-59.0	2362.83-8271.49	BL	$5.6821\ L^{0.6036}$	0.9469
					BV	$40.3447\ L^{1.4059}$	0.8229

Table 29. The mean number of boring bivalves per kg of coral and the mean volume of calcium carbonate eroded per kg of coral in the lagoon during the period from January 1990 till December 1991. Values given in brackets indicate the standard deviation

		1990	1991
a)	Mean number per kg. of coral	4.14 (± 2.01)	4.9 (± 1.90)
b)	Mean volume of calcium carbonate eroded per kg of coral (cub. cm)	38.5 (± 24.1)	38.9 (± 30.5)

Table 30. A check list of boring bivalves collected from the coral reefs of Minicoy during the study

Class	Bivalvia		
Order	Anisomyaria		
Series	Mytilacea		
Family	Mytilidae		
	Genus		Lithophaga (Bolten) Roding, 1798
	Species:		L. nigra (d' Orbingny), 1845
			L. gracilis (Philippi), 1847
		*	L. teres (Philippi), 1846
		*	L. laevigata (Quoy and Gaimard) 1818
	Genus		Botula Morch, 1853
	Species:		B. cinnamomea (Lamarck), 1819
Family	Tridacnidae		
	Genus		Tridacna
	Species:		Tridacna maxima
			T. squamosa
			T. crocera
Order	Eulamellibranchia		
Series	Veneracea		
Family	Petricolidae		
	Genus		Petricola Lamarck, 1801
	Species:		P. lithophaga (Retzius) 1787
			P. divergens (Gmelin), 1790
Series	Gastrochaenacea		
Family	Gastrochaenidae		
	Genus		Gastrochaena Spengler, 1783
	Species:		G. gigantea (Deshayes), 1830
	G. impress (Deshayes), 1854.		

* New records from Lakshadweep

species was 1.31 and 0.81% in Zones 4 and 5, respectively while on the deeper regions of the lagoon it recorded 0.75 and 0.88%.

Other than bivalves, a few gastropods were also seen to be associated with lives corals. Four specimens of the gastropod Magillus sp. belonging to fam. Coralliophilidae (Plate XII) were found inside the skeleton of Favia pallida, Leptoria phyrgia (one each) and Platygyra lamellina. The animal was found within burrows in the coral with the siphon extending to a small aperture at the surface. The aperture was lined with calcareous material.

The occurrence of the boring bivalves (Lithophaga) in the present study was restricted to the lagoon shoal while its occurrence on the reef flat was very rare. Only 3 specimens were recorded from the lagoon reef flat including L. laevigata. Except for one sample where L. gracilis was recorded from the stalk of Lobophyllia corymbosa, the lithophagids were recorded only from dead corals.

During the period from 26.1.1990 till 28.12.1990, the mean number of boring bivalves recorded per kg of coral in the lagoon shoal was 4.14 while the mean volume of calcium carbonate eroded by the boring bivalves was 38.5 cub.cm/kg of coral head. The corresponding values for the period from 5.1.1991 till 28.12.1991 it was 4.9 and 38.9 cub.cm/kg of coral head. Due to the non-detection of boring bivalves in other habitats on the reefs, the corresponding density and volume of calcium carbonate eroded by the bivalves could not be computed.

Polychaetes

In the present study a total of 34 polychaete species belonging to 24 genera of 13 families were represented in the collection (Table 33). Of these Eunicidae was by far the most abundant in the collection. The remaining families Phyllodocidae, Tomopteridae, Syllidae, Nephthydidae, Glyceridae, Cirratulidae, Chaetopteridae, Oweniidae, Ampharetidae, Terebellidae, Sabellidae and Serpulidae were recorded only in a few samples. The dominant family Eunicidae had 5 genera comprising of 13 species while Glyceridae had 3 species. Terebellidae, Sabellidae and Serputidae had 3 genera each. The remaining families were represented by single genus each comprising of very few individuals.

The number of polychaetes per unit weight of the coral head and their biomass varied between the different habitats as well as in samples within a habitat. Samples with a high biomass of polychaetes generally had a low level of other boring invertebrates. Habitats with the maximum biomass of polychaetes did not contain the highest number of individuals. Such habitats normally had a few large eunicids whose length varied between 9.0 and 22.0 cm in while the weight varied between 0.510 and 4.363 g. In the present study it was observed that though the coral samples collected from the lagoon had a higher number of individuals per unit weight of coral, the biomass of these animals was relatively higher on the reef flats. While the live coral samples were represented by a very poor population of polychaetes, the dead eroded coral substrates in the lagoon shoal had higher number of individuals and species. Only one species, the serpulid Spirobranchus giganteaus was observed from living coral heads of Porites lutea, P. solida and faviid mounts in the lagoon. The tube of the species was surrounded by an overgrowth of the coral and the branchial crown and operculum of the worm protruded during feeding. One specimen of Owenia fusiformis (Plate XII), a new record of polychaete from Lakshadweep, was recorded from the crevice in the shoal in the lagoon at the north-eastern side. The fan worm Sabellastarte sanctijosephi was also recorded in pockets in the lagoon shoal. Dense colonies of Hydroides norvegica were observed on the dead bases of live coral colonies sampled from the lagoon. Another new record of sabellid worm Hypsicomus phaeotaenia was observed in the lagoon shoal at the northeastern side of the lagoon (Plate XII). The polychaete Syllis (Syllis) gracilis, a new record was collected from the coral boulders on the seaward reef flat (Plate XII).

Table 31. The mean number of individuals of polychaetes in one kg of coral in the different reef habitats observed during the period from January 1990 to December 1991. The figures given in brackets indicate the standard deviation

Reef Habitat	1990	1991
a. Sea ward reef flat	2.1 (± 1.10)	1.9 (± 1.59)
b. Lagoon reef flat	9.41 (± 7.75)	3.94 (± 3.45)
c. Lagoon	9.6 (± 2.15)	15.7 (± 4.34)

Table 32. The mean biomass (g) of polychaetes recorded in one kg of coral in the different reef habitats observed during the period from January 1990 to December 1991. The figures given in brackets indicate the standard deviation

Reef habitat	1990	1991
a. Sea ward reef flat	2.769 (± 1.420)	1.942 (± 1.590)
b. Lagoon reef flat	1.228 (± 1.246)	3.034 (± 2.905)
c. Lagoon	2.300 (± 1.129)	1.6 (± 1.813)

Table 33. Checklist of polychaetes collected during the study in Minicoy coral reefs

Fam. Phyllodocidae

1. Lopadorhynchus uncinatus Fauvel, 1915
2. Phyllodoce (Anaitides) madeirensis Langerhans, 1880

Fam. Tomopteridae

3. Tomopteris elegans Chun 1888

Fam. Syllidae

* 4. Syllis (Syllis) gracilis Grube 1840

Fam. Nephthydidae

5. Nephtys (Aglaophamus) dibranchis Grube 1877

Fam. Glyceridae

6. Glycera lancadivae Schmarda 1861
7. G. gigantea Quatrefages 1865
8. G. rouxi Audouin and Milne Edwards 1833

Fam. Eunicidae

9. Eunice norvegica (Linnaeus, 1767)
10. E. tentaculata Quatrefages 1865
11. E. aphroditois (Pallas 1788)
12. E. afra afra Peters 1845
13. E. coccinea Grube 1878
14. E. antennata Savigny
15. E. indica Kinberg 1865
16. E. siciliensis Grube 1840
17. E. grubei Gravier 1900
18. Lysidice collaris Grube 1870
19. Onuphis (Nothria) holobranchiata Marenzeller 1879
20. Lumbrineris tetraura (Schmarda 1861)
21. Rhamphobrachium chunni Ehlers 1908

Table 33. Contd..

Fam. Cirratulidae

22. Cirratulus filiformis Keferstein 1862

Fam. Chaetopteridae

23. Phyllochaetopterus gardineri Crossland

Fam. Oweniidae

* 24. Owenia fusiformis Delle Chiaje 1844

Fam. Ampharetidae

25. Amphicteis gunneri (Sars, 1835)

Fam. Terebellidae

26. Eupolymnia nebulosa (Montagua 1818)
27. Terebella ehrenbergi Grube 1870
28. Terebellides stroemi Sars 1835

Fam. Sabellidae

* 29. Seballastarte sanctijosephi (Gravier 1906)
30. Potamilla ehlersi Monro
31. Hypsicomus phaeotaenia Schmarda 1861

Fam. Serpulidae

32. Spirobranchus giganteus (Pallas 1766)
33. Filograna implexa Berkeley 1835
34. Hydroides norvegica (Gunnerus 1768)

* New records from Lakshadweep

The mean number of polychaetes was higher in the coral samples collected from the lagoon than those collected from the reef flats. In the lagoon, the mean number recorded was 9.6 and 15.7 per kg of coral head during 1990 and 1991 respectively (Table 31). On the seaward reef flat the mean density was 2.1 and 1.9 during 1990 and 1991 while it was 9.41 and 3.94 on the lagoon reef flat during 1990 and 1991 respectively. However the biomass of polychaetes was higher in coral samples collected from the reef flat than those collected from the lagoon. The mean biomass in one kg of coral on the seaward reef flat recorded 2.769 and 1.942 g during 1990 and 1991 respectively (Table 22), while on the lagoon reef flat it was 1.228 and 3.034 g in 1990 and 1991. Coral samples collected from the lagoon recorded a mean biomass of 2.300 and 1.6 g per kg of coral during 1990 and 1991 respectively.

Sipunculids

The sipunculids associated with the coral reef habitats of Minicoy were collected during the study and were found to represent a total of 18 species belonging to 9 genera (Table 36). Among the 354 specimens collected, the major genera were Aspidosiphon, Cleosiphon and Phascolosoma which constituted 39.55, 33.62 and 19.78% respectively while the remaining were represented by Paraspidosiphon, Golfingia, Fisherana and Phascolin. Of the above, the genus Phascolosoma comprised of 8 species including P. nigrescens a new record while Aspidosiphon had 2 species and Cleosiphon was represented by a single species only.

The density of sipunculids was higher on the lagoon shoal than on the reef flats (Table 37). In the lagoon, the mean number of sipunculids per kg of coral was 8.92 and 10.64 during 1990 and 1991 respectively per. On the seaward reef flat, the mean number of sipunculids per kg of coral was 2.67 and 2.23 for 1990 and 1991 respectively while on the lagoon reef flat, the corresponding values were 6.48 and 5.75. The biomass of sipunculids was also higher in the lagoon shoal recording 2.14 and 2.22 g per kg of coral in 1990 and 1991 respectively while it was 1.50 & 1.17 g and 1.44 & 1.26 g for the seaward reef flat and lagoon reef flat respectively during the corresponding period (Table 38).

The monotypic genus Cleosiphon aspergillum was widely distributed and represented 33.62% of the specimens collected in the study. The species was recorded from all types of calcareous substrates from the highly eroded limestone, fossile coralline limestone and coarse-grained calcareous beach rock. In some samples collected it was found to occur along with one or more other species of boring invertebrates in the same rock. In the present study 119 specimens of this species were collected, all from dead coral samples. Most of the specimens had an ivory colour translucent skin with a unique white compound and acorn like cap at the anterior end of the trunk through which the introvert protruded (Plate VIII). Reflecting the shape and the activity of the species, the burrows of this species were long and narrow with a single opening to the surface of the rock. The anterior end of the animal was always directed towards the opening of the burrow. Examination of the gut contents of a few specimens revealed that calcareous fragments occupied the major part of the gut. Though the species was widely distributed in the lagoon and reefs, it was more common along the shoal in the north-eastern part of the lagoon (Plate II). Though the species was recorded from both soft and hard calcareous structures and from dense dead coralline substrates in the lagoon, it was rarely encountered in recent limestone coralline boulders along the reef flats.

The length of the animals collected ranged between 13.2 and 57.7 mm while their weight ranged between 0.056 and 0.606 g. The larger specimens were recorded from the highly eroded lagoon shoals and the dense coralline substrates on the reefs. The equation for length (x), weight (y) relationship established for this species (n = 119), was $\log_e y = \log_e 0.001150293 + 1.4971 \log_e x$ (r = 0.994).

The genus Aspidosiphon by far the most abundant group was represented by A. cumingii and A. steenstrupii. A. cumingii constituted 15.82%

of the specimens collected. All the 56 animals of A. cumingii were collected from dead coralline substrates and dead base of live corals while A. steenstrupii constituted 26.55% with 94 numbers in the collections. These species were found to inhabit rocks of varying texture from the coarse grained calcareous beach rock to the dense coralline limestone and were widely distributed all over the lagoon and reefs. The characteristic anterior shield of A. steenstrupii surrounded by a thickened rim was often covered by calcareous deposits. The posterior shield of the species was found to vary in shape from flattened to rounded to pointed, depending on the state of contraction of the animal at the time of preservation of the animal at the time of preservation. The burrows of these species were short, straight and rounded posteriorly. The anterior shield was always directed towards the mouth of the opening.

The length of A. cumingii ranged between 7.0 and 18.2 mm while the weight ranged from 0.012 to 0.080 g (Table 34). In the case of A. steenstrupii while the length of the animals varied between 7.0 and 28.0 mm the weight of the individuals ranged from 0.041 to 0.222 g (Table 34). The equation for length (X) weight (Y) relationship for A. steenstrupii ($n = 94$) $\log_e Y = \log_e 0.001805514 + 1.3919 \log_e X$ ($r = 0.8305$) while in the case of A. cumingii due to the varied state of contraction at the time of preservation, the equation derived did not hold true to establish a relationship ($r = 0.4327$).

The different species of the genus Phascolosoma included P.dentigerum, P. asser, P. pacificum, P. rupelli, P. scolops and a new record from Lakshadweep P. nigrescens (Plate VIII). Most of the species were present throughout the lagoon and reef habitats in Minicoy, particularly from the shoal in the north-eastern end of the lagoon (Plate II). All the 8 specimens of P. nigrescens obtained in the present study was collected from the seaward reef rock boulders (Plate II). The colour of the specimens varied from dark to very pale brown (Plate VIII), with alternating dark and light cross bands on the introvert. In one specimen, the introvert was about as long as the trunk, and had about 30 rows of hooks. In the P. dentigerum all the expanded introverts were at least half as long as and some as long as the body. Most of the individuals had a very pale body with the introvert showing reddish-brown bands (Plate VIII). Reflecting the shape and presumably the activity of the animals, burrows of these species were found to be narrow with a single opening to the surface (Plate VII). The anterior end of the animal was always directed towards the opening of the burrow and the animal was tightly ensconsed within the walls of the burrow (Plate VII). When exposed or removed from the substrate, the body expanded to exceed considerably the diameter of the burrow. When disturbed while extracting from the burrows, the animals were observed to extend introvert frequently to the exterior and then retract it (Plate VII).

During the study, the length of P. dentigerum extracted ranged between 21.0 and 54.2 mm while the weight ranged from 0.260 to 0.992 g (Table 34). While the length for P. nigrescens varied between 47.0 and 61.3 mm the weight was between 0.850 and 1.022 g. The equation for length (X) weight (Y) relationship for P. dentigerum (n = 40) was $\log_e Y = \log_e 0.006614755 + 1.2134 \log_e X$ (r = 0.6931).

One specimen identified as Lithocrosiphon sp. (Plate) was collected from the lagoon reef flat. It measured 9.0 mm and had a width of 2.1 mm. The burrow of this species was short, straight and rounded posteriorly.

An exponential relationship of $Y = aX^b$ was fitted on the data for 4 species, with weight of the animal (W), length of the animal (L), and length of burrow (BL), volume of burrow (BV), and the equations derived are given in Table 35. Accordingly the equation for the relationship between weight of the animal (W) and the volume of the burrow (BV) was $BV = 2914.9735\ W^{1.0460}$ (r = 0.88) for Cleosiphon aspergillum (samples n = 54); $BV = 1836.8602\ W^{0.9680}$ (r = 0.79), for Phascolosoma dentigerum (n = 32) and $BV = 448.9857\ W^{0.6590}$ (r = 0.79) for Aspidosiphon streestrupii (η = 44). The equation was $BV = 238.8438\ W^{0.3467}$ (r = 0.69) for Aspidosiphon cumingii (n = 42). Those samples in which the burrow length and width could not be measured due to complete breakage were not included.

Table 34. Length-weight relationship of the common boring sipunculids found in the Minicoy Atoll of Lakshadweep

Species	No. of animals	Length (X) mm	Weight (Y) g	Length weight relationship $\log_e Y \quad \log_e a + b \log_e X$	r value
Cleosiphon aspergillum	119	13.2-57.7	0.056-0.606	$\log_e Y \quad \log_e 0.001150293 + 1.4971 \log_e X$	r 0.994
Phascolosoma dentigerum	40	21.0-54.2	0.260-0.992	$\log_e Y \quad \log_e 0.006614755 + 1.2134 \log_e X$	r 0.6931
Aspidosiphon cumingii	56	7.0-18.2	0.012-0.080	$\log_e Y \quad \log_e 0.00147931 \quad 1.2073 \log_e X$	r 0.4327 (not significant)
Aspidosiphon steestrupii	94	7.0-28.0	0.041-0.222	$\log_e Y \quad \log_e 0.001805514 + 1.3919 \log_e X$	r 0.8305

Table 35. Exponential relationship ($Y = aX^b$) established between size of the sipunculid (length and weight) and burrow dimensions (length and volume) for four species found in the coral reefs of Minicoy Island. The parameters a and b were estimated by regression analysis after logarithmic transformation of the data.

Name of species	No. of animals	Length(L) mm	Weight(W) g	Burrow length(BL) mm	Burrow volume(BV) cub.mm	Y	aX^b	r
Cleosiphon aspergillum	54	13.2-57.7	0.056-0.606	41.0-143.0	201.15-1695.6	BL	$3.6027\ L^{0.8954}$	0.9659
						BV	$2.3891\ L^{1.5741}$	0.8813
						BL	$204.3739\ W^{0.5925}$	0.9627
						BV	$2914.9735\ W^{1.0460}$	0.8819
Aspidosiphon cumingii	52	7.0-18.2	0.012-0.080	19.0-35.0	42.2-109.9	BL	$8.20.28\ L^{0.4653}$	0.7810
						BV	$6.6560\ L^{0.9647}$	0.6890
						BV	$238.7438\ W^{0.3467}$	0.6938
Aspidosiphon streestrupii	44	7.0-28.0	0.041-0.222	15.0-59.0	38.86-266.78	BL	$3.1177\ L^{0.8323}$	0.9062
						BV	$5.0305\ L^{1.0439}$	0.7500
						BL	$73.6393\ W^{0.3706}$	0.6762
						BV	$448.9857\ W^{0.6590}$	0.7935
Phascolosoma dentigerum	40	21.0-54.2	0.260-0.992	32.0-121.0	157.0-2374.6	BL	$3.7429\ L^{0.8571}$	0.9491
						BV	$1.0706\ L^{1.9075}$	0.8865
						BL	$100.8180\ W^{0.3605}$	0.7021
						BV	$1836.8602\ W^{0.9680}$	0.7913

Table 36. Distribution of coral boring sipunculids in the different zones in the coral reef habitats of Minicoy where the survey was conducted.

(C = common P Present R Rare not recorded)

Zone	Habitat	Depth(m)	Phascolosoma nigrescens	P.dentigerum	P.ruepelli	P.agassizi	P.asser	P.pacificum	P.pelma	P.scolops	Aspidosiphon streestrupii	A.cumingii	Aspidosiphon sp	Paraspidosiphon sp.	Cleosiphon aspergillum	Lithacrosiphon sp.	Golfingia spp.	Fisherana papilitera	Phascolin strombi
1	Sandy flat	0.5-1.0									R				R				
2	Lagoon	5.9-8.10		P			R	R			P	P			P				
3.	Lagoon shoal	2.3-3.1		C	P	R	R	R	R	P	C	C	P	P	C			R	R
4	Lagoon	4.55-6.25		R	R					R	P	P			C		P		
5	Lagoon reef flat coralline lime stone boulders	Exposed		P			R	R			C	P		P	C	R	P	P	
6.	Dead coral rubbles intertidal	Exposed		P							C	C			C				
7.	Lagoon	8.1-9.3		P			R				P	P			P				
8.	Lagoon	12.5-13.4		P				R			P	P			P				
9.	Seaward reef flat coralline limestone intertidal	0.5-1.0	R	P			R	R		C	P				C	P	P		

Table 37. Mean number of boring sipunculids in one kg of coral (wet weight) in the different reef habitats observed during the period from January 1990 to December 1991. The figures given in brackets indicate the standard deviation

Reef Habitats	1990	1991
a) Seaward reef flat	2.67 (± 2.08)	2.23 (± 1.0)
b) Lagoon reef flat	6.48 (± 4.64)	5.75 (± 4.50)
c) Lagoon	8.92 (± 5.44)	10.64 (± 5.34)

Table 38. Mean biomass (g) of sipunculids recorded in one kg of coral (wet weight) in the different reef habitats observed during the period from January 1990 to December 1991. The figures given in brackets indicate the standard deviation

Reef Habitats	1990	1991
a) Seaward reef flat	1.50 (± 1.29)	1.17 (± 0.96)
b) Lagoon reef flat	1.44 (± 1.33)	1.26 (± 1.58)
c) Lagoon	2.14 (± 2.22)	2.22 (± 1.65)

Sponges

In the present study 15 species of boring sponges belonging to eight genera of four families were identified from the reef corals at Minicoy Island (Table 39). Cliona was the largest genera represented by five species namely C. celata, C. vastifica, C. carpenteri, C. ensifera and C. mucronata. The genus Spirastrella constituted three species viz. S. coccinea, S.cuspidifera and S. inconstans while Aka had two species, A. minuta and A. laccadivensis. The remaining genera, Rhabdermia, Amorphinopsis Thoosa, Halina and Samus were represented by a single species each.

In the present study though in most cases, more than one species was encountered from a coral head, in the case of Rhabderemia prolifera, in general, other boring sponges were seldom present in the galleries occupied by this species. Cliona celata and C. vastifica were the dominant clionid sponges observed in most of the samples collected from the reefs and lagoon. The species Spirastrella inconstants and S. cuspidefera were observed to overgrow the dead bottom of a few samples of Porites sp. and Leptoria phyrgia in the deeper areas of the lagoon. In a few coral samples also collected from Zone 7 and 8, non-boring sponges were found to overgrow the dead basal portion of coral heads. A branching Porites sp. collected from Zone 7 at a depth of 8.6 m had a network of clionid filaments mostly seen concentrating at the apex of the colony. In samples collected from the reefs and other areas in the lagoon the clionid boring was mostly confined to the marginal layers. The cavites made by the sponge ranged from regular to spherical to ovoid to irregular. The network of galleries made even extended upto 1.0 cm into the substrate.

During the study it was observed that Cliona celata was one of the most dominant species of boring sponge in the reef habitats of Minicoy Island (Table 39). Of the 200 number of coral samples examined (132 samples in the lagoon and 68 samples from the reefs) C. celata was detected in 12.57% of the samples. The detection of this species varied between 13.56 and 20.00 per cent in samples from Zones, 1, 2, 3, 4, 5, 6 and 9. In the

Table 39 Percentage occurrence of 15 species of boring sponges belonging to 8 genera of 4 families, in the samples collected from each zone during the survey in the reefs of Minicoy Island (No. of samples taken from each zone are given in brackets)

Zone	Site	Depth(m)	Rhabderemia prolifera	Spirastrella coccinea	Spirastrella cuspidifera	Spirastrella inconstans	Amorphinopsis excavans	Aka minuta	Aka laccadivensis	Cliona celata	Cliona vastifica	Cliona carpenteri	Cliona ensifera	Cliona mucronata	Thoosa armata	Halina plicata	Samus anoyma
1 (n=10)	Sandy flat	0.5-1.03	3.22	6.45	6.45	9.68	3.22	3.22	9.68	19.35	12.90	3.22	3.22	9.68	3.22	3.22	3.22
2 (n=25)	Lagoon	5.9-8.10	5.26	3.51	1.75	3.51	5.26	1.75	1.75	14.04	19.30	10.53	8.78	14.04	1.75	5.26	3.51
3 (4=24)	Lagoon shoal	2.3-3.1	5.26	1.85	12.96	16.67	11.11	3.70	1.85	5.56	1.85	7.41	9.26	3.70	1.85	7.41	9.26
4 (n=13)	Lagoon	4.55-6.25	6.98	6.98	11.63	9.31	6.38	2.33	4.65	14.28	2.33	6.98	2.33	13.95	2.33	4.65	2.33
5 (4=29)	Reef flat	0	5.08	1.69	10.17	3.39	1.69	1.69	10.17	13.56	15.27	3.39	5.08	11.86	8.47	1.69	6.78
6 (n=25)	Reef flat	0	2.5	5.0	2.5	7.5	7.5	2.5	5.0	15.0	17.5	12.5	5.0	7.5	2.5	5.0	2.5
7 (n=20)	Lagoon	8.1-9.3	5.71	11.43	2.86	5.71	14.29	5.71	2.86	5.71	11.43	5.71	8.57	2.86	2.86	11.43	2.86
8 (n=20)	Lagoon	11.2-13.4	4.65	6.98	9.31	2.33	6.98	6.98	6.98	9.31	6.98	2.33	4.65	9.31	11.63	9.31	2.33
9 (n=34)	Reef flat	0	4.55	4.55	3.03	6.06	4.55	4.55	6.06	13.64	9.09	7.58	10.61	7.58	10.61	6.06	1.52
Average		0	4.83	5.38	6.74	7.13	6.84	3.60	5.44	12.49	10.74	6.63	6.39	8.94	5.04	6.00	3.81

deeper regions of the lagoon (Zone 7 and 8) the species was encountered with less abundance (Table 39). C. vastifera was another common species and it was recorded in 12.90, 19.30, 15.27, 17.5 and 11.43% of the samples collected from Zones, 1, 2, 5, 6 and 7 (Table 39) while in the samples from the remaining zones, the percentage varied between 1.85 and 9.09. Cliona mucronata was observed in 9.68, 14.04, 13.95 and 11.86% of the coral heads examined from zones 1, 2, 4 and 5. On the lagoon reef flats, the clionid sponges were detected in 49.14 and 57.5% of the coral heads in zones 5 and 6 while Spirastrella accounted in 15.75 and 15.0% of samples respectively. In the deeper regions of the lagoon where the depth varied between 8.1 and 13.4 m, the clionid sponges were detected in 34.28 and 32.08% of the corals examined in Zones 7 and 8 respectively while Spirastrella was present in 22.86 and 18.62% of samples in the respective zones. In general clionid sponges were present in 45.32% and Spirastrella in 19.33% of the samples examined from the different reef habitats. The remaining groups were observed between 3.82 and 7.91% of the samples examined. C. celata was not only one of the most dominant species of boring sponge observed in the present study, but was also found to occupy larger area in some samples.

Crustaceans

The boring cirripeds of the Minicoy Island were represented by 2 species Lithotrya valentiana and L. dorsalis (Plate XI) belonging to one genus and an unidentified species. L. valentiana and L. dorsalis constituted 54.63 and 12.03% of the 108 specimens collected, while the unidentified species was represented by 36 specimens (Table 40).

The length of L. valentiana in the collection ranged from 41.8 to 76.4 mm and the weight betwen 1.220 and 5.962 g (Table 40). The length of L. dorsalis varied between 48.0 and 75.0 mm while the weight ranged from 2.131 to 4.020 g and for the unidentified Lithotrya sp. the ranges were 31.9 to 62.0 mm and 1.163 to 1.250 g respectively. The regression equation for the length (X) - weight (Y) relationship worked out was $\log_e Y$

$= \log_e 0.001472002 + 1.8344 \log_e X$ (r = 0.9840) for L. valentiana (n = 59), $\log_e Y = \log_e 0.005286656 + 1.5435 \log_e X$ (r = 0.9631) for dorsalis (n = 13) and $\log_e Y = \log_e 0.00002591969 + 2.5730 \log_e X$ (r = 0.9843) for the unidentified Lithotrya sp. (n = 36).

The borings of Lithotrya were quite long. The length of burrow ranged between 102.0 and 165.0 mm for L. valentiana and between 106.0 and 140.0 mm for L. dorsalis (Table 41). The burrows of the unidentified Lithotrya sp. ranged between 69.0 and 125.0 mm. The volume of the burrow ranged from 5649.7 to 15672.53 6011.92 to 13807.5 and 1144.53 to 3925.0 cub. mm for L. valentiana, L. dorsalis and Lithotrya sp. respectively (Table 41).

Based on the length (L) weight (W) and burrow dimensions of the animal (length BL and volume BV, an exponential relationship was established. The equation was BL = 11.0897 $L^{0.5919215}$, r = 0.9397 and BV = 149.304 $L^{1.0496}$, r = 0.7991 and BL = 91.9283 $W^{0.3111}$, r = 0.9203, BV = 6182.8091 $W^{0.5803}$, r = 0.8234 for L. valentiana based on 59 samples (Table 41). The exponential relationship for Lithotrya sp. was BL = 5.7396 $L^{0.7175}$, r = 0.8850 and BL = 108.3211 $W^{0.2680}$, r = 0.8725 while the relationship between length of the animal and burrow volume as well as weight of the animal and volume of burrow for this species did not hold true for the data. The maximum extent of bioerosion due to this species observed during the study was a removal of 8.66% volume of coral boulder.

The distribution of Lithotrya spp. in the study area was restricted to the reef flats only occuring more abundant in coral boulders and rocks on the seaward reef flats. The species was not detected in any sample from the lagoon all through the study. The species was found to bore into the large coral rocks and boulders on which there was a dense fouling of coralline and non coralline algae on the seaward reef flat.

The mean number of boring Lithotrya spp. in one kg of substrate on the seaward reef flat recorded was 3.34 and 4.14 for 1990 and 1991

Table 40. Length-weight relationship of the boring barnacle *Lithotrya* spp. found in the coral reefs of Minicoy Island

Name of species	No. of animals	Length (x) mm	Weight (y) g	$\log_e y = \log_e a + b \log_e x$	r
Lithotrya valentiana	59	41.8-76.4	1.220-5.962	$\log_e y = \log_e 0.001472002 + 1.8344 \log_e x$	0.9840
Lithotrya dorsalis	13	48.0-75.0	2.130-4.020	$\log_e y = \log_e 0.005286656 + 1.5435 \log_e x$	0.9631
Lithotrya sp.	36	31.9-62.0	0.163-1.250	$\log_e y = \log_e 0.00002591969 + 2.5730 \log_e x$	0.9843

Table 41. Exponential relationship ($Y \; aX^b$) established between size of the animal (length and weight) and burrow dimensions (length and volume) for three species of boring barnacle _Lithotrya_ spp found in the reefs of Minicoy Island. The parameters a and b were estimated by regression analysis after logarithmic transformation of the data.

Name of species	No. of animals	Length (L) mm	Weight (W) g	Burrow length(BL) mm	Burrow volume(BV cub.mm	Y	aX^b	r
Lithotrya valentiana	59	41.8-76.4	1.220-5.962	102.0-165.0	5649.7-15672-53	BL	$11.0987\ L^{0.5919}$	0.9397
						BV	$149.3044\ L^{1.0496}$	0.7991
						BL	$91.9283\ W^{0.3111}$	0.9203
						BV	$6182.8091\ W^{0.5803}$	0 8234
Lithotrya dorsalis	10	48.0-75.0	2.130-4.020	106.0-140.0	6011.92-13807.5	BL	$6.8403\ L^{0.7074}$	0.9660
						BV	$47.3174\ L^{1.3119}$	0.7182
						BL	$77.6154\ W^{0.4330}$	0.9476
						BV	$4489.174\ W^{0.7570}$	0.6641
Lithotrya sp.	32	31.9-62.0	0.163-1.250	69.0-125.0	1144.53-3925.0	BL	$5.7396\ L^{0.7175}$	0.8850
						BL	$108.3211\ W^{0.2680}$	0.8725
						BV	$2522.2257\ W^{0.3265}$	0.5822

Table 42. The mean number of individuals of the rock boring barnacle *Lithotrya* spp. in one kg fresh wet weight of rock substrate in the different reef habitats observed during the period from January 1990 to December 1991. The figures given in brackets indicate the standard deviation.

Reef Habitat	1990	1991
Seaward reef flat	3.34 (± 1.09)	4.14 (± 1.92)
Lagoon reef flat	4.07 (± 1.16)	5.48 (± 2.48)

Table 43. The mean biomass (g) of rock boring barnacle *Lithotrya* sp. in one kg fresh wet weight of the rock substrate in the different reef habitats observed during the period from January 1990 to December 1991. The figures given in brackets indicate the standard deviation

Reef Habitat	1990	1991
Seaward reef flat	8.58 (± 3.53)	12.17 (± 5.84)
Lagoon reef flat	2.39 (± 0.99)	3.09 (± 1.83)

Plate VII

A. When disturbed while extracting from the burrow the sipunculid Phascolosoma dentigerum was observed to extend introvent frequently to the exterior and then retract it.

B. Phascolosoma sp. tightly ensconsed within the walls of the burrow.

C. The burrows of sipunculids had only one opening and that the anterior end of the animal was directed towards the opening.

D. Reflecting the shape and presumably the activity of the animal, the burrows of Phascolosoma spp. were found to be narrow with a single opening to the surface.

PLATE VII

A B

C D

Plate VIII

A. The introvert of Phascolosoma nigrescens showing the reddish-brown bands.

B. Phascolosoma nigrescens a new record of sipunculid from Lakshadweep

C. Phascolosoma dentigerum

D. Specimens of Cleosiphon aspergillum had an ivory colour translucent skin with an unique white compound, acorn like cap at the anterior end of the trunk through which the introvent protruded.

PLATE VIII

A B

C D

Plate IX

A. The rock boring sea urchin Heterocentrotus mammillatus a new record from Minicoy Island, was observed in the lagoon shoal at the north-eastern part of the lagoon.

B. L. teres in the burrow.

C. Burrows of smaller lithophagids were the same length of the bivalve, but the larger ones exceeded the length of the shell.

D. The boring bivalve Gastrochaena sp. in the burrow.

PLATE IX

A

B

C

D

Plate X

A. Calcium carbonate accretion observed along an entangled plastic twin on live Acropora sp.

B. Dendrophyllia microcranthus a coral species.

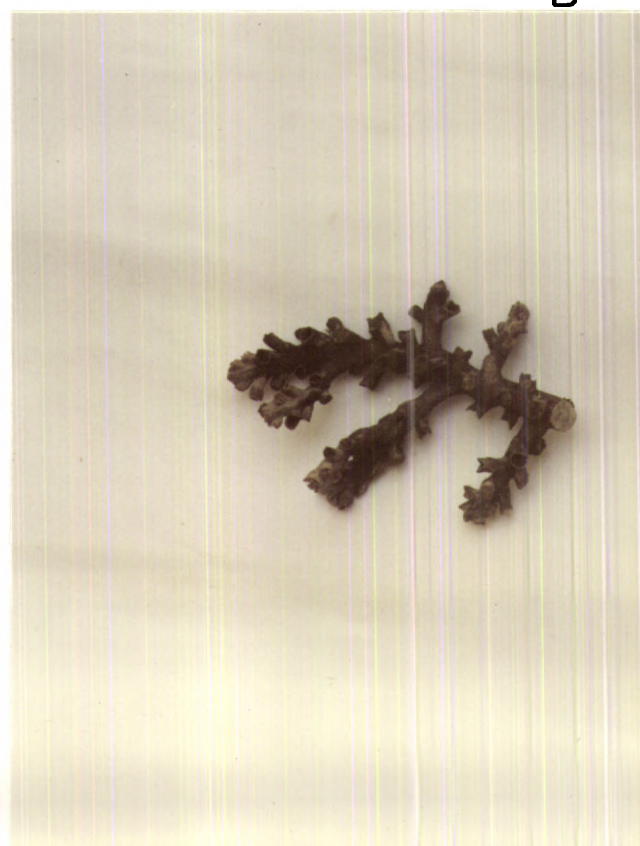
C. The borings of Lithophaga nigra, L. gracilis and L. teres were long, almost cylindrical and scarcely any space existed between the shell and the wall of the burrow.

D. A higher percentage of epifauna and algae favoured the increased settlement and penetration of polychaetes.

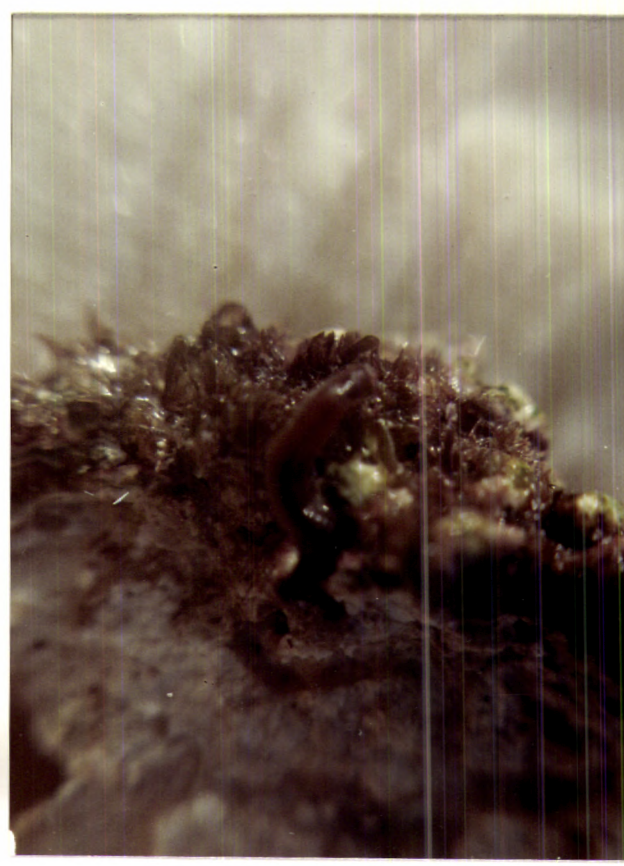
PLATE X

A

B



C



D

Plate XI

New Records of Corals from Minicoy Island (From A to D)

A. Porites rus collected from a depth of 2.1 M in the southwestern part of the lagoon.

B. Cyphastrea seralia, collected from the lagoon reef flat.

C. Favia laxa, collected from the seaward reef flat.

D. Cycloseris cyclolitis, a solitary coral species collected from the lagoon reef flat near Choru Magu Channel.

E. The boring cirriped Lithotrya dorsalis varied in length between 48.0 and 75.0 mm and was recorded from the coral boulders on the reef flats.

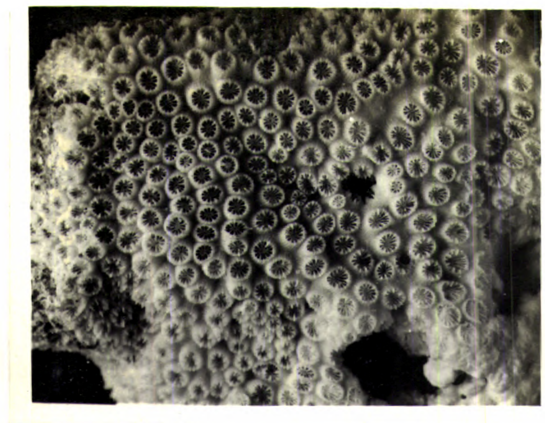
F. The length of the boring cirriped, Lithotrya valentiana collected during the study ranged from 41.8 to 76.4 mm and was recorded from the coral boulders on the reef flats.

G. The boring bivalve Lithophaga nigra was the most common lithophagid collected during the study.

H. Lithophaga teres, a new record of boring bivalve from Lakshadweep was observed in the lagoon shoal.

PLATE XI

A



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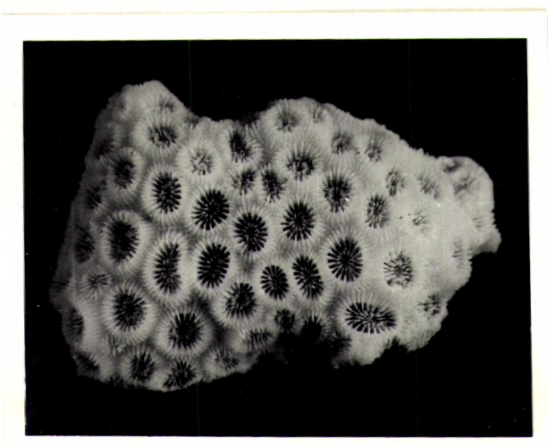
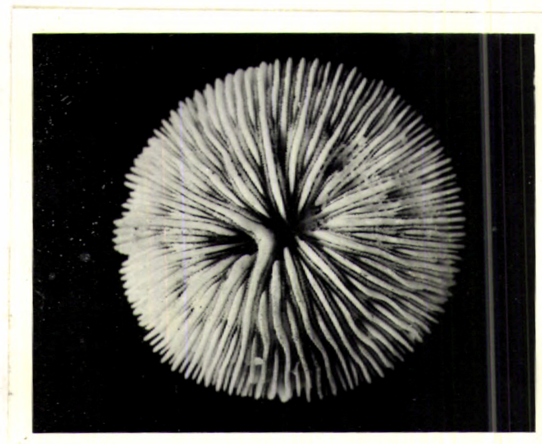


C



D

E

F

G

H

Plate XII

A. Lithophaga laevigata, a new record of boring bivalve from Lakshadweep was collected from the coral boulders on the lagoon reef flat.

B. The gastropod Magillus sp. belonging to fam. Coralliophilidae was observed inside the skeleton of brain corals.

C. Owenia fusiformis, a new record of polychaete from Lakshadweep was recorded from the crevice in the lagoon shoal at the northeastern side.

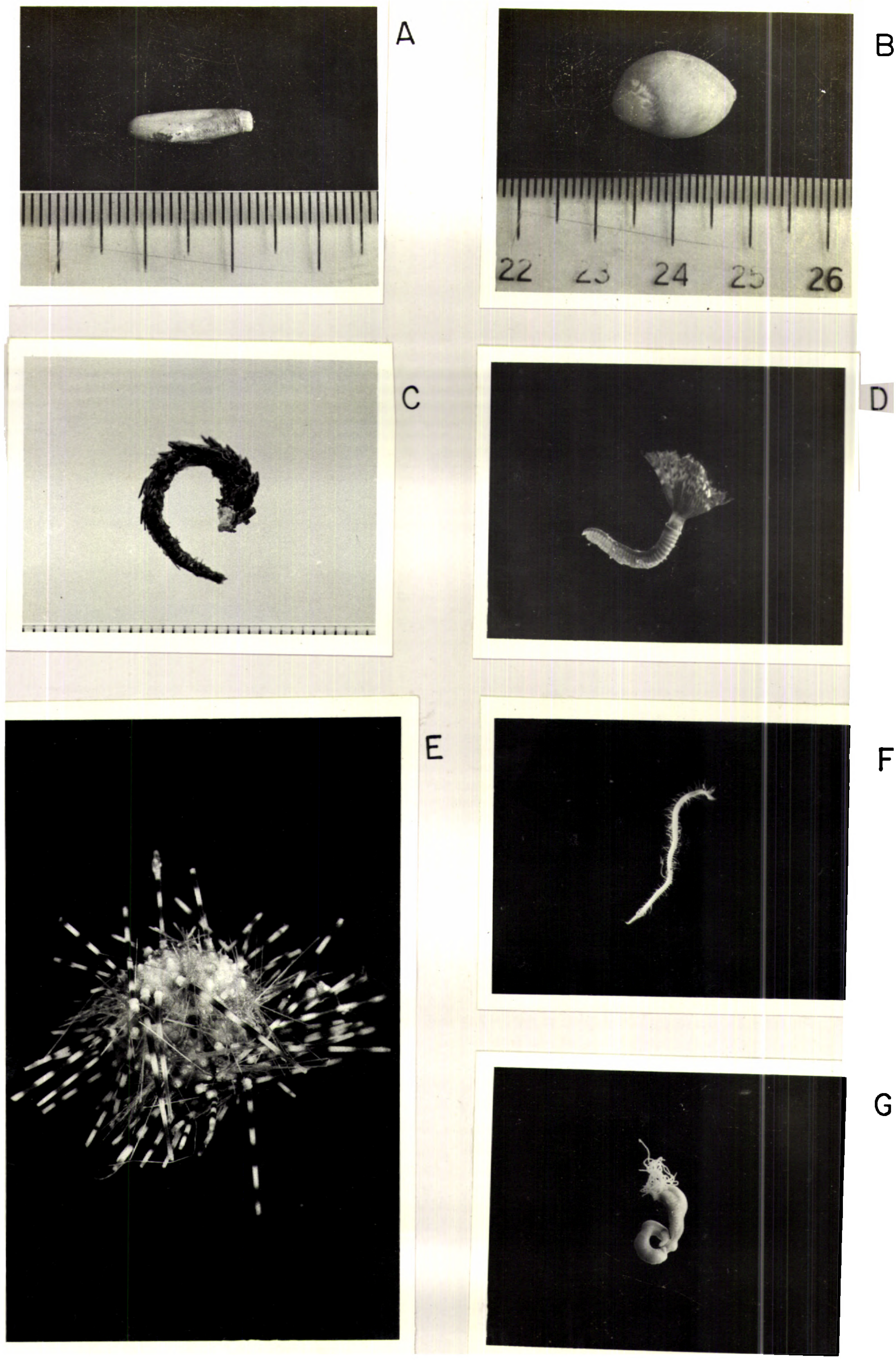
D. The sabellid worm Hypsicomus phaeotaenia, a new record from Lakshadweep, was observed in the lagoon shoal at the northeast side.

E. The diademid sea-urchin Diadema setosum, a new record from Minicoy Island was observed on the lagoon reef flat.

F. The polychaete Syllis (Syllis) gracilis, a new record from Lakshadweep was collected from the coral boulders on the seaward reef flat.

G. A terebellid worm Eupolymnia nebulosa collected from the lagoon shoal in the northeastern side of Minicoy Island.

PLATE XII



respectively while on the lagoon reef flat, the mean number was 4.07 and 5.48 during these years. The mean biomass of boring Lithotrya spp. was higher on the seaward reef flat recording 8.58 and 12.17 g of Lithotrya spp. per kg of reef substrate during 1990 and 1991 while it was 2.39 and 3.09 g respectively on the lagoon reef flat during these periods (Table 43).

DISCUSSION

Fishes

Quantitative studies carried out have elucidated the strong correlation between the coral feeding fishes and scleractinian coral communities. Bouchon et al. (1985) in their studies on the Tiahura reef, French Polynesia observed decrease in the chaetodontid population as a direct consequence of damage occurred in the coral communities of that area. Generally fishes are sensitive to habitat degradation and the substrate complexity is found to be important for determining species richness and diversity (Luckhurst and Luckhurst 1978; Gladfelter et al., 1980; Carpenter et al., 1982) Bell and Galzin (1984) have also discussed the influence of coral reef fishes communities on the live coral cover.

In the present study it was observed that the mean densities of the coral feeding fishes was found to be low in the areas where the live coral cover was poorly represented. The highest mean density coincided with the area of maximum live coral cover (Table 21). The coral feeding fishes recorded a poor abundance in the southwestern part of the lagoon where there was very little live coral cover (Table 21). Bouchon et al. (1985) observed that at the Moorea reefs, a rich coral community favoured a greater density of chaetodontid fishes and that the density of long branching coral colonies were more significant than total live coral cover. William (1982) also reported a similar observation in the Great Barrier Reef where a richer density of the chaetodontid fishes was observed in zones dominated by Acropora palifera and A. hyacinthus. In the Caribbean, Birkeland and

Neudecker (1981) studying the foraging behaviour of two chaetodontid species observed the abundance of Chaetodon cayistratus which fed mostly on Hexacorallians (73%). Their abundance was positively correlated with total coral cover and generic diversity of corals, whereas the abundance of C. aculeatus which does not use corals as food did not correlate with coral diversity and cover. In the Minicoy lagoon, besides inducing a destruction of fish habitat, coral mortality might have also reduced the food availability to the coral feeding fishes. The disappearance of once dominant long branching Acropora spp. colonies in the lagoon (Pillai, 1971) as observed in the present study might have resulted in the decline in density of coral feeding fishes (particularly chaetodontids) since the conditions were unfavourable for their settlement.

Large scale coral mortality observed during the survey in the present study (Fig. 4) might have adversely affected the abundance of the coral feeders in most areas of lagoon while the increased abundance in the deeper Zones (7 and 8) as observed during this study indicates a correlation between abundance and live coral cover. Although reef fishes are known to have extended reproductive cycles, the rate of juvenile recruitment on a reef is highly seasonal (Russell et al., 1977) and that it varied from year to year without reference to the changes in coral communities.

According to the survey carried out by Murthy et al. (1989) in the Minicoy lagoon, coral reef fishes belonging to Pomacentridae, Labridae and Acanthuridae were abundant both in the reef flat and lagoon in Zone 4, 5 and 6, less abundant in Zone 1 and 3 and rare in Zone 7 and also on the seaward reef flat between Teveratu Point and Mou Rhambu. However, in the present study, these fishes were found to be less in Zone 5 and the mean density was observed to vary between 7.46 and 20.3 in Zone 5, 6 and 7. According to Bell and Galzin (1984) the percentage live coral cover should be related to a variety of factors capable of determining the structure of coral reef fish communities and small changes in the extent of live coral cover produced significant changes in species richness and abundance of fishes. The authors also suggested that several species have specific live coral cover requirement and do not join the community until sufficient live coral cover is available. This type of relationship has been predicted by reef ecologist for the common group such as the chaetodontids (Hobson, 1974; Reese, 1977). In the absence of variation in the availability of shelter as observed during the present study, decrease in the abundance of coral polyp feeders can be attributed to the decrease in the availability of food in terms of live coral cover. However, it fails to explain the higher densities of chaetodontids in areas of low live coral cover along the inner reef flat in zones 5 and 6 as observed in the present study.

A more conservative interpretation of the increased abundance of the fishes in the Zone 7 and 8 could be its nearness to the lagoon channel which provides an easy way for the fish in the deeper reef slope to migrate (Kandi-ma channel and Weli-gandola channel) on the northern side of the reefs (Fig. 2). However, as the present study on the extent of live coral cover has revealed that distance does not influence the per cent live coral cover in the lagoon, the hypothesis that live coral and not the proximity to the lagoon pass is more significant to describe the pattern of the data obtained in this study stands good. Moreover the distance involved is small and is unlikely to be a deterrent to these mobile fishes like chaetodontidae, Labridae and Acanthuridae and as there is a continuous net work of shoals throughout the lagoon in Minicoy to provide shelter, adult fishes should also be able to disperse within the lagoon. One probable reason for the decreased occurrence of fishes in general (not only coral feeders) in the shallow habitats near the shore as observed during the present study can be attributed to the increased fishing activities in these areas and the subsequent displacement of the fishes to areas of less human interference. The occurrence of the fishes even in areas of less live coral cover, as observed in the north eastern part of the lagoon in Minicoy, supports this view.

There are numerous reports on the coral feeding nature of species recorded in this study and the effect on coral reefs. Cloud (1952) observed the stomachs of balistid, monocanthid and tetradontid fishes at Onotoa

Atoll to contain fresh tip ends of branching corals upto 5 mm. Randall (1955) reported from field observations in Onotoa that the gut of the tetraodontid Tetraodon nigropunctatus contained largely bite sized pieces of fresh coral while Randall (1974) observed at Enewetok Atoll that this species had fed heavily on corals (85 to 100 per cent of the gut contents) mostly Acropora and some Montipora. Emery (1956) also reported coralline algae and corals from the gut of Tetraodon hispidus, from Plinyra Line Islands. Hiatt and Strasburg (1960) observed coral polyps in the stomach contents of Rhinecanthus aculeatus, Acanthurus triostegus, Halichoeres hoeveni, Thalassoma quinquevittala and Cheilinis trilobatus, while Randall (1974) observed corals, mostly Acropora tips, in the gut of Tetraodon meleagris from Hawaii as well as Enewetok Atoll.

The less specific omnivorous species which take coral polyps as a part of their diet along with algae, always contain a considerable amount of calcareous skeletal particles admixed with the food, while those which are selective and consume only coral polyps do not have this admixture of calcareous skeletal materials (Hiatt and Strasburg, 1960). These observations suggest that the latter species have attained a higher degree of adaptation in nibbling off the polyps. The omnivorous species scrape the fine algal filaments off rock and dead bases and while so consuming coral polyps, they probably also scrape the surface rather than neatly biting off the polyps without touching the corallite. According Chaetodon citrinellus is found to have a strong predetection for browsing and grazing off polyps of corals as well as algal filaments while C. lunula is a strict browser on coral polyps and C. auriga an habitual non-selective omnivore (Hiatt and Strasburg, 1960).

In the present study it was noted that not only the number of species but also the density of the coral feeding fishes is low in the coral reefs of Minicoy Island. The maximum density of 30 per transect i.e. 1.5 per sq.m. is very low when compared to the reported abundance of 250 per sq.m. of chaetodontids in Moorea reefs French Polynesia as observed by

Bell and Galzin '1984). The low density in the fish communities in Minicoy reefs is probably due to factors that might have operated synergestically. The adult fishes might have migrated towards zones in the outer reef flat slopes where the corals would be more flourishing and where there is less fishing interferences also. A reduction in the recruitment rate can also be a factor for the decline in the reef fish communities. Further indepth studies on these factors would provide additional information to derive realistic conclusions on these aspects.

Reese (1977) has opined that since many of the chaetodontids have evolved with corals, the richness of this family would be a good indicator of the 'health' of coral reefs. Bell and Galzin (1984) have further speculated that variation in species richness with increasing live coral cover is not restricted to chaetodontids but several families which include Labridae and Tetraodontidae, thus showing that the trend and health of the reefs may be equally well described by the richness of the whole community. During the survey, in the present study, it was observed that some of the glomerate heads of Porites and Goniastrea in transects of Zone 4, 7 and 8 were marred by scrapping, probably as a result of grazing by fishes. However, such tooth marks were not common which indicate that the populations of coral feeding fishes were quite low in the reefs of Minicoy Island. While it seems that these fishes are not fully exploiting the coral resource in Minicoy lagoon as food, the preference for other kinds of food cannot be rule out. There may also be other reasons for the lack of abundance of these fishes in the lagoon than availability of food. However, it is unlikely that these coral feeders would face the danger of vulnerability to predators in the lagoon environment since these fishes are well endowed with defensive mechanism such as highly compressed body of chaetodontids, tough skin of balistids and their ability to hide themselves into small holes in the lagoon shoals.

The fact that corals in the Minicoy lagoon have been spared from excessive degradation by the coral feeders is very significant since once the coral dies out of predation or any other reason boring organisms waste no time in penetrating the structure. The grazing on algae from the dead substrate or feeding directly on coralline algae have not only a reducing effect on the reef structure but also contribute enormous sediments through defecation by these fishes. This coarser sediment materials are produced by labriids and balistids which feed on molluscs, echinoids, ophiuroides, crustaceans and sponges.

The influence of live coral on the reef fish communities has significance for the management of these communities. Large scale mortality of corals in the coral reefs Minicoy caused a significant reduction in the abundance of coral fishes particularly the coral feeders. The abundance would further decline in the future also as the structure of the coral reefs in Minicoy would get further eroded in the course of time against their very slow process of growth.

The present study concludes that in the lagoon of Minicoy, lower density of the coral feeding fishes was observed in areas of poor live coral cover while in the deeper areas where there was a good live coral cover, higher density was recorded. The progressive coral mortality and subsequent disappearance of the once dominant branching Acropora spp. in the lagoon could have led to the decline of chaetodontids, while in general, the migration of adult fishes to deeper areas in the outer reef slopes, where there is less fishing intereferences and better live coral cover could be attributed for the less abundance of the fishes in the lagoon. The study also suggests that corals in the lagoon have been spared from excessive degradation by the coral feeding fishes and that it is unlikely that these fishes are significant contributors to the sediments in the lagoon.

Echinoderms

Echinoids were observed to act as agents of disturbance and predation on coral reefs causing competition for space between corals and associated epibiota at all stages of development (Glynn, 1988). The grazing by echinoids affects numerous community characteristics of the reef in a species-specific manner.

In the present study, the population of E. mathei was higher in the lagoon shoal than in the inner reef flat of Zone 6 while the distribution of Echinothrix diadema was only restricted to the reef flats. One probable reason for the difference can be the availability of required substrate for the animals to inhabit. E. mathei is found to have a preference for pre-formed burrows (Russo, 1980). The preforated and badly eroded lagoon shoal at the northeastern end of the lagoon (Plate II) provides a suitable substratum for the species. In the shoal, the animals were observed to occupy the crevices which were already existing. Besides the shoal situated about 1.2 km away from the open sea and reef entrance (Fig. 2), the less violent waves would probably allow the larvae of E. mathei to settle more easily on the protected lagoon shoal than on the more violent inner reef flat in Zone 6. Moreover the sub littoral nature of the lagoon shoal which reduces dangers of exposure to sun and air, supports the increased population of E. mathei in the lagoon shoal than in the shallow inner reef flat. Thus reduced effect of wave action, availability of suitable substrate and less exposure in the lagoon shoal relative to the region of Zone 6 probably account for the difference in population density of E. mathei between the lagoon shoal and the inner reef flat. Higher population density of E. mathei in the shoal which is further away from the open sea than in the inner reef flat as observed in the present study also supports the hypothesis that this species tends to settle in relatively calm and sheltered intertidal waters rather than in turbulent waters. Since the physico-chemical parameters like water temperature, salinity and dissolved oxygen did not exhibit, any significant variations in the lagoon (Table 13) it is unlikely that the small range in temperature, salinity and dissolved oxygen variations observed in the present study has any effect on the distribution and behaviour of E. mathei. Other factors, such as food supply and breeding pattern may also modify the distribution of the species but the present study suggests that wave-action may be one of the major factors responsible for the observed differences in habitat selection.

Similarly the distribution of Echinothrix diadema restricted to the reef flats is also interesting. On the lagoon reef flat, there are numerous irregular surface structures which are characterised by distinctive framework and depressions (Plate VI). These dead reef surfaces provide suitable habitats for E. diadema as it also protects the animals from the severe wave action experienced on the reef flat. It is likely that the exposure conditions on both the reef flats favoured a strong settlement of this species followed by high recruitment and survival. The dead coral substratum which dominated the reefs also allowed an increase in benthic algae, the principal food of the echinoid species. The dwindling biomass of the fish predators of sea urchins (belonging to the group Balistidae, Diodontidae, Labridae and Tetraodontidae) as observed in the present study (Table 21) due to the destruction of coral heads as well as increased fishing activities in the lagoon can also be a factor for the increased abundance of E. diadema on the lagoon reef flat. On the seaward reefs, Murthy et al. (1989) have reported a higher biomass of the echinoid feeding fishes. The low density of E. diadema on this reef can be attributed to the higher biomass of echinoid feeding fishes as reported by Murthy et al. (1989). Sammarco (1982) also made a similar observation from the caribbean reefs and suggested that the removal of potentially important fish predators of diademid urchin Diadema antillarum, by man has resulted in an increased population density of the urchin. However, the absence of the fish predators on the lagoon reef flat does not account for the restricted distribution of this species even on the reef flat. Moreover, the absence of these predators also fails to account for the low density of Echinothrix diadema as observed in the present study. The maximum count obtained was 18 individuals per sq.m. against 71 numbers per sq.m. in the caribbean reefs as reported by Sammarco (1982). The high abundance of caribbean diademid urchins has been attributed to overfishing of the fish predators (Woodley, 1979; Hay, 1984). The density of Echinothrix diadema recorded in the present study is very low when compared to 50-150 individuals per sq.m. of Diadema mexicanum observed on the Panama reefs (Glynn (1988) and 71 individuals per sq.m. is the Caribbean reefs (Sammarco, 1982). Diadema antillarum occurred at density of upto 23 per sq.m. on Barbados fringing reefs (Hunter, 1977; Stearn and Scoffin, 1977). According to Sammarco (1980, 1982) Diadema sp. in densities greater than 16 individuals per sq.m. appeared to be an efficient grazer, being capable of clearing algae from the reef and in the absence of echonoids, coral cover was clearly depressed and many corals characteristic of shallow water were unable to survive extensive overgrowth by algae in Discovery Bay, Jamaica. In the present study since the study was confined to the reef flats only the relationship existing between grazing activities and coral recruitment was not observed. Probably further studies carried out in the deeper sites of outer reef flat would generate more information on the subject.

During the study smaller individuals of E. mathei were observed on the sheltered lagoon shoal while larger individuals were recorded in the inner reef flat. Russo (1980) also reported a similar observation at Diana beach Kenya. This is contrary to the observation made by Ebert (1968) who found smaller individuals of E. mathei on the exposed areas and larger individuals in sheltered areas. Ebert attributed the small size of animals in the region of violent wave action to the breakage of more spines by turbulent waves and hence more energy expended for repairs while for the animals in protected areas, the larger size was due to the utilization of this energy for the growth of the test. However, results of the present study indicate that the factor is more complex than the simple reason attributed by Ebert (1968) and that further observation seems necessary. It may be unlikely that the lower mean size of animals in the areas of higher density in the lagoon shoal, reflects the result of competition for space and food. Russo (1977) reported that competition over long periods of time for larval settling sites in high density areas may lead to a restricted number of burrows being formed by Echinometra in Hawaii. In the present study the density of E. mathei recorded in the lagoon shoal is far less than the very high 100-150 individuals of the species per sq.m. as observed by Russo (1977) in Hawaii or 50 individuals per sq.m. as reported by Sammarco (1982) for Echinometra, and hence it is unlikely that there is competition for space and food. Khamala (1971) observed at Diani Beach, Kenya that the moving specimens of E. mathei in search of a sheltered crevice picked up shells and other debris which they deposited on their tests. In the present study it was observed that the animals in crevices not directly exposed to sunlight did not cover themselves with debris (Plate VI), thus confirming observations made by Mortensen (1943) and Moore (1966) that this is a protective measure against strong light among urchins.

In the Caribbean reefs, Diadema antillarum population present at high densities were observed to feed upon live corals (Bak and Van Eys, 1975; Carpenter, 1981). In this study, the switching of feeding habits to live corals where algae may have been limiting was never observed for Echinothrix diadema.

Endean (1971, 1976) noted that the sea star Culcita novaeguineae commonly preyed on reef-building corals. C. novaeguineae was often more abundant on coral reefs than A. planci in Saipan-Mariana Islands (Goreau et al., 1976), Guan Mariana Islands (Yamaguchi, 1975) and Oahu, Hawaiian Islands (Glynn and Krupp, 1986). Preliminary information indicated that like A. planci, Culcita spp. preys selectively on certain species of coral and thus may be important in affecting the size, structure and relative abundance of corals in coral reef communities (Goreau et al., 1972b; Thomassin, 1976). Field studies in the western Pacific (Goreau et al., 1972; Endean, 1976) have indicated that corals such as Pocillopora, Acropora and Porites are the usual preys of Culcita novaeguineae, while in Pacific habitats (Guam shallow reef flats), it preys heavily on plate like and encrusting pavonid species (Wilkins, 1979). Goreau et al. (1972) concluded that C. novaeguineae specialized on small corals, regardless of colony form because the sea star lacks prehensile arms and cannot climb large or high corals. However, in the present study the species was found to be very rare in the reef habitats of Minicoy. Only a few numbers were recorded during the survey and mostly on the reef flats where there was no live coral cover. According to Potts (1982) Culcita novaeguineae does feed occasionally on nonpreferred corals and other kinds of organisms. This could be due to the adaptability of the sea star's feeding behaviour vis-a-vis local prey availability (Ormond et al., 1976). Though Culcita novaeguineae is reported to eat 1.0 sq.m. of Pocillopora damicornis or

0.9 sq.m. of mixed coral prey per year (Glynn and Krupp, 1986), in view of their rare occurrence, it is unlikely that this species would cause; serious destruction of coral reef or have an effect on coral community structure or limit the abundance of corals in Minicoy reefs.

The nondetection of the Crown-of-Thorns Acanthaster planci during the study was quite unexpected. Though Sivadas (1977) has reported the presence of this species in the coral reefs of Lakshadweep and in Minicoy in particular (Murthy et al., 1979), the occurrence of the species was not found all through the survey. Suresh (unpublished could only detect one specimen of the species in Kalpeni lagoon during a survey of 9 islands (excluding Minicoy) of Lakshadweep. James (1989) during a study had recorded one specimen from Kadmat and Kalpeni; two specimens from Kavarathi and Agathi and 3 specimens from Minicoy. The results of the present study reveal that the much dreaded Crown-of-Thorns star fish does not pose any threat to the Lakshadweep corals at present. In the past, the population outbreaks of the coral eating A. planci, which has occurred on coral reefs in many parts of the Indo-West Pacific region could have been due to over-collecting of their natural predators by man (Endean, 1974). Acanthaster planci in the eastern Pacific appeared to be limited due to predation (Glynn, 1982). The harlequin shrimp Hymenocera picta and the polychaete Pherecardia striata (both not observed in Minicoy) are reported to be the principal predators of A. planci in the Eastern Pacific (Endean and Cameron, 1990) and in the Great Barrier Reef the giant triton Charonia tritonis appears to be the principal predator of adult and larger juvenile A. planci. Predation is also reported to prevent recruitment to breeding population (Endean, 1976; 1982). On reefs of the Indo-west Pacific marked damage to the hard coral cover was not apparent. A. planci was either not observed or found at very low population density Indo-Pacific (Chesher, 1969; Vine 1970; Weber and Woodhead, 1970); Great Barrier Reef (Pearson and Endean, 1969); Red Sea (Campbell and Ormond, 1970). Endean (1974) in a survey on the Great Barrier Reef observed only 6 specimens per sq.km. Recently, Endean and Cameron (1990) suggested that in the species-rich reefs of the Indian and West Pacific Oceans, A. planci usually occurred at low density of 0.06 numbers per hectare and caused negligible damage to the coral cover. The population density of A. planci observed in the present study seems to be the lowest when compared with the earlier estimates to Sivadas (1977) and Murthy et al. (1979) in the Lakshadweep and very low in comparison with normal incidence of this species on the reefs in the central Pacific area (Chesher, 1969) and for reefs in the Red Sea (Campbell and Ormond, 1970). However, due to lack of quantitative data in the past it is not possible to understand the normal range of variation. It is possible that in the future the numbers of A. planci may occasionally exceed the normal levels as a result of an out-break as observed in the past.

Russo (1980) who did bioerosional studies on the Hawaiian reefs, estimated that the daily erosion rate for E. mathei ranged between 0.1 and 0.2 g per day per urchin on the reef flats. In calculating daily erosion rates it was assumed that all carbonate scraped was freshly eroded and that 20% of the ingested carbonate rock was in situ sediment. In the Persian Gulf, Shinn (as quoted in Hughes and Keij, 1973) estimated the daily erosion rate to be 0.5 g per day per urchin. Ogden (1977) recorded an annual erosion rate for Echinometra lucunter with densities upto 100 per sq.m. as 3.9 kg per sq.m. per year (equivalent to 0.107 g per day per urchin). In the present study the estimated amount of calcium carbonate in the gut of E. mathei of size range between 2.39 and 4.15 cm test diameter was between 0.072 and 0.120 g. In bioerosional studies it is important to report both density and mean size of the bioeroding organisms since total calcium carbonate removed is dependent on both density and size. Differences in erosion rates reported for E. mathei by various authors may be due to the difference in the size of the animal observed since daily erosion rates increase geometrically with test diameter (Russo, 1980). There may also be substantial error in extrapolating the daily erosional rates of E. mathei to an annual rate since E. mathei is sedentary in certain environments (Ogden, 1977; Russo, 1977) and mobile in others (Grunbaum et. al., 1978). E. mathei is reported to remain sedentary as long as its food supply is sufficient (Kelso, 1970; Russo, 1977). Yet if erosion rates obtained in the present study are applied for the populations of E. mathei in Minicoy reefs, a quantity between 170.82 and 284.7 g/m^2 of substrate would be eroded per year from the lagoon (mean density 6.5 numbers/ sq.m.) while on the inner reef flat the rate would range from 26.28 to 43.8 g/m^2/yr. The values reported in the present study conforms well with the results obtained from the Hawaiin reefs where Russo (1980) estimated the annual erosion rate per individual of E. mathei to be between 80 and 325 g per m^2/year. Russo reported that in Hawaiian Islands on the northern periphery of the coral belt, Echinometra sp. can be a significant bioeroder since the population densities of E. mathei could reach values as high as 100-150 individuals per m^2. Hence the erosion of calcium carbonate may exceed its production.

In the present study the amount of calcium carbonate eroded by the diademid urchin Echinothrix diadema varied between 0.125 and 0.625 g/day per sea urchin for different size groups. If these rates are used to extrapolate the amount of sediments produced for the population of Echinothrix diadema (mean density 5.2/m^2) along the reef flats in Minicoy. a gross estimate between 237.25 and 1186.25 g/m^2 sediments would be produced per year on the reef flat. The bioerosion rates of Diadema mexicanum that grazed on dead coral substrate at the Uva reef was found to be between 0.110 and 0.240 g per day per urchin (Glynn, 1988) while in the Caribbean reefs, the bioerosion rates for Diadema antillarum ranged from 0.510 to 2.950 g per day per urchin (Ogden, 1977; Scoffin et al., 1980; Bak et al., 1984). However, the rate of erosion estimated in the present study is very low when compared with 4000 g per m^2 per year reported for Diademid urchins on the Enewetak Atoll (Smith, 1973) and 9000 per m^2 per year on the Caribbean reefs (Stearn and Scoffin, 1977). The very high rates of erosion by echinoid observed at Enewetak Atoll and Caribbean reefs have been attributed to the high densities of the diademid urchin Diadema antillarum on these coral reefs, 50-100 individuals per m^2 and echinoids are considered the major eroders in these regions (Sammarco, 1982; Glynn, 1988).

The ecology of echinoids on the coral reefs of Minicoy thus affects the reef geology in two ways. Firstly, the grazing echinoids (Echinothrix spp. Echinometra spp. mainly) while feeding on calcareous and non-calcareous algae would inhibit the build up of extensive algal mats, especially on the reef flats and lagoon shoal. Since, algae cementation is one of the most important lithification process in shallow water limestone (Chilingar et al., 1967) in the presence of increased echinoid grazing, reef growth through algae cementation may decrease substantially. Secondly, in the process of feeding and boring into coralline substrates by echinoid like Echinometra mathei, the substrate is broken down. This sediment is added to the pool of unconsolidated sediment, some of which eventually undergo submarine lithification and diagenesis as reported by Seibold et al. (1973).

The present study highlighted the role of echinoids as bioeroders of coral reefs of Minicoy. During the study Echinothrix diadema and Echinometra mathei were the most abundant echonoids along the reef flat and in the lagoon shoal respectively. The higher densities of E. mathei recorded in the lagoon shoal was explained on the basis of substrate preference and the tendency of the species to settle on calmer regions and sheltered intertidal waters while the role of ecological factors on the distribution of E. mathei was thought minimum. The increased abundance of Echinothrix diadema on the reef flats was attributed to strong settlement and high recruitment of the species and increased food supply (Benthic algae). The role of echinoid preying fishes was also partially attributed. The coral polyp feeding echinoids, Culcita novaeguieae and Acanthaster planci were not considered as a serious threat in limiting the abundance of corals in Minicoy, in view of their limited (complete absence for the former) occurrence. The annual erosion rates estimated for E. mathei and Echinothrix diadema were comparatively lower for the same species reported elsewhere.

Molluscs

Corals afford a substrate for several boring bivalves and provide food and shelter. As early as 1903 Gardiner pointed out the destructive role played by the boring organisms in the disintegration of coral reefs. However, the majority of studies on boring bivalves have been qualitative (Otter, 1937; Yonge, 1963; Kleeman, 1980).

In the present study it was observed that in the coral reefs of Minicoy Lithophaga spp. were the commonest of boring bivalves. While the lagoon shoal in the northeastern part of the atoll having a higher skeletal damage and a dense growth of coralline and non-coralline algae (Plate III) had a higher abundance of these bivalves (Table 29), on the reefs their occurrence was limited.

There are few accounts of boring bivalves settling on and burrowing into live corals. In Ghardaqa Red Sea Gohar and Soliman (1963) observed Lithophaga hanleyana inside the coral species of Cyphastrea microphthalma, C. chalcidicum, Montipora lanuginosa, Goniastrea spp. and Stylophora spp. In Enewetak Atoll Highsmith (1980b) recorded Lithophaga curta in Montipora berryi. There are also reports on the occurrence of boring bivalves from the dead reef substrates such as Lithophaga lesseplana (Gohar and Soliman, 1963; Fishelson, 1973) L. hanleyana (Otter, 1937; Gohar and Soliman, 1963) and L. calcifer (Iredale, 1939). In the present study, except on one occasion where L. gracilis was recorded from the stalk of Lobophyllia corymbosa the boring bivalves were recorded from dead coralline substrates only. Otter (1937) was of the opinion that Lithophaga hanleyana settled on dead spots of Porites spp. and become incorporated into the live surface by coral growth. Highsmith (1980b) observed that 70% of boring bivalves in the massive coral heads in Caribbean Reefs occurred in dead surface areas of coral head. These bivalves initially penetrated a dead surface and were subsequently surrounded by coral growth. Soliman (1969) suggested that association between Lithophaga spp. and living corals originates by settlement of a young Lithophaga on the living coral surface and then the calcium carbonate will be gradually deposited around the bivalves which will then burrow outward, to maintain contact with the exterior. Soliman was of the opinion that boring is sporadic and its extent depends on the degree to which the host deposits the skeleton around the siphons. Several possible advantages of the bivalve in settling on and boring into the dead substrate can be postulated. Juvenile survivorship could be enhanced by settling on dead coral substrate thus avoiding incidental predation by grazing predators which are abundant in live coral cover. Lithophagids are consumed vigorously by several fishes (Balistidae, Tetraodontidae, Labridae) which break corals in search of infaunal organisms (Al-Hussaini 1947; Randall, 1967; 1974; Randall et al., 1978; Glynn et al., 1972). The increased occurrence of boring bivalves in the lagoon shoal can also be due to large number of free-swimming adults resulting from substrate specificity which may enhance reproduction success. However, it is quite interesting to note that since these dead substrates in the lagoon shoal have dense colonies of coralline and non-coralline algae (Plate Ill) overgrowing them, there is a probability of the siphonal openings being covered over by these algae.

In the present study it was significant to observe that while there was a high density of boring bivalves in the lagoon shoal, the population was poorly represented on both the reef flats. At Enewetak Atoll, a similar observation was made by Highsmith (1979) where inspite of the availability of ample substrate, only 3 of the 102 massive coral heads examined contained a single boring bivalve in the dead surface of the skeleton. Highsmith suggested that presumably larvae of the boring bivalves are induced to settle and metamorphose by some stimulus (probably chemical) from the preferred substrate since these bivalves were normally found in some particular substrates while were only occasionally observed in other calcareous rocks. If the larvae do not receive the appropriate stimulus, metamorphosis is likely to be delayed and selectivity may decline. Highsmith (1979) observed that boring bivalves were abundant where the overall bioerosional damage to corals was more and considered that the abundance of boring bivalves could be an index in the estimation of relative bioerosional damage caused to corals of different geographic locations. Though the weak coral skeleton of the lagoon shoal (Plate III) can be one factor for the increased abundance of the bivalves, this factor fails to explain the relative absence of boring bivalves on weak skeletons of coralline substrates on the reef flats. Connell

(1973) reported that fast growing coral species constructed skeletons of low density that are easily bored by bivalves, i.e. the rate of attack is an inverse function of the density of the skeleton. It has also been proposed that a very dense outer skeletal layer along the sides of corals, (Eg. Pavona spp. and Psammacora spp.) enhances resistance to boring organisms (Buddemeier and Kinzie, 1976). However, Highsmith (1981a) observed at Enewetak Atoll that bioerosional damage to reef corals is positively correlated with skeletal density. Highsmith was of the opinion that denser species of corals are generally less adopted at recolonizing dead areas on their skeletons by tissue growth and such recolonization requires considerable skeletal deposition and reorientation of existing polyps growth direction as in Goniastrea retiformis. Thus a larger proportion of the skeleton of dense corals is exposed to attack by borers since the planktonic larvae settle on dead surface. During early seventies, Pillai (1971) and Nair and Pillai (1972) have observed huge colonies of Goniastrea retiformis, Diploastrea, Lobophyllia in the lagoon shoal in the northeastern side of the lagoon. However, in the present study, the abundance of Lithophaga spp. in the lagoon shoal suggest that bivalve larvae are able to settle unharmed on this substrate in the lagoon. The relatively open and irregular surfaces between the edges in the lagoon shoal with a higher degree of bioerosional damage probably provide safe settlement sites for the larvae. The lagoon shoal is situated near to the main entrance (Tori Gandu Channel) through which water is brought in during high tide. It is also likely that a long search for a suitable substrate may result in a greater loss of energy. (Roughgarden, 1975) which would otherwise be used for burrowing and growth. The fact that greater density of the bivalves were recorded from the other end of the lagoon shoal facing the lagoon (towards North) than on the side facing the shore, also supports the above theory of early settlement of the larvae. Moreover larger periods of exposure of the larvae would also increase the susceptibility to predation by the coral reef fishes.

In the present study there was a general absence of boring forms in the beach rock on the seaward and lagoon reef flat. There are similar observation of paucity of beachrock fauna in the Lakshadweep (Gardiner,

1903) and in the Great Barrier Reef (Stephenson and Searle, 1960; Mclean, 1974). At Enewetak Atoll Highsmith (1980b) observed a reciprocal dependence of the larvae of coral Montipora berryi to settle on bivalve burrows of Lithophaga curta. However, no such relationship was observed in the present study. Mac Geachy and Stearn (1976) recorded a greater percentage of bioerosion on deeper bank corals than on a shallow fringing reef at Florida while in contrast Reed and Mikkelsen (1987) observed greater population density of boring molluscs at 6 m station than at 42 or 80 m station on the reefs off eastern Florida. However, the present study was limited to the lagoon and reef flats and that the deeper habitats at 40 and 80 m depths were not covered under this study. Hence the results obtained in the present study does not provide any information to the relationship between depth and bioerosion by bivalves as observed by Mac Geachy and Stearn (1976) Reed and Mikkelsen (1987).

In the present study the overall mean number of bivalves per kg of coral head was 4.14 and 4.9 during 1990 and 1991, while the overall mean volume of calcium carbonate eroded per kg of coral head was 38.5 and 38.9 cub. cm for these years. It is evident that though the presence of boring bivalve probably has little effect on survival of the coral, as majority of then settle on dead coral surface the amount of calcium carbonate eroded in these cases is highly significant. The greatest extent of bivalve bioerosion recorded in the study was a loss of 125.0 cub. cm of substrate which was worked out to be 10% volume of the coral head. Otter (1937) reported the rate of Lithophaga boring as 1.5 cm in per year while Trudgill (1976) observed the rate to be 0.91 cm per year. McMichael (1974) estimated the population of Tridacna spp. to 2.0 million at One Tree Island, Queensland. Warm (1975) reported a density of 50-500 per sq.m. for pholad bivalves in the Pacific coast. Hein and Risk (1975) reported that in Florida, the boring bivalves had a density of 3.1 per coral head which accounted for 15% of the eroded volume in live corals. Bak (1976) reported that in corals at Curacao in the western Atlantic, boring bivalves accounted for only 1-2% of the eroded volume. Though the density of boring bivalves recorded in the present study is relatively low when compared to Mc Michael (1974) and Warme (1975) the extent of bioerosion caused by these bivalves in the lagoon shoal in Minicoy is quite significant and is higher than values of Bak (1978) and comparable to those reported by Hein and Risk (1975) on the Florida Reefs. The very low density of Gastrochaena, Petricola and Botula as observed in the present study suggest that destruction caused by these groups is not significant, not only because of their low population but also small size of the shell and low amount of calcium carbonate excavated. However, the results obtained in the present study have to be interpreted very cautiously since the distribution of boring bivalves was restricted to certain areas in the lagoon only. No attempt has been made in the study to estimate the total loss of calcium carbonate in the reefs of Minicoy as a result of bivalve bioerosion since the rate of loss of calcium carbonate varied between sites in the lagoon and hence application of data obtained from a particular area cannot be justified for the entire area of the reef.

The present study suggests that though the density of boring bivalve was low, they are significant agents as bioeroders in the coral reefs of Minicoy Island, since these animals eroded relatively large amount of calcium carbonate materials. While there was a high density of these boring bivalves in the lagoon shoals, the population was very poor on the reefs.

Polychaetes

In the present study it was observed that although polychaetes are the most abundant group of invertebrates in virtually all the habitats sampled at Minicoy, their number and biomass varied between habitats and also within habitats. In general a higher number of individuals was observed in the lagoon where there was a number of solid lagoon shoals having a low percentage of live coral cover. The seaward reef habitats which had a small surface area and little epifauna recorded very low numbers of polychaetes. Not all habitats with a large surface area had large numbers of polychaetes. The dead branching Acropora coral habitats did not contain a high number of individuals (values varied between 1.0 to 4.9 per unit weight of sample. A similar observation was also made by Hutchings (1974) while studying the density and distribution of polychaetes in the Great Barrier Reefs and suggested that the volume of the branches was insufficient to support a large population of polychaetes. It can be seen that if a habitat has a large surface area and a high percentage of epifauna or algae, and is relatively porous then a larger biomass of polychaetes can be expected as observed in the present study. Such conditions were available in the lagoon shoal at the northeastern end of the lagoon (Plate III). Hutchings (1974) suggested that a large surface area and high percentage of epifauna and algae are very important in providing protection for the pelagic larvae of polychaetes at the time of their settlement and initial penetration into the substrate since at this stage, the larvae are very susceptible to predation and to being dislodged by currents. In the Minicoy lagoon, having a semi-diurnal tidal influx, there is a very rapid inflow of water into the lagoon during high tide, temporarily creating strong currents (velocities range between 0.300 to 0.600 knots/hr).

It is apparent from the Table 32 that habitats with high number of polychaetes did not necessarily have a high biomass. In some sampling sites the relationship was inversely related. In the lagoon shoal the polychaetes were the dominant invertebrate group not only in terms of number of individuals but also in terms of species present. The polychaetes were represented by 13 families of which eunicidae was by far the most common group. Hutchings (1974) reported dominance of polychaetes among invertebrate group in terms of biomass, number of individuals and also of species recorded at the One Tree, Great Barrier Reef. In his studies the polychaetes were represented by 16 families, of which eunicids, cirratulids, syllids, terebellids and sabellids were the dominant forms. Mc Closkey (1970) working in North Carolina on a non-reef building coral Oculina arbuscula found between 30-57 species of polychaetes living in the coral depending upon whether the coral was living in shallow or deep water. Grassle (1973) working at Heron Island found that syllids were best represented followed by capittelids, terebellids, nereids, lumbrinerids and phyllodocids. The other comparable work is that done by Fauvel (1953) in the Indian Ocean where the bulk of the errant species were constituted by eunicids, nereids and aphroditids, (the latter two groups poorly represented at Minicoy) while cirratulids were only common where the surface of the rock was covered with Porolithon sp. (coralline algae) or had a dense surface cover. Bailey-Brock (1985) reported 7 families and 23 species in his collection of Polychaetes from Fijian Coral Reefs. The number of families observed from the coral reef habitats of Minicoy is similar to that recorded by Hutchings (1974) as One Tree but in terms of the number of species it is relatively less when compared to 100 species reported by Hutchings (1974) at One Tree and 30-57 species in North Carolina by Mc Closkey (1970). Probably further investigations in the deeper waters of Minicoy and other islands of Lakshadweep would certainly add to the present faunal list of polychaetes. These figures give additional support for the generalisation that tropical waters support large number of species. Polychaetes particularly eunicids, and cirratulids are known to activity bore into the corals (Hutchings et al., 1992). Eunicids have strong jaws which may be able to grind the coral, but cirratulids have no jaws and their mechanism of penetration is obscure. Theories involving both chemical dissolution and mechanical abrasion have been advanced to account for the method by which polychaetes penetrated calcareous substrates. Though chemical penetration was thought to be achieved by means of an acid secretion which would dissolve calcium carbonate, no acid has yet been identified in polychaetes (Hutchings and Bamber, 1985). Soderstrom as given in Dorsett (1961) at first considered that boring was effected by an acid secretion of the segmental mucus gland combined with the mechanical action of the chaetae of fifth segment. Those postulating a mechanical method of burrowing have called attention to the uncinate chaetaeof the fifth segment which are thicker and larger than those of the other segments (Dorsett, 1961). However, Ebling (1945) suggested that the tanned protein which forms the chaetae of polychaetes is too soft a material to be alone responsible for the excavation of the burrows in calcareous substrates. In the present study several boring species belonging to the families Sabellidae, Cirratulidae and Eunicidae were observed from different habitats. These groups have been widely reported in the literature as borers (Gardiner, 1903; Hartman, 1954; Hutchings, 1983b; 1986; Hutchings and Bamber, 1985; Hutchings et al., 1992) although the mechanism by which they bore is not fully understood (Jones, 1969; Zottoli and Carriker, 1974).

The large expense in area of the lagoon and reef flats provides a variety of diverse habitats for the polychaetes in Minicoy. The only place with a depauperated polychaetes population was the sand flat area which had relatively few calcareous substrates and in the lush coral areas in the deeper regions of the lagoon (Zone 8). In the lush live coral areas, the larvae of polychaete would be prevented from settling by the lack of available space or by the copious mucus produced by corals or they would be eaten by the polyps (Bailey-Brock, 1976). However, the serpulid worm Spirobrancheus giganteus was found in the living coral heads, Porites lutea and P. solida in Zone 1. According to Bailey-Brock (1976) the fan worm Sabellastare sanctijosephi is an indication of waters with high sediment content. In the present study this species was recorded (for the first time from the Lakshadweep) in the crevices in the lagoon shoal in the north-eastern end of the lagoon where the mean sedimentation rate was 75.17 $g/m^2/day$. Since the species was not recorded from other areas in the lagoon where the gross sedimentation was higher (Fig. 8) it cannot be concluded that this species is an indicator of waters with high sediment content in Minicoy lagoon as observed by Bailey-Brock (1976).

The greater diversity of polychaete families observed in the lagoon than on the reef flat in the present study may be due to the more heterogenaus nature of the lagoon. The majority of the species of polychaetes were represented in the coral habitats in the lagoon shoals, with only a few species collected from the reefs. Such results may be partially due to the sampling procedures; since in this study reef samples were mostly collected from the exposed reef flat areas and not from the deeper reef slopes. Richness and abundance of serpulids have been reported to be usually associated with good coral reef development by several authors (Imajima and ten Hove, 1984; Vine and Bailey-Brock, 1984) while in the present study only few specimens were obtained from the lagoon. In the present study there was wide variation in the density of adult populations between samples collected from different habitats and even within habitats thus reflecting considerable variations in the patterns of polychaete recruitment and subsequent establishment of population. One possible reason is that the polychaetes exhibit many reproductive strategies (Schroeder and Hermans, 1975) which lead to the production of different types of larvae spending varying lengths of time in the plankton (Thorson, 1946). Woodin (1974) has suggested that variations in adult populations of polychaetes are the result of variable success in larval settlement. Most of the boring species are recruited by pelagic larvae (Mc Closkey, 1970; Hutchings, 1981) and that local wind generated currents are responsible for the dispersion of larvae. The length of time spent in the plankton is not known for these larval groups belonging to the families recorded in this study and so it is difficult to suggest that the boring polychaete communities are recruited from Minicoy reefs or from reefs further (nearby Maldives archipelago). Besides, local scale patterns of water movements may also contribute to the variability in colonisation between sites (Hutching et al., 1992). The adultlarval interactions between previously settled species andthe larvae would also modify the density of polychaete recruitment (Woodin, 1974). Polychaete larvae of Hydroides sp. are known to settle preferentially in the presence of their adults (Wisely, 1958; Straughan, 1972; Marsden and Anderson, 1981).

It is also suggested that for most species the recruitment of adults from nearby coral substrates is unlikely since many of the boring species are almost entombed in the coral substrate and have limited powers of movement, and further the coral substrates are not in direct contact with each other (Hutchings and Bamber, 1985). Several studies to investigate spatial and temporal patterns of non-colonial boring organisms in Lizard Island Great Barrier Reef, suggested that larval penetration took place initially and with increasing period of exposure of the substrate, the size of the animal also increased progressively (Hutchings and Murray, 1982; Hutchings, 1983b) and Mc William et al. (1981) reported in a study that plankton just above coral substrates had few adult polychaetes. What they obtained were mainly epitokous nereids or ovigerous syllids which came out of the corals for the spawning purpose. This indicated that relatively few non-reproductive polychaetes emerge from the coral substrate. Hence the variation in adult density observed during different seasons within a particular habitat in this study cannot be attributed to a seasonal variation in the adult population, but can be considered as variation in density as a result of differential recruitment of the larvae into the substrates.

Though many workers have reported that live coral has a poor endo-cryptolithic fauna and the fauna does not develop until the coral dies (Mc Closkey, 1970), when sampling is done in the field, one has no idea of how long the substrate (containing the endo-cryptolithic fauna) has been dead and therefore how old the community is. Also the community has a finite existence as eventually the endolithic fauna will destroy the block of coral completely (Hutchings and Weate, 1978). This probably explains much of the variation observed between samples in the present study. The variation in bioerosional rates reported by various workers between samples on the Great Barrier Reefs (McCloskey, 1970; Hutchings, 1974; Hutchings and Weate, 1979), can also be explained on the above basis. Further studies on the reproductive biology and larval strategies of these boring polychaetes is needed to interpret their recruitment patterns fully and document the changes in their populations in the reef habitat of Minicoy.

In the present study it was observed that in some of the samples collected from the lagoon containing only polychaete had a higher number of individuals, and relatively very low biomass indicating that the majority of the polychaetes in the samples were small (less than 1 cm in length). These animals probably represented the early borers of the newly available substrates. A similar observation was also made at Lizard Island, Great Barrier Reef where polychaetes were the initial borers penetrating the substrate (Davies and Hutching, 1983; Hutchings *et al.*, 1992). A distinct succession occurred in the boring communities by which within polychaetes, cirratulids were the initial colonisers and were later followed by either sabellids or spionids at Lizard Island Great Barrier Reef (Davies and Hutchings, 1983). However, in the present study among polychaetes, eunicids were the initial borers. Other observations made on highly eroded substrates which revealed a higher biomass of the polychaetes (larger species Eunicids) probably suggest that these initial borers (Eunicids) increase in size with increased exposure of the substrate. Hence the distinct successful changes observed by Davies and Hutchings (1983) can only be considered as characteristic of a particular environment. Hutchings and Bamber (1985) have reported that despite larval sipunculids and sponges being available for recruitment, newly laid coral substrates were not bored by these organisms until 9-12 months of polychaete boring had occurred. This suggest that polychaete in some way modify the coral substrate making it more attractive to other types of boring organisms. Dean (1981) has shown that the larvae of the serpulid Hydroides dianthus are gregarious and can establish populations rapidly on newly available substrates. These populations survive for only a few months and since they cannot compete with later arrivals settling on the substrates (Dean and Hurd, 1980) the population declines rapidly and is not re-established. In the present study many dense colonies of Hydroides norvegica were seen on the dead bases of live coral colonies. The preference of the larvae to settle on substrates where adults are abundant (Straughan, 1972; Marsden and Anderson, 1981) could be a significant factor. Similarly the increased abundance of Eunicids observed in the collections obtained in the present study can be explained by the life histories of the groups. Although information on the life histories of borers is lacking, some inferences can be made based on information on related species as given by Hutchings et al. (1992) who reported that Eunicids have longer life spans and breed several times. The authors further observed that at Lizard Island, Great Barrier Reef, eunicids tended to increase with increasing exposure of the coral substrate. In the collections made from the lagoon in the study Sabellids and Serpulids were very poorly represented. This may be due to the site preference of the group as reported by Hutchings et al. (1992) who also recorded very low numbers in the lagoon at Lizard

Island. Most of these tubeworms which are suspension feeders grow away from the substratum to avoid beçoming covered up with silt, which would be detrimental (Vine and Bailey-Brock, 1984). The reef flats and slopes of patch reefs are reported more suitable habitats for these tube worms (Vine and Bailey-Brock, 1984) than the sediment filled lagoon, and this was reflected in the present study also.

Many of the boring polychaetes have short life spans, the burrows become vacant regularly and may be utilised by newly settling larvae of other boring species, while they metamorphose and start to burrow themselves. Thus alternately these vacated burrows may be occupied by non-boring cryptofaunal species, again facilitating the developments of the cryptofaunal communities which include boring and non-boring species (Hutchings et al., 1992).

Sipunculids

The most extensive studies on sipunculids as borers were those of Gardiner (1903) from the Lakshadweep and Maldive group of Islands, Otter (1937) from the Great Barrier Reef and Rice and Macintyre (1982) at Carrie Bow Cay off Belize in the Caribbean. These studies have confirmed that sipunculids are prominent endolithic animals in many reef areas, boring into a variety of calcareous substrates in the intertidal and subtidal corals (Warme, 1975). Recent work by Davies and Hutchings (1983) has indicated that sipunculids are not initial colonizers of newly available coral substrate, however, within 2-3 years such coral substrates become colonised by sipunculids (Hutchings, 1983b; Hutchings and Bamber, 1985; Kiene, 1985).

In the present study sipunculids were observed as one of most dominant groups of boring invertebrates in the lagoon and reefs (Table 37). There was a wide variation in the texture and hardness of the substrate where the sipunculids were recorded and very often several species of sipunculids occurred in the same calcareous substrate. The dominance of any particular species did not show any apparent association with the type of substrate. Although the coral boring sipunculids reported in the study (Table 36) were recorded at all depths in the lagoon where collections were made (from intertidal to about 13.0 m), they occurred with greater abundance in the shoal in the northeastern part of the lagoon (Plate II). The 18 species belonging to 9 genera of sipunculids collected in the present study was quite a high number when compared with the 8 species recorded by Rice and Macintyre (1982) at Carrie Bow Cay off Belize in the Caribbean. Phascolosoma nigrescens collected from the seaward reefs is a new record for the Lakshadweep.

In the present study, Aspidosiphon cleosiphon and Phascolosoma were the most commonly occurring genera while Fisherana was rarely encountered. Fisherana has a short lived lecithotrophic pelagic larval stage and hence a limited distribution and abundance while Phascolosoma and Aspidosiphon have a relatively long lived planktotrophic larvae capable of long survival (Rice, 1975). On the caribbean reefs, Rice (1975) has attributed the abundance of Phascolosoma throughout the corals and beachrock communities to a prolonged breeding season. There are also other reports on the abundance of Aspidosiphon and Phasolosoma dwelling in coral rocks in the eastern mediterranean, Red Sea (Por, 1975) and on the eastern coast of India (Reddiah 1975a). In the present study Aspidosiphon and Phascolosoma represented 40% and 20% respectively of the collections. However, the abundance of the monotypic species Cleosiphon aspergillum which constituted 34% of the collection could not be explained in the absence of any reports on the breeding biology of the species.

Rice (1975) who studied on the rock-boring species Phascolosoma perlucens (now Phascolosoma dentigerum) opined that with fewer and much shorter tentacles and a more extensible introvert, the species fed actively on detritus. The detritus was accumulated as small particles on the tentacles and hooks as the introvert was extended and retracted over the surface of the rock. The structure of the burrows of the coral boring sipunculids and the possible mechanisms by which the burrows are formed have also been reported (Rice, 1969; Rice and Macintyre, 1972). In the present study it was observed that the burrows of most of the species were all characterized by smooth linings and extended at any angle from the surface of the calcareous substrate. In most cases, the burrows had only one opening and that the anterior end of the animal was directed towards the opening (Plate VII). The animal fitted tightly within the burrow and the shape of the burrow reflected that of the species. Thus the burrows of Phascolosoma spp. were short, straight and rounded posteriorly.

Based on studies of the morphology of possible structure in thin rock sections, it was reported that both chemical and mechanical means were utilized by spipunculids for boring into calcareous substrates (Rice, 1969; Rice and Macintyre, 1972). According to Rice (1975) secretions of the numerous epidermal gland openings through the integument may be a possible source for chemical dissolution of the coral substrate while mechanical abrasion might be effected by the frictional movement of thickened articular structures such as papillae and posterior shields against the walls of the burrow. Microscopic examination of the walls of the burrows had revealed alterations in the structure of the constituent grains, suggesting a chemical dissolution while the occurrence of finely carbonate grains in the microscopic pockets of the walls of the burrow suggested mechanical abrasion.

There is a wide discrepancy in views concerning the boring activity of Aspidosiphon. Wesenberg (1957) considered that the species was not able to make the cavities themselves and that it always made use of existing burrows. In the present study, the species was recorded from the coral boulders, calcareous beach rock, dead basal portions of live corals and from the intertidal to a depth of 13.0 m. Though it is difficult to discern active boring from skilful use of fitting crevices, in the porous and hollow calcareous substrates, in the present study it was observed that the burrows of Aspidosiphon streestrupii and Aspidosiphon cumingii clearly reflected the shape and width of the animals, and hence it can be assumed that the animals shaped its own burrow. A similar observation was also made by Por (1975) in the case of Aspidosiphon mulleri in Eilat, on the Red Sea coast where the burrow was driven through massive skeleton and even showed the shape of the subapical introvert in the clearly shaped burrows. Morevoer Por (1975) has also reported a similar observation according to which A. elegans was found burrowing to the corals Stylophora on the landward edge and Lobophyllia on the seaward edge of the reefs at Eilat. It is interesting to note that Wesenberg (1957) had found the gut of Aspidosiphon klunzingeri full of coral debris and suggested an active browsing of the coral tissue. Por (1975) in further support to the boring nature of the species, suggested that the massive and spiraled crown of hooks at the tip of the introvert of A. elegans indicated a mechanical drilling.

According to Herubel as given in Por (1975) Aspidosiphon gracilis and A. truncatus were recorded in living corals in the Gulf of Tadjourah while A. klunzingeri and A. cumingi were recorded in massive Porites spp. Yonge (1975) observed a mutualistic association between the larvae of Aspidosiphon corallicola and the coral species Heterocyathus and Heteropsammia. However, in the present study no such mutualistic association was observed and that no sipunculids were found boring into live coral tissues (though some were recorded on the dead basal portion of live coral colonies). It is unlikely that sipunculids can actually penetrate living coral tissues and that it is more probable that boring initially occurs in the coral skeleton from which the tissue have undergone mortality and after penetration the animal would extend into the skeleton beneath the living coral. A similar view has been reported by Yonge (1975) also.

The increased number of sipunculids in the coraline substrates in the lagoon shoal and the relative absence of the animals in the sandy flat region of the lagoon (devoid of calcareous substrates for penetration) probably signifies the boring activity as an adaptation of the animal against predation. Sipunculids comprise a principal component of the diet of fishes associated with coral reefs such as Mullidae, Labridae, Pomadasyidae, Lutjanidae (Hiatt and Strasburg, 1960). In addition to fishes, the gastropod Mitra sp. was also observed to prey upon sipunculids in the intertidal areas in Hawaii (Kohn, 1975). However, it was observed that smooth rocky substratum and shallow rocky pools on the seaward reef flat were not favoured by the sipunculids while the coral boulders and porous calcareous substrates with a rich percentage of epifauna and coralline algae were habitats preferred by Aspidosiphon, Cleosiphon and Phascolosoma spp. A similar observation was also made by Hutching (1974) in his studies on the density and distribution of invertebrates in the coral reefs of Great Barrier Reef.

In the lagoon shoal and on the reefs it was observed that the solid habitats, some of which had a high biomass of sipunculids, have generally a low level of other boring invertebrates (molluscs crustaceans and polychaetes). The habitats with higher biomass of sipunculids were usually the highly eroded calcareous substrates in the lagoon shoal (Plate III). It was also observed that habitats with higher biomass of sipunculids did not necessarily contain more number of individuals and a high number of individuals was not indicative of a large biomass (Table 35). The habitats with higher biomass of sipunculids were dominated by large size species such as Phascolosoma and Cleosiphon while samples with high number of individuals and less biomass were represented mainly by the small sized animals belonging to Aspidosiphon.

According to Hutchings and Bamber (1985) recruitment into the corals by advanced stages of sipunculids from nearby substrates is unlikely for several reasons. Firstly many of the boring sipunculids were almost entombed in the substrate and have limited power of movement. Moreover the adult sipunculids would have to swim through the water column and in this process would be exposed to predation by the coral reef fishes. This has also been demonstrated by in situ experiments of Hutchings and Bamber (1985) on the recruitment of polychaetes and sipunculids on freshly laid coral substrates where majority of the worms in the blocks initially were of small size and preliminary size frequency analysis suggested that the size increased with increasing period.

In the present study it was observed that though sipunculids were one of the dominant groups of boring invertebrates in most areas of the lagoon and lagoon reef flat, their number and biomass varied between sites within the lagoon as well as within the reef flat. Some of the variation in the number of individuals observed in this study can be explained on the basis of variable success in larval recruitment of sipunculids in these areas. Most of the larvae of boring species are recruited by pelagic larvae and that local wind generated currents are responsible for the dispersion of larvae (Hutchings et al., 1992). Hence variation in patterns of water movements in and around the Minicoy lagoon could have been one factor responsible for the variation observed. Besides the initial colonization of sipunculids may also be influenced by previously settled species since the adult-larvae interactions of sipunculids in the substrate could modify the densities (Hutchings and Bamber, 1985). The higher number of individuals and species observed in the shoal at the northeastern side of the lagoon can be explained on the basis of availability of suitable substrate for larval settlement. The relative absence of boring sipunculid communities in the sand flat areas on the south-western part of the lagoon can be due to non-availability of suitable substrate. The greater diversity of sipunculids in the lagoon than on the seaward reefs may be due to the more heterogenous nature of the lagoon. Samples taken from areas of lush coral heads, in the deeper zones, had relatively very limited sipunculids. One possible reason for this is that the sipunculid larvae might have been prevented from settling by the lack of available space or by the copious mucus produced by corals or they might have been eaten by the polyps (Bailey-Brock, 1976). It is also likely that a high percentage of epifauna and algae are very important in providing protection for the pelagic larvae of sipunculids at the time of settlement and their penetration into the coral. At this stage, the larvae are very susceptible to predation and are likely to be dislodged by currents. A similar opinion was suggested by Hutchings (1974) based on his studies in the Great Barrier Reef where there was an increase in polychaetes and sipunculids as the percentage of epifauna and algae increased and the hardness decreased. In the present study coral block sample which were relatively porous or easy to break, collected from the shoal in the lagoon had a larger population of sipunculids. The smooth rocky substrate (with increased hardness) on the seaward reef flat, did not harbour much sipunculids. Bromley (1978) concluded that in the caribbean reefs, sipunculids mainly occurred in low energy lagoonal situation while in contrast, Rice and Macintyre (1982) observed that sipunculids occurred in greatest abundance in high energy reef crest areas at Carrie Bow. Davies and Hutchings (1983) also observed that sipunculids were most consistent on the high energy reef front. The reef crest in Minicoy is subjected to winds of 3-7 knots per hour 8-9 months of the year (Table 20) which can be considered lower to that experienced at the high energy Lizard Islands subjected to trade winds of 20-25 knots for 8-9 months of the year (Davies and Hutchings, 1983). However, the present study was not extended to the reef crest and hence it is not possible to opine with concrete evidence on influence of the energy conditions on the abundance of sipunculids as observed by Bromley (1978) and Rice and Macintyre (1982).

From the bioerosion point of view, a higher biomass (percentage ratio of weight of the animal to the weight of the coral) would mean a higher degree of erosion of calcareous materials from the substrate and hence a more significant factor, than the number of individuals causing bioerosion. In the present study it can be inferred from the equation for exponential relationship established for the weight of the animal and the volume of the burrow that the amount of calcareous materials eroded by Cleosiphon aspergillum and Phascolosoma spp. are relatively higher (maximum biomass 1.79 and 2.91 respectively) when compared to smaller sized animals of Aspidosiphon. Hence the higher biomass of sipunculids (represented mainly by Cleosiphon aspergillum and Phascolosoma) in the lagoon shoal and on the reef flat as observed in the present study points out the significant role placed by these species as the bioeroders of the coral reefs in Minicoy. When samples are collected to determine rate of bioerosion, one has no idea of how long the block of coral has been dead, and therefore how old the community is. Moreover, the community has a finite existence as eventually the endolithic fauna will destroy the block of coral completely (Hutchings and Weate, 1978). This probably explains much of the variation in the rate of bioerosion reported by various workers between samples (Mc Closkey, 1970; Kohn and and Lloyd, 1973; Hutchings 1974; Hutchings and Weate, 1979). According to Hutchings et al. (1992) the rates of bio-erosion vary between sites on a single reef and period of time. Thus rates of bioerosion by borers will vary significantly between different reef environ-ments. Hence the candidate feels that extrapolation from a set of data to an entire reefal system cannot be justified. However, based on mean values of the biomass it can be inferred that the rate of bioerosion caused by sipunculids in the lagoon shoal and reef flat in the Minicoy reef is comparatively higher when compared with that on the seaward reefs.

From the above study it can be concluded that sipunculids can be considered as one of the chief bioeroders of coral reefs in Minicoy. The number of individuals were slightly higher in the lagoon shoal and the reef flat than present on the seaward reef flat. Aspidosiphon, Phascolosoma and Cleosiphon were by far the most abundant groups. A higher number of individuals was not necessarily indicative of a larger biomass.

The variation in the number of individuals observed between sites was explained on the basis of variable success in larval recruitment. The possible influence of local variations in water movements in the lagoon, the presence of previously settled species, adult-larvae interactions, avail-ability of suitable substrate, growth of epifauna and algae over the substrate and the degree of hardness of the substrate are the factors responsible for larval recruitment colonization and abundance of sipunculids.

Sponges

Boring sponges are found to bore into calcareous substrates including dead and live corals and inhabit cavities that they excavate, and are found to be a significant agent in the destruction of reef corals all over the world (Goreau and Hartman, 1963). In the present study also, it was obser-ved that the boring sponges penetrated corals in the reefs of Minicoy and made extensive burrows throughout the skeleton. The living coral polyps appeared not be affected by the activities of boring sponges. In a few samples, on the dead basal portion of the live corals, the non-boring sponges were observed to overgrow. Clionid sponges were by far the most commonly occurring species of boring sponges in the reef corals.

In the present study, it was observed that the tunnel and chambers formed inside the calcareous material by the activity of sponge presented a pitted appearance. These pits formed at the inner surface of the tunnels and chambers can be attributed to the removal of minute calcareous chips. According to Pomponi (1977) the process of boring is similar in all species of sponges.

In the present study it was observed that the sponges can bore into both live and dead corals alike. The boring of a dead substrate would not influence the destruction of polyps, and the death of the coral will never affect the activities of the boring sponge since there is no trophic relationship between them. However, under such a situation it is likely that the process of chipping of calcium carbonate would go on incessantly as far as the sponge inside the substrate is alive. This will not only weaken the entire reef frame-work considerably and make it more susceptible to the physical forces of destruction, but also contribute much to the mineral fraction of sediments produced in the reef environment. Goreau and Hartman (1963) have reported that these chips contribute much to the mineral fraction of sediments generated in the reef environment in Jamaica. In the Fanning Island, it was estimated that the clionid chips, contributed to about 30% of the total sediment load (Futterer, 1974). Moreover the weakened substrate may also accelerate the activity of secondary borers such as polychaetes, sipunculids and bivalves.

According to Hartman (1958) coral reefs do not present a variety of clionids as might be expected. Only two clionid species were reported from Bermuda (De Laubenfels, 1954a) and five from the West Central Pacific

(De Laubenfels, 1954b) while Burton (1934) could not record the presence of clionid from the Great Barrier Reef. However, in the present study, it was observed that the reef habitats of Minicoy provided a rich fauna of clionids, represented by 5 species. The clionid sponges were by far the most dominant group of boring sponges in the reefs and were present in 46.34% of the samples examined. A similar observation was also made by Thomas (1989) who made a detailed study on the boring and non-boring fauna of Lakshadweep. He observed that Cliona celata was the dominant species in Kavaratti and Suheli Islands, while it was C. ensifera in Kalpeni and C. mucronata in Androth. C. celata and C. vastifica were earlier observed equally dominant in Minicoy Island. In the present study also, it was observed that C. celata and C. vastifica were present at an average of 12.57 and 11.3% respectively in the samples examined. In the study it was observed that Spirastrella inconstans and S. cuspidifera overgrew the substrate even after disintegrating it. In those substrates which were totally disintegrated, the sponge grew into structures bearing excurrent and incurrent openings. This overgrowth can be compared with the gama stage in the growth form of C. celata. S. inconstans exhibits the habit of producing sexual bodies from the surface as well as from the tip of tubular branches in advanced stages, which get nipped off from the sponge and float in water indefinitely (Thomas, 1988). On reaching a suitable substratum these bodies may get anchored to it and form new colonies. The abundance of coralline sand in Zone 1 probably explains the abundance of this species in the region.

The distribution of C. ensifera and C. mucronata has been reported in the past from the coral reefs of the Gulf of Mannar, Palk and Bay and southern coast of Kerala (Thomas, 1979). The species has also been reported as typical coral boring species in the Lakshadweep lagoons (Thomas, 1989). Though the different clionid species were recorded from a single coral head during the study it is unlikely that the activity of C. mucronata and C. ensifera would pose a severe competition for space and check the activity of C. celata and C. vastifica. Thomas et al. (1983) have reported Cliona margaritifera and C. lobata in the molluscan beds in the southwest coast of India. However, these species have not been reported from Lakshadweep in the past (Thomas, 1989) nor recorded in the present study. However, the transfer of any consignment of pearl oyster, edible oyster or mussels infected with sponges to Lakshadweep from mainland for cultivation without proper screening, can cause far reaching repurcussions in the ecological equilibrium of the sponge fauna in the Lakshadweep.

In the study based on the area occupied by different boring species of sponges on the substrate it was found that the etchings of C. celata occupied a larger area in comparison to the borings of other species. The species was found in the interior of the substrate with its tunnels and chambers. Hence, the damage done to coral in Minicoy is much more intense than that caused by any other species. The cavities of C. mucronata and C. ensifera assumed the shape of irregular tunnel inside the calcareous substrate with little ramification sideways. Chipping of calcium carbonate particle from the substratum can cause a decrease in the total weight of the substratum. It has been experimentally shown that in new colonies the boring activity of sponge will be intense but subsequently the substratum limitation and competition for food would retard the activity considerably (Rutzler, 1975). Besides, the sponge has to set apart some energy for nutrient storage and reproduction also. In such cases, the quantum of calcareous substrate eroded would be less and in such species, the distingration of the substratum is not expected. However, in species such as Cliona celata, Spirastrella inconstans and S. cuspidifera, the sponge at a later stage, becomes massive and overgrows the substratum. A similar observation was also made in the present study.

According to Thomas (1989) in the case of C. celata, soon after the settlement of the larvae on the coral, it flattens to form an encrusting mass. This is followed by the etching out of calcium carbonate particles to form an initial chamber and the further spreading of the sponge inside the coral is affected through chambers originating from this initial chamber. These mass of chambers fill the entire thickness of the coral, and the death of the branch occurs from this stage onwards. In the present study in several samples examined, these mass chambers were observed. From these chambers sponges were seen growing. Very often these branches were located at the periphery of the coral, very close to the outer surface. In samples, where boring was in the advanced stage, a peripheral cavity filled with the boring sponge encircling a central core of calcareous material was observed. Since C. celata prefers to grow upwards (negatively geotropic), towards the distal end of the branches of corals, the larvae when enters at the middle of any branch, the disintegration and death of the branch occurs from this point upwards, while the part of branch below this point remains unaffected. In the present study, several colonies of corals bearing distally dead branches were observed which only corroborate this point.

Though boring sponge can make extensive galleries inside the coral, it is very difficult to estimate the magnitude of damage caused by them unlike other endolithic boring sipunculids, bivalves and polychaetes. A mere external examination of the galleries alone would not be enough since in some samples, the outer layers of the coral remain practically unaffected, more or less intact except for a few pores. A few samples, in the advanced stage of boring, had their inside practically hollow except for a few calcareous tunnels within the skeleton. In the present study no attempt was made to quantify the rate of sponge generated bioerosion.

The factors that influence the activity of boring sponge are many. Rutzler (1975) when experimentally cut this sponge into two, the boring activity was found in stimulated the resultant bits considerably. Boring animals and also human intervention by way of cutting channels across the reef may accelerate the boring activity of sponges already existing in such locality. Illumination also plays an important role in the boring activity of the sponge. Calcite blocks infested with Cliona sp. when illuminated by low voltage microscope lamp produced calcareous chips at a higher rate (Rutzler, 1975). One possible reason for the abundance of boring sponges in Minicoy lagoon as observed in the present study can be the exceptional clarity of water (euphotic zone is about 90 m). Localised death of a colony may not produce any far reaching consequences unless considerable damage occurs to the stalk portion which can result in the collapse of the entire colony into the substratum where it will be burried by sediments. Due to lack of studies in the pat, it cannot be concluded that the dead Acropora spp. branches found buried in the lagoon sediment in Zone 1 and 6 in the present study are due to sponge generated bioerosion. According to James et al. (1989) the branching colonies which occupied the level bottom would never collapse into the ground, since the inter locking of the branches of adjacent colonies would keep them in position even after the total disintegration of the stalk. However, it is felt unlikely that in a lagoon, where the bottom currents during monsoon are very strong (in a range between 0.300 and 0.600 knots per hour) these bottom disintegrated colonies of Acropora would survive. Goreau and Hartman (1963) who made extensive surveys of the reefs off Jamaica, concluded that too much accumulation of fouling organisms caused considerable strain on the coral colony in which the stalk had already been weakened by borers. But they have suggested that such a situation often turns out to be a blessing for corals because massive sponges that grow across adjacent colonies will help to keep any coral colony (which is in distress) in position. In the case of massive corals, the question of getting themselves dislodged is quite remote, and in such cases partial death is only possible. In the present study, it was observed in Zone 7 and 8 where the depth of water ranged between 8.1 and 13.0 m that algae flourished in the upper, well illuminated side of the massive corals killing the polyps. But the coral colony was seen to accelerate its growth along the periphery, producing a circular rim around the zone of dead polyps. In a few cases, sedentary organisms were also observed to attach themselves and grow in this area of dead polyps.

The present study points out that the damage caused to corals by boring sponges is rather wide spread in all the zones of the coral reefs of Minicoy where the study was conducted. Clionid sponges was by far the most dominant boring group. In many cases, it could be seen that the sponge infection could kill the colony either partly or fully. The incessant process of chipping off calcareous materials by the boring sponge was observed not only to weaken the reef-frame work considerably but also contribute much to the mineral fraction of sediments. The exceptional clarity of the lagoon water is considered a positive factor for the rich boring sponge fauna in the coral reefs of Minicoy.

Crustaceans

Cirripeds are sessile animals and hence are needed to attach themselves to a firm holdfast. It might be expected that there would be numerous and characteristic habitats in the coral reefs giving so many opportunities for their settlement on the calcareous substrates. But curiously enough Darwin (as given in Gardiner, 1903) has remarked that coral reefs are, for some reasons, not favourable for them.

In the present study, it was observed that though the distribution of the boring cirrepeds are restricted to the seaward and lagoon reef flats only, they can cause significant damage to coral reefs because of the high biomass of these animals in the boulders and rocks. The mean number of individuals per unit weight of the substrate was higher in the lagoon reef flat while the mean biomass of the individuals was higher on the seaward reef flat. Interestingly the species was not recorded anywhere from the lagoon. According to Mclean (1974) the secondary maxima of boring barnacle Lithotrya in the beachrock in the Caribbean and Great Barrier Reefs illustrated that breaks of reef slope are particularly adapted for these boring organisms. The cirrepede excavates its burrows in the rocks by means of the studs on the peduncle (Plate XI). The studs consist of a chitinous core with a calcareous covering. Borradaile (1903) has observed L. dorsalis on the underside of overhanding coral rocks in Fadifolu Atoll and Miladumadulu Atoll in the Maldives. It is quite interesting to note that eventhough Borradaile had emphasized on the significance of the rock boring barnacle Lithotrya spp. in the destruction of coral reefs in Lakshadweep as early as 1903 subsequent workers who studied the role of bioeroding agents in these habitats failed to identify these animals. What is true for Lakshadweep is also true for other reef habitats. In comparison to the reports on the role of the major bioeroding agents like sponges, polychaetes, sipunculids, bivalves and echinoids, boring activities of Lithotrya have received very little attention. The non-detection of this species in the lagoon would have led in the past to make unrealistic conclusions on the role of boring Lithotrya spp. in the removal of calcareous materials in the reefs of Minicoy. The material removed by the animal from the burrow on the reef flats. as observed in the present study would be transported by the current and deposited in the adjacent lagoon or deeper water offshore. The intense boring of Lithotrya spp. would naturally weaken the beach rock and boulders and make reef framework susceptible to physical factors of destruction and crumble into the sea.

Trudgill (1976) reported that the boring rate of Lithotrya was 0.844 cm per year at Aldabra, Indian Ocean. In the present study it was observed that the volume of calcareous materials eroded by an individual varied between 5.65 and 15.67 cub. cm. (Table 41). Since the biomass of boring Lithotrya was higher on the seaward reef flat, it can be expected that the bioerosion caused by this species is higher on the seaward reef flat than the lagoon reef flat. The maximum extent of bioerosion observed in the present study due to boring Lithotrya was 8.66% volume eroded in coral boulders observed on the seaward reef flat. This value is quite significant when compared to the greatest extent of overall bioerosion which amounted to 28% for a patch reef in florida (Hein and Risk, 1975) and 18.3% in dead coral rubble on the patch reef or the northeast of St. Croix, USA (Moran and Reaka, 1988).

The present study suggest that eventhough the distribution of boring barnacle Lithotrya in Minicoy was restricted to the open reefs the role of this species in the erosion of calcareous substrates was quite significant.

CHAPTER - IV

INFLUENCE OF HUMAN INTERFERENCE ON CORAL REEFS

INTRODUCTION

The impact of interference of man and nature in an atoll environment will manifest conspicously within a short time because the habitat is a relatively restricted one. This ecosystem is fragile, diverse and easily vulnerable to adverse environmental conditions. The effects of adverse factors on these ecosystems are often of very serious consequences.

Today, almost all inhabited atolls of the world, are facing environmental stress both in the terrestrial and aquatic habitats as a result of both man made and natural factors of destruction. The human activities like active settlement, extensive cultivation of crops, military establishments, oil exploitation, pollution, over exploitation of resources, destruction of natural fauna and flora, and dredging and construction activities are the major agents that have effected notable changes in the physiography, morphology and biotic communities of the atolls, over the recent years. Lack of large buffer zones around atolls is a major impediment in the replenishment of the fauna which are depleted due to man made or natural agents.

The Lakshadweep atolls are no exception to this global phenomenon of deterioration of reefs and their environment. In the recent years, there has been brisk developmental activities in the different Lakshadweep islands. Pillai (1986) described the destruction of natural vegetation at Minicoy atoll as a consequence of the expanding settlement and agricultural operations. There are also reports on the side effects of developmental activities in the marine and terrestrial habitats in Lakshadweep (Pillai and Madan Mohan, 1986) and on the areas of ecological stresss and different man made factors threatening the coastal zone habitats in Lakshadweep (Pillai, 1986). In a recent report James et al. (1989) have given an account of the effect of dredging, pollution and predators on corals in Lakshadweep while Pillai (1990) has described some ecological changes and their impact on the mass mortality of corals in Lakshadweep.

In view of the deteriorating environmental conditions of the atolls, effective measures of conservation need to be implemented. A more careful and effective coastal zone management requires a detailed information on the various human activities that cause environmental damage and its long term consequences on these fragile ecosystems. In this chapter a detailed account of the influence of human activities on the destruction of coral reefs of Minicoy atoll is given.

The human interference on the coral reefs of Lakshadweep, especially in Minicoy can be dealt with in detail under the following heads:

1. Dredging and Blasting,
2. Removal of coral stones for construction,
3. Destruction of vegetation,
4. Hand picking of live corals,
5. Fishing activities and
6. Pollution.

Dredging and Blasting

Blasting of the reef flat and the lagoon shoals and the dredging of the lagoon bottom are common practices in some islands. This is to facilitate the entry of mechanised boats into the lagoon. Between 1968 and 1977, the lagoon of Minicoy was subjected to long term dredging by the Lakshadweep Harbour Department. The dredged soil was deposited on the lagoon shoal. A good part was deposited at the lagoon beach of the northern tip of the island. The dredging caused stirring up of the bottom sand and this sand was transported towards the south along with the water current. This has resulted in a 0.5 m thick of additional deposit of soil at the central and southern parts of the lagoon, when compared to early seventies (Pillai, 1990). The subsequent sediment transport in the lagoon has resulted in mass mortality of corals near the northern end of the atoll (opposite to the leper's colony). In other islands, like Kavaratti, the dredged material is being dumped out into the open sea near the lagoon. In this case, there is always a chance for these sediments being transported back into the lagoon as a result of the currents.

Blasting of the reef flat at the entrance and subsequent dredging for deepening of the channel also resulted in a greater influx of water into the lagoon at high tide. This led to increased rate of erosion of the lagoon beaches. A 25 m wide sandy stretch of land situated all along the beach side of the northern end of the atoll opposite Aoumage village some 50 years ago (local enquiry) has now been reduced to a narrow strip of 4.0 m width (personal observation).

The large 50 m wide and 100 m long shoal situated at the northern end of the atoll (Zone 3), earlier had a profuse growth of huge colonies of Goniastrea retiformis, Diploastrea heliopora, Lobophyllia sp. and Porites (Nair and Pillai, 1972). Today this area has very little live coral coverage (Plate IV). The shoal is mostly burried under the soil dredged.

Removal of coral stones for construction

Another major intereference on coral reefs has been the removal of coral rocks and coral shingles. This includes pitting the ground, removal of beach sand and mining of sand stones. The larger coral species which are slow growing are commonly preferred for use as construction material and for lime production. Coral stones and beach sand are favoured by the inhabitants for use in construction as frame works for building materials since it is cheaper over the cost of granite metal. Moreover river sand is also expensive and not available too.

Removal of the coral stones from the intertidal area on the flat seaward reef would result in the exposure of the loose beach sand beneath and would lead to increased removal of beach sand. This has been noticed in Minicoy on the seaward beach side, especially during monsoon when winds are strong and wave action is severe (Plate II). It is believed that during the south-west monsoon, a current arising from the southern part of the atoll, bifurcates, as it approaches the seaward reef flat and then proceeds towards the north (local enquiry). Hence it is quite possible that during the monsoon, the strong south-westerly winds initiates powerful wave actions along the seaward face of the island and the sediments washed away subsequently could be transferred from the seaward side to the lagoon. This can be a major source of sediments that contributes to the filling up of the lagoon.

Removal of coral stones and shingles from the lagoon, also limits the available substrate for the settlement of planulae larvae. In the lagoon, planulae larvae of Pocillopora damicornis were observed to settle on artificial structures made of cement (Personal observation). The complete absence of any coral heads in Zone 1 of the sandy flat area in the lagoon can be attributed to the removal of substrates available for larval settlement.

Destruction of vegetation

Minicoy is one of the few islands in the Lakshadweep blessed with a fairly good growth of mangrove vegetation. The vegetation is dominant in the southern tip of the island beyond the light house. Recently these land masses were all leased out to the local inhabitants as a part of the rehabilitation programme in view of the expanding settlement and agricultural operation. The local inhabitants are now in the process of clearing these mangrove vegetations located along the beaches, for setting up tourist huts and other temporary holdings. The present destruction of these rare mangrove vegetations, which serves as efficient soil binders and act as sediment traps, would result in the loss of sediments into the lagoon.

Hand Picking of live corals

Hand picking of live corals is another human interference which has contributed significantly to the destruction of branching forms of corals from the lagoon and reefs in Minicoy. This practice is carried out mainly by visitors and also by the local people themselves who clean it and sell to tourist or present as gifts. Eventhough the practice has been banned by the administrative authorities, due to the absence of strict enforcement, this practice is still being continued in Minicoy. The dimension of this problem can be inferred from the fact that, one cannot see even a single branching coral of more than 6 inches in height anywhere in those areas, where people tread upon during low tides for collection of corals and ornamental shells. The branching forms which include Acropora, and Pocillopora are the most exploited forms. During the early seventies, there was a rich fauna of branching forms, mainly Acropora sp. in Zone 5, between Tunda Point and Viringli island (local enquiry) which is absent now.

Fishing Activities

When compared to the lagoons of other islands, fishery activities are carried out more frequently and in greater intensily in the Minicoy lagoon. Large nets and ropes are used during these fishing operations and these cause extensive damage to the branching forms. Besides, in order to avoid entangling of fishing nets and ropes with the corals, the common fishing grounds are cleared off of branching corals. In the present study calcium carbonate accretion was seen along the entangled plastic twine (Plate X). Small coral stones might get displaced during fishing operations while the nets are being dragged in the lagoon. Mooring and anchoring of fishing boats and cruising of boats in shallow areas also cause considerable damage to these corals.

On the reef flat too, fishing activities are quite frequent. The Octopus hunters while capturing the animals, very often destroy the burrows in the reef flats in which the animals live. This also contributes to the destruction of the reefs. Besides, in Kavaratti, there is another form of fishing activity being carried out along the seaward reef flat called 'Padu Vekkal'. Using large coral boulders and rocks, artificial structures are constructed in a circular pattern in such a way that there is sufficient space in between. The fishes sheltered among the boulders are caught by operating cast nets over these artificial structures and then removing the coral boulders. In this process, many small budding coral heads are broken and get destroyed (Personal observation).

Pollution

Coastal zones of the atolls are subjected to low levels of pollution due to human refuse, excreta and fish wastes. Retting of coconut husk kept along the beach under stones is also seen in some islands like Minicoy. Kiltan and Chetlat.

Oil is leaked out into the lagoon when oil barrels unloaded into the lagoon are drifted towards the beaches. Mechanised fishing boats also contribute to the oil pollution in the lagoon. Though the quantity of oil spilled in the lagoon may not contribute to an immediate threat for the environment, its long term effect on coral mortality is yet to be studied.

In addition to the above human interferences on the coral reef ecosystem, it is also worth considering the effect of the recent introduction of two speed ferry boats. These speed ferry boats jet out about 3000 l of water per second. This result in the churning up of the bottom sediments in the lagoon causing turbidity (personal observation). As a result of the churning up of sediments, there is deposition of silt on seagrass bed in some areas, while in other areas, the bottom sediments are being displaced. Though it may be for too early to predict any significant effect in the environment caused by these modifications, it can very well be inferred that, the introduction of these speed boats would effect considerable change in the ecosystem.

Coral Reef Management

The corals and coral reefs in Lakshadweep are at present undergoing rapid changes in the ecosystem. The ecosystem is not only being modified as a result of the human interferences but also on the way to transformation. Recently the International Union for Conservation of Nature and Natural Resources has identified Lakshadweep as one area which needs highest priority for the protection of the ecosystem (Anon., 1988). In this context, based on the observations made on aspects of coral destruction the following suggestions are put forward for the protection of these fragile ecosystems.

1. Establish small reserves wherever good coral cover exists. Such reserves can include a protected area and also a buffer zone where restricted activities are allowed.
2. Dredging activities and blasting of reefs should be restricted. A detailed study on the long term effect of such activities would be relevant in the context of protecting these fragile resources.
3. Erosion of beach sand can be prevented by constructing sea walls. Fast growing plants can be grown all along the beach where erosional activities are severe.
4. Strict enforcement of the ban on picking of live corals should be complemented.
5. Removal of coral stones and beach sand for construction purpose should be restricted to limited areas. Efforts should also be made so as to make bricks and granite stones available at subsidised rates as alternatives.
6. The anchoring of boats over good coral cover areas should be prohibited. Sand bags can be used as temporary anchors for small boats so that damage to corals can be avoided.
7. Walking on reefs at low tide has caused damage to highly developed cover of fragile corals. There should be a system of periodic closure

and controlled reef walking so that the fragile reef communities can recover.

8. Collection of aquarium fishes and live bait should be restricted to designated areas only. This would help to create undisturbed breeding grounds for these fishes.

9. Over exploitation of resources and fishing activities in the lagoon can be restricted by adopting culture and farming techniques.

Conservation and management of the coral reef ecosystems would pose some problems in the beginning. A greater public awareness and participation would solve this problem to some extent. The people should be educated on the relevance of these measures and its long term impact upon the islands. It would be appreciable to envisage a practical approach which involves surveys, description, suggestions and research. Precedents from the management of terrestrial systems will be helpful. The major challenge lies in the development of management systems which are appropriate for these marine environments.

EXECUTIVE SUMMARY

The coral reefs of Lakshadweep just like any other reefs have been extremely vulnerable to forces of destruction (James et al., 1989). Till date no study has been undertaken to study the extent of coral degradation and various agents of destruction acting on the coral reefs. A study was undertaken to investigate qualitatively and quantitatively the agents of coral destruction and their possible role in the breakdown and erosion of calcareous materials in Minicoy Island where the problem of coral degradation is most pronounced in Lakshadweep (Pillai, 1990).

1. **CORAL REEF SURVEY**

A survey of the coral reefs of Minicoy Island was undertaken from January 1990 to December 1991. The objective of the survey was to understand the percentage of live and dead coral cover, to determine species composition and diversity of corals and to collect coral samples for studying the different bioeroding agents causing coral destruction.

1. On the reef flats, the live coral cover varied between nil and 15.75%. The live coral cover in zone 2.3 and 4 varied between 29.88 and 74.56% while in the deeper areas of the lagoon (Zone 7 and 8) it varied between 53.89 and 91.75%.

2. Porites sp. was by far the most abundant coral species in the lagoon while in the deeper areas (Zone 8) Psammacora dominated. The once dominant branching coral Acropora was very poorly represented in the quadrat.

3. Recolonization of encrusting forms of corals was observed along the sides of numerous shoals in the lagoon. On the reef flats, reproductive reinvasion and partial regeneration accounted for the presence of corals.

4. The species Cyphaestrea seralia, Cycloceris cyclolitis, Favia laxa and Porites rus, collected during the study are new records from Minicoy Island.

5. On the lagoon reef flat the species diversity (H') varied between 1.0591 and 2.0613 while on the seaward reef flat it varied between 1.0588 and 2.0489. In the lagoon the index of species diversity varied between nil and 2.0901. The index of species diversity was generally higher on the reefs. A strong predictable pattern of species diversity was not observed with depth in the coral reefs of Minicoy.

6. There was no significant change in the species diversity in the lagoon and along the reef flats although there was considerable change in the pattern of live and dead coral cover.

II. ECOLOGICAL STUDIES

The various physico-chemical parameters acting in the Minicoy lagoon was studied for a period of two years (20.1.1990 to 26.12.1991) to investigate the role of these factors in the destruction of reef corals.

1. The annual mean temperature of the surface water in the lagoon varied between 29.4 and 29.6°C. The instantaneous daily temperature in the shallow habitats in the lagoon ranged from 26.5 to 36.5°C.

2. The mean salinity varied between 32.6 and 34.5 ppt in the lagoon while on the seaward reef flat the variation was between 33.7 and 34.6 ppt.

3. The temperature and salinity variations recorded during the study were well within the limit of lethal levels determined for corals and hence these are not considered as major factors that cause mortality to reef corals in Minicoy.

4. The sedimentation rate in the lagoon varied between 64.38 and 172.0 $g.m^{-2}\ d^{-1}$ during the study. The rate of sedimentation was higher on the southwestern part of the lagoon. The higher rates coincided with the pre-monsoon period.

5. Eventhough sedimentation has been considered a significant factor in the past, contributing to coral mortality in Minicoy lagoon, the

present rates are well within the normal values reported for coral reefs.

6. The average dissolved oxygen content in the lagoon varied between 4.69 and 5.25 ml/l while on the seaward reef flat it was 5.61 ml/l.

7. In general, during the pre-monsoon, the westerly flowing south-west and north-west currents dominated. During monsoon, the north-west currents dominated while in post-monsoon, south-east and north-west currents equally dominated. The velocity of these currents during the different seasons varied from 0.011 to 0.633 knots per hour.

8. The chlorophyll a concentration in the Kalpeni lagoon ranged from 0.13 to 1.68 mg m^{-3}, with lower values in the sandy patch and higher values in areas dominated by dense live corals and seagrass bed.

9. In the different areas of the Minicoy lagoon nitrite concentration varied between 0.05 and 0.410 ug at/l, nitrate between 0.025 and 0.411 ug at/l, Phosphate between 0.015 and 0.155 ug at/l and silicate between 1.45 and 5.0 ug at/l.

III. BIOLOGICAL DESTRUCTION OF CORAL REEFS

1. Coral reef fishes belonging to 6 families, 9 genera and 25 species were identified as coral feeding fishes in Minicoy coral reefs. Their mean density varied between 5.32 and 29.9 numbers per 20 sq.m. transect. Acanthurids and Chaetodontids were the most predominant groups and their percentage occurrence varied between 18.79 and 65.98 in each zone. Higher density of fishes was observed in the deeper areas where there was good live coral cover.

2. Eight species of echinoids belonging to 7 genera and 5 families associated with grazing and boring of coral reefs of Minicoy were identified during the study. The diademid sea urchin *Diadema setosum* and rock boring urchin *Heterocentrotus mammillatus* have been recorded for the first time from Minicoy Island.

3. The population of rock boring sea urchin Echinometra mathei was rich in the protected lagoon shoal and the monthly numerical density of this species varied from 5.3 to 8.8 per sq.m. in 1991.

4. The diademid sea urchin Echinothrix diadema was more abundant on the lagoon reef flat and was not recorded in the lagoon. A two year study on the population density of this species showed that the mean numerical density varied from 3.09 to 10.38 per sq.m. along the lagoon reef flat.

5. It was estimated that a quantity between 170.820 and 284.700 g of calcareous substrate was eroded per sq.m. every year by E. mathei in the lagoon shoal, while on the inner reef flat the quantity eroded by this species ranged from 26.280 to 43.800 g. The sea urchin Echinothrix diadema was estimated to remove 237.250 to 1186.250 g of calcareous substrate from one sq.m. of reef flat every year.

6. The coral polyp feeding echinoids Culcita novaeguinea and Acanthaster planci are not considered as serious threat to the coral reefs in view of their limited occurrence as revealed during the present study.

7. Boring bivalves belonging to 12 species of 6 genera were collected from the coral reefs of Minicoy. Of these Lithophaga teres and L. laevigata are new records from Lakshadweep.

8. The boring bivalves (Lithophagids) were more abundant in the highly eroded lagoon shoal than on the reefs. Out of a total of 193 specimens of Lithophagids collected, L. nigra, L. gracilis and L. teres constituted 46, 36 and 12% respectively.

9. The mean density of boring bivalves in the lagoon shoal was 4.14 and 4.9 numbers per kg of coral substrate for the year 1990 and 1991 respectively. The mean volume of calcareous material eroded by boring bivalves was 38.5 and 38.9 cub. cm per kg of coral during 1990 and 1991 respectively.

10. An exponential relationship ($Y=aX^b$) between shell length (L) and volume of calcareous material eroded (BV) by the boring bivalve was established for 4 species of lithophagids.

a. L. nigra BV = $0.3232\ L^{2.6815}$

b. L. gracilis BV = $0.0025457\ L^{4.1154}$

c. L. teres BV = $0.4791\ L^{2.6169}$

d. L. sp. BV = $40.3447\ L^{1.4059}$

11. Thirty four species of polychaetes belonging to 24 genera of 13 families were represented in the collection of these Owenia fusiformis Hypsiocomus phaeotaenia and Syllis (Syllis) gracilis are new records from Lakshadweep.

12. Euncidae was the most abundant group of boring polyphaetes in the reef habitats in Minicoy.

13. Most of the boring polychaetes were recorded from dead coral substrates except the serpulid Spirobranchus giganteaus which was observed from living corals.

14. A greater diversity of polychaete families was observed in the lagoon.

15. The numbers and biomass of polychaetes varied between habitats and also within habitats. A substrate with high number of polychaetes did not necessarily have a high polychaete biomass. The mean density of polychaetes in one kg coral collected from the lagoon was 9.6 and 15.7 during 1990 and 1991 respectively and their mean biomass was 2.300 and 1.600 g. On the lagoon reef flat the mean number was 9.41 and 3.94 and mean biomass 1.228 and 3.034 g per kg of coral during 1990 and 1991 respectively. The mean density was 2.1 and 1.9 and mean biomass 2.769 and 1.942 g on the seaward reef flat during 1990 and 1991 respectively.

16. Sipunculids associated with coral reef habitats of Minicoy were found to represent a total of 18 species belonging to 9 genera. Phascolosoma nigrescens is a new record from Lakshadweep.

17. Among the 354 specimens collected, Aspidosiphon, Cleosiphon and Phascolosoma constituted 39.55, 33.62 and 19.78%.

18. The exponential relationship ($Y = aX^b$) between length (L) and weight (W) of the sipunculid and the volume of calcareous material eroded by the animal (BV) was established for 4 species.

a)	Cleosiphon aspergillum	$BV = 2.3891\ L^{1.5741}$
		$BV = 2914.9735\ W^{1.0460}$
b)	Aspidosiphon cumingii	$BV = 6.6560\ L^{0.9647}$
		$BV = 238.7438\ W^{0.3467}$
c)	A. streestrupii	$BV = 5.0305\ L^{1.0439}$
		$BV = 448.9857\ W^{0.6590}$
d)	Phascolosoma dentigerum	$BV = 1.0706\ L^{1.9075}$
		$BV = 1836.8602\ W^{0.9680}$

19. The mean density and biomass of sipunculids were higher in coral samples collected from the lagoon than those from the reef flats. The mean number per kg of sample in the lagoon was 10.38 and 13.46 during 1990 and 1991 while the biomass was 4.183 g and 2.592 g per kg of sample during these years. On the seaward reef flat, the mean density was 3.27 and 2.43 and biomass 1.917 and 1.175 g during 1990 and 1991 respectively. The mean density on the lagoon reef flat was 8.3 and 6.28 while biomass 1.842 and 1.417 g per kg of sample during 1990 and 1991 respectively.

20. Fifteen species of boring sponges belonging to 8 genera of 4 families were identified from the reef corals at Minicoy.

21. Cliona was the most common group of boring sponge, representing 49.19% of the samples studied while Spirastrella was represented in 19.25% of the samples. Cliona celata and C. vastifica were the most dominant species of boring sponge observed in 12.49 and 10.74% of the coral samples collected from the reefs and lagoon in Minicoy.

22. The species Spirastrella inconstants and S. cuspidifera were observed to overgrow the dead corals.

23. Clionid boring was mostly confined to the marginal layers and the cavities made by the sponge ranged from regular spherical to irregular.

24. The living coral polyps appeared not to be affected by the activities of boring sponges, but the entire reef frame work was weakened considerably.

25. The damage caused to corals by boring sponges is wide spread.

26. The boring cirripeds of the Minicoy coral reefs were represented by two species belonging to one genus and one unidentified species.

27. *Lithotrya valentiana* and *L. dorsalis* respectively constituted 54.63 and 12.03% of the 108 specimens collected.

28. The length of *L. valentiana* ranged between 41.8 and 76.4 mm and the weight between 1.200 and 5.962 g while the length of *L. dorsalis* varied between 48.0 and 75.0 mm and weight between 2.131 and 4.020 g.

29. The exponential relationship ($Y = aX^b$) between length (L), weight (W) of boring cirriped *Lithotrya* spp. and the volume (BV) of calcareous material eroded by the animal was found to be.

a. *L. valentiana* $BV = 149.3044\ L^{1.0496}$

$BV = 6182.8091\ W^{0.5803}$

b. *L. dorsalis* $BV = 47.3174\ L^{1.3119}$

$BV = 4489.174\ W^{0.7570}$

c. *L.* sp. $BV = 2522.2257\ W^{0.3265}$

30. The distribution of *Lithotrya* was restricted to the reef flats only while it was not detected in any coral sample collected from the lagoon.

31. The mean density of *Lithotrya* per kg of substrate on the seaward reef flat was 3.34 and 4.14 during 1990 and 1991 while its mean biomass was 8.580 and 12.170 g per kg of sample during these years respectively. On the lagoon reef flat, the mean density was 4.07 and 5.48 while the mean biomass was 2.390 and 3.090 g per kg of sample during 1990 and 1991 respectively.

D. HUMAN INTERFERENCES ON CORAL REEFS

1. The influence of human activities like blasting and dredging in the lagoon, removal of coral stones for construction, hand picking of live corals and fishing activities were found to contribute to the destruction of corals in Minicoy coral reefs.

The study provides conclusive evidence that coral reefs of Minicoy Island may be considered as a model of reef under stress. The reef corals are characterised by low species diversity and live coral cover, except for a few monospecific species in the deeper zones. The variation in ecological parameters are not considered as a major factors that cause mortality to corals while human activities were found to contribute to the destruction of reef corals in Minicoy. Trends discussed in the present study may became on useful tool for early identification of stress factors and for the effective management of the coral reefs.

REFERENCES

ACHITUV, Y. and **Z. DUBINSKY,** 1990. Evolution and zoogeography of coral reefs. In: Z. Dubinsky (Ed.). Ecosystems of the World **25:** Coral Reefs. Elsevier: pp. 1-10.

AHR, W.M. and **R.J. STANTON,** 1973. The sedimentologic and paleocologic significance of Lithotrya, a rock boring barnacle. J. Sed. Petrol., **43:** 20-33.

AL- HUSSAINI, A.H. 1945. The anatomy and history of the alimentary tract of the coral feeding fish, Scarus sordidus Klunz. Bull. Inst. Egypte, **27:** 349-377.

AL-HUSSAINI, A.H. 1947. The feeding habits and the morphology of the alimentary tract of some teleosts living in the neighbourhood of the Marine Biological Station, Ghardaqa, Red Sea. Publ. Mar. Biol. Sta. Ghardaqa Red Sea, **5:** 1-61.

ALLER, R.C. and **R.E. DODGE,** 1974. Animal-sediment relations in a tropical lagoon Discovery Bay, Jamaica. J. Mar. Res., **32:** 209-232.

ANDREWS, J.C. 1983. Water masses, nutrient levels and seasonal drift on the outer Queensland reef (Great Barrier Reef). Aust. J. Mar. Fresh. Res., **34:** 821-834.

ANDREWS, J.C. and **G.L. PICKARD,** 1990. The physical oceanography of coral reef systems. In: Z. Dubinsky (Ed.) Ecosystems of the World **25:** Coral Reefs. Elsevier: pp. 11-48.

***ANNANDALE, N.** 1915. Indian boring sponges of the family Clionidae. Res. Indian Mus., **11:** 1-24.

ANONYMOUS, 1983. Coral reefs, seagrass beds and mangroves. Their interaction in the coastal zones of the Caribbean. UNESCO Reports in Marine Sciences, **23:** 1-14.

ANONYMOUS, 1988. Coral Reefs of the World, Vol.2 Indian Ocean, Red Sea and Gulf. UNEP Regional Seas Directories and Bibliographics, IUCN, Gland, Switzerland and Cambridge, UK/UNEP, pp. 90-92.

ANSELL, A.D. and **B.N. NAIR,** 1969. A comparative study of bivalves which bore mainly by mechanical means. Am. Zool., **9:** 857-868.

APPUKUTTAN, K.K. 1972. Coral boring bivalves of Gulf of Mannar and Palk Bay. Proc. Symp. Corals and Coral reefs. Mar. Biol. Ass. India. 379-398.

APPUKUTTAN, K.K. 1973. Distribution of coral boring bivalves along the Indian coasts. J. Mar. Biol. Ass. India, **15**(1): 427-430.

ARNAUD, P.M. and **B.A. THOMASSIN,** 1976. First records and adaptive significance of boring into a free-living scleractinian coral (Heteropsammia michelini). Veliger, **18:** 367-374.

ATKINSON, M.J. 1988. Are coral reefs nutrient limited ? Proc. Sixth Int. Coral Reef Symp. Australia, **1:** 157-165.

BABCOCK, R. and **P. DAVIS,** 1991. Effects of sedimentation on settlement of Acropora millepora. Coral Reefs, **9:** 205-208.

BAILEY-BROCK, J.H. 1976. Habitats of Tubicolous polychaetes from the Hawaiian Islands and Johnston Atoll. Pac. Sci.,**30:** 69-81.

BAILEY-BROCK, J.H. 1985. Polychaetes from Fijian Coral Reefs. Pac. Sci., **39**(2): 195-220.

BAK, R.P.M. 1978. Lethal and sublethal effects of dredging and corals. Mar. Pollut. Bull.,**9:** 14-16.

BAK, R.P.M., M.J.E. CARPAY and **E.D. de RUYTER VAN STEVENINCK,** 1984. Densities of the sea urchin Diadema antillarum before and after mass mortalities on the coral reefs of Curacao. Mar. Ecol. Progr. Ser., **17:** 105-108.

BAK, R.P.M. and **J.H.B.W. ELGERSHUIZEN,** 1976. Patterns of oil sediment rejection in corals. Mar. Biol., **37:** 715-730.

BAK, R.P.M. and **M.S. ENGELS,** 1979. Distribution, abundance and survival of juvenile hermatypic corals (scleractinia) and the importance of life history strategies in the parent coral community. Mar. Biol., **54:** 341-352.

BAK, R.P.M. and **G. VAN EYS,** 1975. Predation of the sea urchin Diadema antillarum Philippi on living coral. Ocelogia, **20:** 111-115.

BAKUS, G.J., 1990. Quantitative Ecological Techniques. In: Quantitative Ecology and Marine Biology. Oxford of IBH Publishing Co. **153** pp.

BALASUBRAMANIAN, T. and **M.V.M. WAFAR,** 1974. Primary productivity of some fringing reefs of southeast India. Mahasagar, **7**(3&4): 157-162.

BANNER, H. ALBERT, 1974. Kaneohe Bay, Hawaii: Urban pollution and a coral reef ecosystem. Proc. Second Int. Coral Reef Symp. Brisbane, **2:** 685-702.

BARDACH, J.E. 1961. Transport of calcareous fragments by reef fish. Science, **133:** 98-99.

BATHEN, K.H. 1968. A descriptive study of the physical oceanography of Kaneohe Bay, Oahu, Hawaii. Hawaii Inst. Mar. Biol. Tech. Rep. **14:** 353 pp.

BAUER, J.C. 1980. Observations on geographic variations in population density of the echinoid Diadema antillarum within the western Atlantic. Bull. Mar. Sci., **30:** 509-514.

BELL, J.D. and **R. GALZIN,** 1984. Influence of live coral cover on coral-reef fish communities. Mar. Ecol. Prog. Ser., **15:** 265-274.

BERTRAM, G.C.L. 1936. Some aspects of the breakdown of corals at Ghardaqa Red Sea. Proc. Zool. Soc. Lond., **106:** 1011-1026.

BIRKELAND, C. 1977. The importance of rate of biomass accumulation in early successional stages of benthic communities to the survival of coral recruits. Proc. Third Int. Coral Reef Symp. Miami ,**1:** 15-21.

BIRKELAND, C. and **S. NEUDECKER,** 1981. Foraging behaviour of two Caribbean chaetodontids: Chaetodon capistratus and C. aculeatus. Copeia, **1:** 169-178.

BIRKELAND, C. and **R.H. RANDALL,** 1982. Facilitation of coral recruitment by echinoid excavations. Proc. Fourth Int. Coral Reef Symp. Manila, **1:** 695-698.

BLAKE, J.A. and **J.W. EVANS,** 1973. Polydora and related genera as borer in mollusk shells and other calcareous substrates. Veliger, **15:** 235-250.

BOAZ LAZAR and **YOSSI LOYA** (1991). Bioerosion of coral reefs - A chemical approach. Limnol. Oceanogr., **36**(2): 377-383.

BORRADAILE, L.A. 1906. Marine Crustaceans: The barnacles (Cirripedia). In: J.S. Gardiner (Ed.). The Fauna and Geography of the Maldives and Laccadive Archipelagoes. Cambridge University Press Vol.**2.** pp. 440-443.

BOUCHON-NAVARO, Y.C. BOUCHON and **M.L. HARMELIN-VIVIEN,** 1985. Impact of coral degradation of a chaetodontia fish assemblage (Moorea French Polynesia). Proc. Fifth. Int. Coral Reef Cong. Tahiti, **5:** 427-437.

BRANHAM, H.M. 1973. The crown of thorns on coral reefs. Bioscience, **23**(4): 219-225.

BRAWLEY, S.H. and **W.H. ADEY,** 1982. Coralliophila abbreviata: a significant corallivore: Bull. Mar. Sci., **32:** 595-599.

BROMLEY, R.G. 1978. Bioerosion of Bermuda reefs. Palaeogeogr. Palaeoclimatol Palaeocol. **23:** 169-197.

BUDDEMEIER, R.W. 1981. The geohydrology of Erewetak Atoll Islands and reefs. Proc. Fourth Int. Coral. Reef Symp. Manila, **1**: 339-345.

BUDDEMEIER, R. and **R. KINZIE,** 1976. Coral growth. Oceanogr. Mar. Biol. Annu. Rev., **14**: 183-225.

BURKHOLDER, P.R., L.M. BURKHOLDER and **L.R. ALMODOVAR,** 1967. Carbon assimilation in neritic waters of southern Puerto Rico. Bull. Mar. Sci., **17**: 1-15.

BURTON, M., 1934. Sponges. Sci. Rep. Great Barrier Reef Exped. **4**(14): 513-614.

CAMPBELL, A.C. and **R.F.G. ORMOND,** 1970. The threat of the crown-of-thorns starfish (Acanthaster planci) to coral reefs in the Indo-Pacific area: observations on a normal population in the Red Sea. Biol. Conserv., **2**: 246-251.

CARPENTER, R.C., 1981. Grazing by Diadema antillarum (Philippi) and its effects on the benthic algal community. J. Mar. Res., **39**: 749-765.

CARPENTER, R.C., 1984. Predator and population density control of homing behaviour in the Caribbean echinoid Diadema antillarum. Mar. Biol., **82**: 101-108.

CARPENTER, R.C. 1986. Partitioning herbivory and its effects on coral reef algal communities. Ecology, **56**: 345-363.

CARPENTER, K.E., R.I. MICLAT, V.D. ALBALADEJO and **V.T. CORPUZ,** 1982. The influence of substrate structure on the local abundance and diversity of Philippine reef fishes. Proc. Fourth Int. Coral Reef Symp. Manila, **2**: 498-502.

CHARUCHINDA, M. and **J. HYLLEBERG,** 1984. Skeletal extension of Acropora formosa at a fringing reef in the Andaman Sea. Coral Reefs, **3**: 215-219.

CHESHER, R.H. 1969. Destruction of Pacific corals by the sea star Acanthaster planci. Science, **165:** 280-283.

CHILINGAR, G.V., H.J. BISSELL and **K.H. WOLF,** 1967. Diagenesis of Carbonate Rocks. In: B. Larsen and G.V. Chilingar (Eds.). Diagenesis of Sediments. Elsevier Publ. Co. New York, pp. 1-551.

CHOAT, J.H. 1966. Parrot fish. Aust. Nat. Hist., **15:** 265-268.

CHOAT, J.H. 1983. Estimation of the abundance of herbivorous fishes and their grazing rates within reef systems. In: J.T. Baker, R.M. Carter, P.W. Sammarco and K.P. Stark (Eds.), Proceedings of the Inauguree Conference, Townsville, Great Barrier Reef, JCU, Townsville, pp. 171-177.

CLARK, R.B. and **M.E. CLARK,** 1960. The ligamentary system and the segmental musculature of Nephtys. Q. J. microsc. Sci., **101:** 149-176.

CLOUD, P.E., 1952. Preliminary report on the geology and marine environment of Onotoa Atoll, Gilbert Islands. Atoll. Res. Bull., **12:** 1-73.

CONNELL, J.H. 1973. Population ecology of reef-building corals. In: O.A. Jones and R. Endean (Eds.) Biology and Geology of Coral Reefs. Vol. **2** (Biol-1): 205-245.

CONNELL, J.H., 1978. Diversity in tropical rain forests and coral reefs. Science, **199:** 1302-1309.

COOPER, M., 1966. Destruction of marine fauna and flora in Fiji caused by the hurricane of February 1905. Pac. Sci., **20:** 137-141.

CORREDOR, J.E., C.R. WILKINSON, V.P. VINCENT, S.M. MORELL and **E.V. OTERO,** 1988. Nitrate release by Caribbean reef sponges. Limnol. Oceanogr., **33:** 114-120.

CORTES, J.N. and **M.J. RISK,** 1985. A reef under siltation stress: Cahuita, Costa Rica. Bull. Mar. Sci., **36:** 339-356.

CROSSLAND, C.J., B.G. HATCHER and **S.V. SMITH,** 1991. Role of coral reefs in global ocean production. Coral Reefs, **10:** 55-64.

***DARWIN, C.R.,** 1845. Journal of researches during the voyage of H.M.S. Beagle. Nelson London (Reprint).

DAVIS, P.J. and **P.A. HUTCHINGS,** 1983. Initial colonization, erosion and accretion on coral substrate: Experimental results. Lizard Island Great Barrier Reef. Coral Reefs, **2:** 27-35.

DEAN, T.A., 1981. Structural aspects of sessile invertebrates as organizing forces in an estuarine fouling community. J. Exp. Mar. Biol. Ecol., **53:** 163-180.

DEAN, T.A. and **L.E. HURD,** 1980. Development in an estuarine fouling community: the influence of early colonists on later arrivals. Oecologia, **46:** 295-301.

DE LAUBENFELS, M.W. 1954a. The Porifera of Bermuda Archipelago. Trans. Zool. Soc. Lond., **27:** 1-154.

DE LAUBENFELS, M.W., 1954b. The sponges of the West Central Pacific. St. Monogr. Stud. Zool., **7:** 1-306.

D'ELIA, C.F. and **K.L. WEBB,** 1977. The dissolved nitrogen flux of reef corals. Proc. Third Int. Coral Reef Symp. Miami, **1:** 325-330.

DITLER, H., 1978. Zonation of corals (Scleractinia Coelenterata) on intertidal reef flats at Ko Phukat, Eastern Indian Ocean, Mar. Biol., **47:** 29-39.

DODGE, R.E., R.C. ALLER and **J. THOMPSON,** 1974. Coral growth related to resuspension of bottom sediments. Nature, **247:** 547-577.

DODGE, R.E. and **J.R. VAISNYS,** 1977. Coral populations and growth patterns: Response to sedimentation and turbidity associated with dredging. J. Mar. Res., **35:** 715-730.

DORSETT, D.A., 1961. The behaviour of Polydora ciliata (Johnst). Tube building and burrowing. J. Mar. Biol. Ass. U.K., **41**: 577-590.

DOWNING, N. and **C.R. EL-ZAHR**, 1987. Gut evacuation and filling rates in the rock-boring sea urchin, Echinometra mathaei. Bull. Mar. Sci., **41**: 579-584.

DUERDEN, J.E., 1902. Boring algae as agents in the disintegration of corals. Bull. Am. Mus. Nat. Hist., **16**: 323-332.

EBBS, N.R., 1966. The coral-inhabiting polychaetes of the northern Florida reef tract. 1. Aphroditidae, Polynoidae, Amphinomidae, Euncidae and Lysaretidae. Bull. Mar. Sci., **16**: 485-555.

EBERT, T.A., 1968. Growth rates of the sea urchin Strongulocentrotus purpuratus related to food availability and spine abrasion. Ecology, **49**: 1075-1091.

EBLING, F.J., 1945. Formation and nature of the opecular chaetae of Sabellaria. Quart. J. Micr. Sci., **85**: 153-176.

EDMONDSON, C.H., 1928. Ecology of a Hawaiian coral reef. Bernice P. Bishop Mus. Bull.,**45**: 1-64.

EDMONDS, S.J., 1955. Australian Sipunculoidea. 1. The genera sipunculus, Xenosiphon and Siphonosoma. Aust. J. Mar. Fresh. Res., **6**: 82-97.

EDMONDS, S.J., 1956. Australian Sipunculoidea. II. The Genera Phascolosoma Dendrostomun, Golfingia, Aspidosiphon and Cleosiphon. Aust. J. Mar. Fresh. Res., **7**: 281-315.

EHRLICH, P.R., 1975. The population biology of coral reef fishes. Annu. Rev. Ecol. Syst., **6**: 211-247.

EMERY, K.O., 1956. Marine biology of Johnston Islands and its surrounding shallows, central Pacific Ocean. Bull. Geol. Soc. Amer., **67**: 1505-1520.

ENDEAN, R., 1971. The recovery of coral reefs devastated by catastrophic events with particular reference to current Acanthaster planci plagues in the tropical Indo-west Pacific region. J. Mar. Biol. Assoc. India, **13:** 1-13.

ENDEAN, R., 1973. Population explosions of Acanthastar planci and associated destruction of hermatypic corals in the Indo-West Pacific region. In: O.A. Jones and R. Endean (Eds.), Biology and Geology of Coral Reefs, 2. Biology 1. Academic Press, New York, pp. 389-438.

ENDEAN, R., 1974. Acanthaster planci on the Great Barrier Reef. Proc. Second Int. Coral Reef. Symp. Brisbane, **1:** 563-576.

ENDEAN, R., 1976. Destruction and recovery of Coral Reef communities. In: O.A. Jones and R. Endean (Eds.). Biology and Geology of Coral Reefs. Academic Press. Vol. **111** Biology 2, pp. 215-250.

ENDEAN, R., 1982. Crown-of-thorns starfish on the Great Barrier Reef. Endeavour, **6:** 10-14.

ENDEAN, R. and **A.M. CAMERON**, 1985. Ecocatastrophe on the Great Barrier Reef. Proc. Fifth Int. Coral Reef Congr. Tahiti, **5:** 309-314.

ENDEAN, R. and **M. CAMERON**, 1990a. Trends and new perspectives in coral reef ecology. In: Z. Dubinsky (Ed.). Ecosystems of the World **25:** Coral Reefs. Elsevier, pp. 469-492.

ENDEAN, R. and **M. CAMERON**, 1990b. Acanthaster planci population outbreaks. In: Z. Dubinsky (Ed.), Ecosystems of the World **25:** Coral Reefs. Elsevier, pp. 419-438.

ENDEAN, R. and **R.H. CHESHER**, 1973. Temporal and spatial distribution of Acanthaster planci population explosions in the Indo-West Pacific region. Biol. Conserv., **5:** 87-95.

ENDEAN, R. and **W. STABLUM**, 1973. The apparent extent of recovery of reefs of Australia's Great Barrier Reef devastated by the crown-of-thorns starfish. Atoll Res. Bull., **168**: 1-37.

EVANS, J.W., 1970. Palaeontological implications of a biological study of rock boring clams (Family Pholadidae). In: T.P. Crimes, and J.C. Harper (Eds.), Trace fossils. Seel, Liverpool, pp. 127-141.

FAO, 1975. Manual of methods in aquatic environment research. FAO. Fish. Tech. Paper, **137**: 1-238.

* **FAUVEL, P.**, 1930a. Annelides polychaetes de Nouvelle-Caledonie recuillies par Mme A. Pruvot-Folen 1928. Arch. Zool. Exp. Gen. Paris, **69**: 501-562.

FAUVEL, P., 1930b. Annelida Polychaeta of the Madras Government Museum. Bull. Madras Govt. Mus. New Ser., **1**(2): 1-72.

FAUVEL, P., 1932. Annelida Polychaeta of the Indian Museum, Calcutta. Mem. Indians Mus., **12**: 1-262.

FAUVEL, P., 1953. Annelida Polychaeta. In: R.B. Scymour Sewell (Ed.). The Fauna of India including, Pakistan, Ceylon, Burma and Malaya. Allahabad Press. 507 pp.

FISHELSON, L., 1973. Ecological and biological phenomena influencing coral species composition on the Reef Tables at Eilat (Gulf of Aqaba, Red Sea). Mar. Biol., **19**: 183-196.

FISK, D.A. and **V.J. HARRIOTT**, 1989. The effects of increased sedimentation in the recruitment and population dynamics of juvenile corals at Cape Tribulation, North Queensland. Great Barrier Reef Marine Park Authority Tech. Mem: 1-33.

* **FRYDL, P.**, 1977. The geological effect of grazing by parrot fish on a Barbados reef. M.Sc. thesis, Mc Gill University.

FRYDL, P. and **G.W. STEARN,** 1978. Rate of bioerosion by parrot fish in Barbados Reef environments. J. Sediment. Petrol., **48:** 1149-1157.

FUTTERER, D.K. 1974. Significance of the boring sponge Cliona for the origin of fine grained material of carbonate sediments. J. Sediment, Petrol., **44:** 79-84.

GANAPATI, P.N. and **R. NAGABHUSHANAM,** 1958. Record of a new pholad Panitella sp. from Shingle Island (in the Gulf of Mannar) with a note on its distribution. Curr. Sci., **27:** 394-398.

GARDINER, J.S. (Eds.). 1903, 1906. The Fauna and Geography of the Maldive and Laccadive Archipelagoes. Vol. **1&2.** Cambridge University Press, Cambridge, 470-1079 pp.

GARDINER, J.S., 1930. Photosynthesis and solution in formation of coral reefs. Proc. Linn. Soc. Lond., **5:** 65-71.

GARDINER, J.S., 1936. The reefs of the Western Indian Ocean. Trans. Linn. Soc. Lond., (Zool.) **19:** 393-465.

GARDINER, W.D., 1980a. Field assessment of sediment traps. J. Mar. Res., **38:** 41-52.

GARDINER, W.D., 1980b. Sediment trap dynamics and calibration: a laboratory evaluation. J. Mar. Res., **38:** 17-39.

GIRIJAVALLABHAN, K.G., I. DAVIDRAJ and **S.V. ALAVANDI,** 1989. Hydrobiology of the lagoons. Cent. Mar. Fish. Res. Inst. Bull. No.**43:** 200-211.

GLADFELTER, W.B., J.C. OGDEN and **E.H. GLADFELTER,** 1980. Similarity and diversity among coral reef fish communities a comparison between tropical western Atlantic (Virgin Islands) and tropical Central Pacific (Marshall Islands) patch reefs. Ecology, **61:** 1156-1168.

GYLNN, P.W., 1973. Ecology of Caribbean coral reef: plankton community with evidence for depletion. Mar. Biol., **22:** 1-23.

GLYNN, P.W. 1976. Some physical and biological determinants of coral community structure in the eastern Pacific. Ecol. Monogr. **46:** 431-456.

GLYNN, P.W. 1982. Acanthaster population regulation by a shrimp and a worm. Proc. Fourth Int. Coral Reef Symp. Manila, **2:** 607-612.

GLYNN, P.W. 1988. El Nino Warming, Coral mortality and reef framework destruction by echinoid bioerosion in the Eastern Pacific. Galaxea, **7:** 129-160.

GLYNN, P.W. 1990. Feeding ecology of selected coral reef macro consumers: patterns and effects on coral community structure. In: Z. Dubinsky (Ed.). Ecosystems of the World - **25** : Coral Reefs. Elsevier, pp. 365-400.

GLYNN, P.W. and **D.A. KRUPP,** 1986. Feeding biology of a Hawaiian sea star corallivore, Culcita novaeguineae Muller and Troschel. J. Exp. Mar. Biol. Ecol., **96:** 75-96.

GLYNN, P.W., R.H. STEWART and **J.E. McCOSKER,** 1972. Pacific coral reefs of Panama: structure, distribution and predators. Geol. Rundsch. **61:** 483-519.

GLYNN, P.W. and **G.M. WELLINGTON,** 1983. Corals and Coral Reefs of the Galapagos Islands. University of California Press, Berkeley, 330 pp.

GLYNN, P.W., G.M. WELLINGTON and **C. BIRKELAND,** 1979. Coral growth in the Galapagos: limitation by sea urchins. Science, **203:** 47-49.

GOHAR, H.A.F. and **A.F.A. LATIF,** 1963. Digestive proteolytic enzymes of some scarid and labrid fishes (from the Red Sea). Publ. Mar. Biol. Stn. Ghardaqa, **12:** 4-42.

GOHAR, A.F. and **G.N. SOLIMAN,** 1963. On three mytilid species boring in living corals. Publ. mar. biol. Stn. Ghardaqa, **12:** 66-98.

GOLUBIC, S., R.D. PERKINS and **K.T. LUKAS**, 1975. Boring micro-organisms and micro-borings in carbonate substrates. In: R.W. Frey (Ed.), The study of Trace Fossils. Springer, Berlin, Heidelberg, New York, pp. 229-259.

GOMEZ, E.D. and **A.C. ALCALA**, 1984. Survey of Philippine Coral Reefs using transect and quadrat techniques. In: Comparing Coral Reef Survey Method. UNESCO Reports in Marine Science, **21:** 57-69.

GONZALES, J.C. 1965. Primary production of the neritic and off shore waters of western Puerto Rico. Rep. Inst. Mar. Biol. Puerto Rico, **5:** 1-49.

GOODING, R.M. and **J.J. MAGNUSON**, 1967. Ecological significance of a drifting object to pelagic fishes. Pacif. Sci., **21:** 486-497.

GORDON, D.C., R.O. FOURNIER and **G.J. KRASINAK,** 1971. Note on the primary production in the Fanning atoll lagoon. Pac. Sci., **25:** 228-233.

GOREAU, T.F. 1959. The physiology of skeleton formation in corals. I. A method for measuring the rate of calcium deposition under different conditions. Biol. Bull. mar. biol. Lab., Woods Hole, **116:** 59-75.

GOREAU, T.F., N.I. GOREAU and **C.M. YONGE**, 1972a. On the mode of boring in Fungiacava cilatensis (Bivalvia: Mytilidae) J. Zool., Lond., **166:** 55-60.

GOREAU, T.F., N .I. GOREAU, C.M. YONGE and **Y. NEUMANN,** 1970. On feeding and nutrition in Fungiacava eilatensis (Bivalvia, Mytilidae), a commensal living in fungiid corals. J. Zool., Lond., **160:** 159-172.

GOREAU, T.F., N.I. GOREAU, T. SOOL RYEN, and **C.M. YONGE**, 1969. On a new commensal mytilid (Mollusca:Bivalvia) opening into the coelenteron of Fungia scutaria (Coelenterata). J. Zool., Lond., **158:** 171-195.

GOREAU, T.F. and **W.D. HARTMAN,** 1963. Boring sponges as controlling factors in the formation and maintenance of control reefs. Amer. Assoc. Adv. Sci., **75:** 25-54.

GOREAU, T.F., J.C. LANG, E.A. GRAHAM and **P.D. GOREAU,** 1972b. Structure and ecology of the Saipan reefs in relation to predation by Acanthaster planci (Linnaeus). Bull. Mar. Sci., **22:** 113-152.

GOSWAMY, S.C., 1973. Observations on some planktonic groups of Kavaratti Atoll (Laccadives). Indian Nat. Sci. Acad., **391**(6): 676-686.

GOSWAMY, S.C. 1979. Zooplankton studies in the Laccadive Sea (Lakshadweep). NIO Tech. Rept., 131-144.

GOSWAMY, S.C., 1983. Production and zooplankton community structure in the lagoon and surrounding sea at Kavaratti Atoll (Lakshadweep). Indian J. Mar. Sci., **12:** 31-34.

GRASSLE, J.F. 1973. Variety in coral reef communities. In: O.A. Jones and R. Endean (Eds.). Biology and Geology of Coral Reefs. Vol.**2:** pp. 247-270.

GRAVELY, F.H. 1941. Shells and other animal remains found on the Madras beach. I. Groups other than snails etc. Bull. Madras Govt. Mus. New Ser., **5:** 1-112.

GRIFFITHS, D.J. 1976. The photosynthetic activity of phytoplankton in the waters of coral reefs. Aust. J. Plant Physiol., **3:** 53-56.

GRIGG, R.W. 1983. Community structure, succession and development of coral reefs in Hawaii. Mar. Ecol. Prog. Ser., **11:** 1-14.

GRIGG, R.W. and **S.J. DOLLAR,** 1990. Natural and anthropogenic disturbance on coral reefs. In: Z. Dubinsky (Ed.). Ecosystems of the The World 25: Coral Reefs. Elsevier. pp. 439-452.

GRIGG, R.W. and **J.E. MARAGOS,** 1974. Recolonization of hermatypic corals on submerged lava flows in Hawaii. Ecology, **55:** 387-395.

GRUNBAUN, H., G. BERGMAN, D.P. ABBOTT and **J.C. OGDEN,** 1978. Intraspecific agonistic behaviour in the rock-boring sea urchin Echinometra lucunter (L.) (Echinodermata: Echinoidea). Bull. Mar. Sci., **28:** 181-188.

GYGI, R.A. 1975. Sparisoma viride (Bonnaterre) the stoplight parrotfish, a major sediment producer on coral reefs of Bermuda? Ecol. Geol. Helv., **68:** 327-359.

HALDER, B.P. 1975. Sipuncula of the Indian Ocean in the collection of the Zoological Survey of India. Proc. Int. Symp. on the Biology of the Sipuncula and Echinura **1:** 51-92.

HALLDAL, P. 1968. Photosynthetic capacities and photosynthetic action spectra of endozoic algae of the massive coral Favia. Biol. Bull. Mar. Biol. Lab. Woods Hole, **134:** 411-424.

HARGER, J.R.E. 1984. Rapid survey to technique to determine distribution and structure of coral communities. In: Comparing Coral Reef Survey Methods, UNESCO Reports in Marine Science, **21:** 83-91.

* **HARRIGAN, J.F.** 1972. The planula larva of Pocillopora damicornis: Lunar periodicity of swarming and substratum selection behaviour. Ph.D. dissertation, Department of Zoology, University of Hawaii, Honolulu.

HARRIOTT, V.J. 1985. Recruitment patterns of scleractinian corals at Lizard Island, Great Barrier Reef. Proc. Fifth Int. Coral Reef Symp. Tahiti, **4:** 367-372.

HARTMAN, O. 1954. Marine Annelids from the northern Marshall Islands Bikini and nearby atolls, Marshall Islands. US Geol. Surv. Prof. Pap. 260-Q, 617-644.

HARTMAN, W.D. 1958 Natural history of the marine sponges of southern New England. Bull. Peabody Mus. Nat. Hist., **12:** 1-155.

HAY, M.E. 1984. Patterns of fish and urchin grazing on Caribbean coral reefs: are previous results typical ? Ecology, **65**: 446-454.

HEIN, F.J. and **M.J. RISK,** 1975. Bioerosion of coral heads: inner patch reefs, Florida Reef Tract. Bull. Mar. Sci., **25**: 133-138.

HIATT, R.W. and **D.W. STRASBURG,** 1960. Ecological relationships of the fish fauna on coral reefs of the Marshall Islands. Ecol. Monogr., **30**: 65-127.

* **HIGHSMITH, R.C.** 1979. Corals: The inside story. Ph.D. Thesis, Univ. of Washington, Seattle. 321 pp.

HIGHSMITH, R.C. 1980a. Geographic patterns of coral bioerosion: A productivity hypothesis. J. Exp. Mar. Biol. Ecol., **46**: 177-196.

HIGHSMITH, R.C. 1980b. Burrowing by the Bivalve Mollusc Lithophaga curta in the Living Reef Coral Montipora berryi and a hypothesis of reciprocal larval recruitment. Mar. Biol., **56**: 155-162.

HIGHSMITH, R.C. 1981a. Coral Bioerosion: Damage relative to skeletal density. Am. Nat. **117**(2): 193-198.

HIGHSMITH, R.C. 1981b. Lime-boring algae in hermatypic coral skeletons. J. Exp. Mar. Biol. Ecol., **55**: 267-281.

HOBSON, E.S. 1974. Feeding relationships of Teleostean fishes on the coral reefs in Kona, Hawaii. U.S. Natl. Mar. Fish. Serv. Fish. Bull., **72**(4): 95-131.

HODGSON, G. 1990. Sediment and the settlement of larvae of the reef coral Pocillopora damicornis. Coral Reefs, **9**: 41-43.

HOEK, P.P.C. 1907. The cirripedia of the SIBOGA EXPEDITION. In: E.J. Brill (Ed.). SIBOGA EXPEDITION. Publishers and Printers Leiden, pp. 122-127.

HORNELL, J. 1922. Common Mollusca of South India. Madras Fish. Bull. **14:** 1-131.

HUBBARD, J.A.E.B. 1973. Sediment shifting experiments: a guide to functional behaviour in colonid corals. In. R.S. Boardman, A.H. Cheetham and W.A. Oliver, Jr. (Eds.). Animal Colonies: Development and Function Through Time. Dowden, Hutchinson and Ross. Penn. pp. 31-34.

HUBBARD, J.A.E.B. 1974. Scleractinian coral behaviour in calibrated current experiment: an index to their distribution patterns. Proc. Second. Int. Coral Reef Symp. Brisbane, **2:** 107-126.

HUBBARD, D.K. 1986. Sedimentation as a control of reef development. St. Corex, U.S. Coral Reefs, **5:** 117-175.

HUDSON, J.H. 1977. Long term bioerosion rates on a Florida reef: new method. Proc. Third Int. Coral Reef Symp. Miami, **2:** 491-498.

HUGHES, M.W. and **A.J. KEIJ**, 1973. Organisms as producers of carbonate sediment and indicators of environment in the Southern Persian Gulf. In: B.H. Purser. (Ed.) The Persian Gulf. Springer-Verlag, New York, 537 p.

HUNTER, W.R. 1949. The structure and behaviour of Hiatella gallicana (Lamarck) and H. arctica (L.) with special reference to the boring habit. Proc. Roy. Soc. Edinburg, **63:** 271-289.

HUNTER, I.G. 1977. Sediment production of Diadema antillarum on a Barbados fringing reef. Proc. Third Int. Coral Reef Symp. Miami, **2:** 105-109.

HUSTON, M.A. 1985. Patterns of species diversity on coral reefs. Ann. Rev. Ecol. Syst., **16:** 149-177.

HUTCHINGS, P.A. 1974. A preliminary report on the density and distribution of invertebrates living on coral reefs. Proc. Second Int. Coral Reef Symp. Brisbane, **1:** 285-296.

HUTCHINGS, P.A. 1981. Polychaete recruitment onto dead coral substrates at Lizard Island, Great Barrier Reef, Australia. Bull. Mar. Sci., **31**: 410-424.

HUTCHINGS, P.A. 1983a. Cryptofaunal Communities of Coral Reefs. In: D.J. Barnes (Ed.). Perspective on Coral Reefs. AIMS pp. 200-208.

HUTCHINGS, P.A. 1983b. Bioerosion of coral substrates. In: J.T. Baker, R.M. Carter, P.W. Sammarco, and K.P. Stark (Eds.). Proceedings: Inaugural Great Barrier Reef Conference, Townsville. JCU Townsville, pp. 113-120.

HUTCHINGS, P.A. 1984. A preliminary report on the spatial and temporal patterns of polychaete recruitment on the Great Barrier Reef. Proc. First Int. Poly. Conf. Sydney, Linn. Soc., N.S.W. 227-237.

HUTCHINGS, P.A. 1985. Variability in polychaete recruitment at Lizard Island, Great Barrier Reef: A long term study and an analysis of potential impact on coral reef ecosystems. Proc. Fifth Int. Coral Reefs Congr. Tahiti, **5**: 245-250.

HUTCHINGS, P.A. 1986. Biological destruction of coral reefs. A review. Coral Reefs, **4**(4): 239-252.

HUTCHINGS, P.A. and **L. BAMBER** (1985). Variability of bioerosion rates at Lizard Island, Great Barrier Reef: Preliminary attempts to explain these rates and their significance. Proc. Fifth Int. Coral Reef Congr. Tahiti, **2**: 333-338.

HUTCHINGS, P.A., W.E. KIENE, R.B. CUNNINGHAN and **C. DONNELLY,** 1992. Spatial and temporal patterns of non-colonial boring organisms (Polychaetes, Sipunculans and bivalve molluscs) in Porites at Lizard Island, Great Barrier Reef. Coral Reefs, **11**: 23-31.

HUTCHINGS, P.A. and **A. MURRAY,** 1982. Patterns of recruitment of polychaetes to coral substrates at Lizard Island, Great Barrier Reef - an experimental approach. Aust. J. Mar. Fresh. Res., **33**: 1029-1037.

HUTCHINGS, P.A. and **P.B. WEATE,** 1978. Comments on the technique of acid dissolution of coral rock to extract endo-cryptolithic fauna. Aust. Zool., **19:** 315-320.

HUTCHINGS, P.A. and **P.B. WEATE,** 1979. Experimental recruitment of endocryptolithic communities at Lizard Island, Great Barrier Reef. Preliminary results. NZ Dep. Sci. Ind. Res. Inf. Ser., **137:** 239-256.

IMAJIMA, M. and **H.A. ten HOVE,** 1984. Serpulinae (Annelida, Polychaeta) from the Truk Islands, Ponape and Majuro Atoll, with some other new Indo-Pacific records. Proc. Jap. Soc. Syst. Zool., **27:** 35-66.

IREDALE, T. 1939. Mollusca, Part I. Sci. Rep. Great Barrier Reef. Exped. **5:** 209-425.

IRVINE, G.V. 1981. The importance of behaviour in plant herbivore interactions: a case study. In: G.M. Caillet, and C.A. Simenstad (Eds.), Gutshop'81, Fish Food Habitat Studies. University of Washington Sea Grant Program, pp-240-248.

JACCARINI, V., W.H. BANNISTER and **H. MICALLEF,** 1968. The pallial glands and rock boring in Lithophaga lithophaga (Lamellibranchia, Mytilidae). J. Zool. Lond. **154:** 397-401.

JAGTAP, T.G. and **A.G. UNTAWALE,** 1984. Chemical composition of marine macrophytes and their surrounding water and sediment from Minicoy, Lakshadweep. Indian J. Mar. Sci., **13**(3): 123-125.

JAMES, D.B. 1989. Echinoderms of Lakshadweep and their zoogeography. Cent. Mar. Fish. Res. Inst. Bull. No.**43:** 97-144.

JAMES, D.B., C.S.G. PILLAI and **G. GOPAKUMAR,** 1990. A case study of infestation of Acanthaster planci in Andaman waters. Mar. Fish Infar. Serv. T & E Ser. No.**106:** 1-3.

JAMES, P.S.B.R., C.S.G. PILLAI, P.A. THOMAS, D.B. JAMES and SAID **KOYA,** 1989. Environmental damage and consequences. Cent. Mar. Fish. Res. Inst. Bull No.**43**: 212-227.

JAYARAMAN, R., C.P. RAMAMIRTHAM and **K.V. SUNDARARAMAN,** 1959. The vertical distribution of dissolved oxygen in the deeper waters of the Arabian Sea in the neighbourhood of the Laccadives during the summer, 1959. J. mar. biol. Ass. India, **2**(1): 24-34.

JOHANNES, R.E. 1970. How to kill a coral reef. Mar. Pollut. Bull., **1**: 186-187.

JOHANNES, R.E. 1975. Pollution and degradation of coral reef communities. In: E.J. Ferguson and R.E. Johannes (Eds.) Tropical Marine Pollution. Elsevier Scientific Publishing, Amsterdam. pp. 13-50.

JOHANNES, R.E., W.T. WIEBE and **C.J. CROSSLAND,** 1983. Three patterns of nitrogen flux in a coral reef community. Proc. Gt. Barrier Reef Conference, Australia: 331-332.

JONES, R.S. 1968. Ecological relationships in Hawaiian and Johnston Island Acanthuridae (Surgeon fishes). Micronesia, **4**: 309-361.

JONES, M.L. 1969. Boring of shell by Caebangia in freshwater snails of southeast Asia. Amer. Zool., **9**: 829-835.

JONES, S. and **M. KUMARAN,** 1980. Fishes of the Laccadive Archipelago. Nature Conservation and Aquatic Sciences Service, Trivandrum. pp. 1-760.

KAMURA, S. and **S. CHOONHABANDIT,** 1986. Algal communities within territories of the damselfish Stegastes apicalis and the effects of grazing by the sea urchin Diadema spp. in the Gulf of Thailand. Galaxea, **5**: 175-193.

KANWISHER, J.W. and **S.A. WAINWRIGHT,** 1967. Oxygen balance in some reef corals. Biol. Bull. Mar. Biol. Lab. Woods Hole, **133**: 378-390.

* **KELSO, D.** 1970. A comparative morphological and ecological study of two species of genus Echinometra in Hawaii. Ph.D. dissertation, Univ. of Hawaii, Dept. of Zoology.

KENCHINGTON, R.A. 1978. Visual surveys of large areas of coral reefs. In: D.R. Stoddart and R.E. Johannes (Eds.). Coral Reefs : Research Methods. UNESCO pp. 149-162.

KHAMALA, C.P.M. 1971. Ecology of Echinometra mathaei (Echinoidea: Echinodermata) at Diani Beach, Kenya. Mar. Biol., **11**: 167-172.

KIENE, W.E. 1985. Biological destruction of experimental coral substrates at Lizard Island, Great Barrier Reef, Australia. Proc. Fifth Int. Coral Reef Symp. Tahiti, **5**: 339-344.

KINSMAN, D.J.J. 1964. Reef coral tolerance of high temperatures and salinities. Nature, **202**: 1280-1282.

KIRSTEUER, E. 1972. Quantitative and qualitative aspects of the nemertean fauna in tropical coral reefs. Proc. Symp. Coral and Coral Reefs Mar. Biol. Assoc. India, 367-371.

KLEEMAN, K.H. 1977. A new species of Lithophaga (Bivalvia) from the Great Barrier Reef, Australia. Veliger, **20**: 151-154.

KLEEMAN, K.H. 1980. Boring bivalves and their host corals from the Great Barrier Reef. J. Moll. Stud., **46**: 13-54.

KOBLUK, D.R. and **M.J. RISK,** 1977. Rate and nature of infestation of carbonate substrates by a boring algae Ostreobium sp. J. Exp. Mar. Biol. Ecol., **27**: 107-115.

KOHN, A.J. 1975. Predation on sipunculans.· Proc. Int. Symp. on the Biology of the Sipuncula and Echiura, **1**: 313-334.

KOHN, A.J. and **P. HELFRICH,** 1957. Primary organic productivity of a Hawaiian coral reef. Limnol. Oceanogr., **2**: 241-251.

KOHN, A.J. and **M.C. LLOYD**, 1973. Polychaetes of truncated reef, limestone substrates on eastern Indian Ocean coral reefs diversity, abundance, and taxonomy. Int. Rev. Ges. Hydrobiol., **58:** 369-399.

KUNDU, H.L. 1965. On the Marine fauna of the Gulf of Kutch Part III. Pelecypoda. J. Bombay Nat. Hist. Soc., **62:** 84-103.

LEWIS, J.B. 1974. Settlement and growth factors influencing the contagious distribution of some Atlantic reef corals. Proc. Second Int. Coral Reef Symp., Brisbane, **2:** 201-206.

LEWIS, J.B. 1976. Experimental tests of suspension feeding in Atlantic reef corals. Mar. Biol., **36:** 147-150.

LEWIS, J.B. and **W.S. PRICE**, 1976. Patterns of ciliary currents in Atlantic reef corals and their functional significance. J. Zool. Lond., **178:** 77-89.

LOYA, Y. 1972. Community structure and species diversity of hermatypic corals at Eilat, Red Sea. Mar. Biol., **13:** 100-123.

LOYA, Y. 1982. Life history strategies of boring bivalves in corals. The reef and man. Proc. Fourth Int. Coral Reef Symp. Manila, **2:** 756 (Abstr.).

LOYA, Y. and **B. RINKEVICH**, 1980. Effects of oil pollution on coral reef communities. Mar. Ecol. Prog. Ser., **3:** 167-180.

LUCKHURST, B.E. and **K. LUCKHURST**, 1978. Analysis of the influence of substrate variables on coral fish communities. Mar. Biol., **49:** 317-323.

MAC GEACHY, J.K. 1977. Factors controlling sponge baring in Barbados reef corals. Proc. Third Int. Coral Reef. Symp. Miami, **2:** 477-483.

MAC GEACHY, J.K. and **C.W. STERAN**, 1976. Boring my macro-organisms in the coral Montastrea annularis on Barbados reefs. Int. Rev. Ges. Hydrobiol., **61:** 715-745.

MADHUPRATAP, M., M.V.M. WAFAR, P. HARIDAS, B. NARAYANAN, P. GOPALA MENON and **P. SIVADAS**, 1977. Comparative studies in the abundance of zooplankton in the surrounding sea and lagoons in the Lakshadweep. Indian J. Mar. Sci., **6**: 138-141.

MARAGOS, J.E. 1978. Measurement of water volume transport for flow studies. In: D.R. Stoddart and R.E. Johannes (Ed.). Coral Reefs: Research Methods, UNESCO, pp. 353-360.

MARSDEN, J.R. 1962. A coral eating polychaete. Nature, **193**: 598-612.

MARSDEN, J.R. and **D.T.ANDERSON**, 1981. Larval development and metamorphosis of the serpulid polychaete Galeolaria caespitosa Lamarck. Aust. J. Mar. Fresh. Res., **32**: 667-680.

MARSH, JR.J.A. and **S.V. SMITH**, 1978. Productivity measurements of coral reefs in flowing water. In: D.R. Stoddart and R.E. Johannes (Eds.). Coral Reefs: Research Methods. UNESCO: 361-378.

MARSHALL, N. 1965. Detritus over the reef and its potential contribution to adjacent waters of Eniwetok atoll. Ecology, **46**(3): 343-344.

MARSHALL, S.M. and **A.P. ORR**, 1931. Sedimentation on low Isles Reef and its relation to coral growth. Sci. Rep. Great Barrier Reef Exped., **1**: 93-133.

MAYER, A.G. 1918. Ecology of the Murray Island coral reef. Carnegie Inst. Wash. Publ. **213**: 1-48.

MAYER, A.G. 1924. Structure and ecology of samoan reefs. Carnegie Inst. Wash. Publ., **340**: 1-25.

* **MELVILL, J.C,.** 1909. Report on the marine mollusca obtained by Mr. J. Stanley Gardiner, F.R.S. among the islands of the Indian Ocean in 1905. Trans. Linn. Soc. Lond., **13**: 65-137.

MCCARTHY, J.J. 1972. The uptake of urea by natural population of marine phytoplankton. Limnol. Oceanogr., **17**: 738-748.

McCLOSKEY, L.R. 1970. The dynamics of the community associated with a marine scleractinian coral. Int. Rev. Ges. Hydrobiol., **55:** 13-81.

MCLEAN, R.F. 1974. Geologic significance of Bioerosion of beach rock. Proc. Second. Int. Coral Reef Symp. Brisbane, **2:** 401-409.

MC MICHAEL, D.F. 1974. Growth rate, population size and mantle colouration in the small grant clam. Tridacna maxima (Robing) at One Tree Island, Capricorn Group, Queensland. Proc. Second Int. Coral Reef Symp. Brisbane, **1:** 241-245.

Mc WILLIAM, P.S., P.F. SALE and **D.T. ANDERSON,** 1981. Seasonal changes in resident zooplankton sampled by emergence traps in One Tree Lagoon, Great Barrier reef. J. Exp. Mar. Biol. Ecol., **52:** 185-203.

MOORE, H.B. 1966. Ecology of echinoids. In: R.A. Boolootian (Ed.). Physiology of Echinodermata New York, John Wiley & Sons, pp. 73-83.

MOORE, C.H. and **W.W. SHEDD,** 1977. Effective rates of sponge bioerosion as a function of carbonate production. Proc. Third Int. Coral Reef Symp. Miami, **2:** 499-505.

MOORHOUSE, F.W. 1933. The temperature of the waters in the anchorage, Low Isles. Sci. Rep. Great Barrier Reef Exped., **2:** 98-101.

MORAN, D.P. and **M.L. REAKA,** 1988. Bioerosion and availability of shelter for benthic reef organisms. Mar. Ecol. Prog. Ser., **44:** 249-263.

MORRISON, D. 1988. Comparing fish and urchin grazing in shallow and deeper coral reef algal communities. Ecology, **69:** 1367-1382.

MORTENSEN, T. 1943. A Monograph of the Echinoidea, Camarodonta. C.A. Reitzel (Ed.) Copenhagen. Vol.**3**. No.3. pp.1-189.

MORTON, B.S. and **P.J.B. SCOTT,** 1980. Morphological and functional specializations of the shell, musculature and pallial glands in the Lithophagninae (Mollusca: Bivalvis). J. Zool. Lond., **192:** 179-203.

MULLIN, J.B. and **J.P. RILEY,** 1955. The spectrophotometric determination of nitrate in natural water with particular reference to sea water. Anal. Chim. Acta, **12:** 464-480.

MURPHY, J. and **J.P. RILEY,** 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta, **27:** 31-36.

MURTHY, V.S., M. KUMARAN and **R.S. LALMOHAN,** 1989. Resources of Ornamental Fishes. Cent. Mar. Fish. Res. Inst. Bull. No.**43:** 46-64.

MURTHY, A.V.S., G. SUBBA RAJU, C.S. GOPINADHA PILLAI, V.S.JOSANTO, P. LIVINGSTON and **R. VASANTHAKUMAR,** 1979. On the occurrence of Acanthaster planci (The crown of thorns) at Minicoy atoll. Mar. Fish. Infor. Serv. T&E Ser., **13:** 10-12.

MUSCATINE, L., T.H. MASUDA and **R. BURNAP,** 1979. Ammonium uptake by symbiotic and aposymbiotic reef corals. Bull. Mar. Sci., **29:** 572-575.

NAIR, P.V.R and **C.S. GOPINADHA PILLAI,** 1972. Primary productivity of some coral reefs in the Indian Seas. Proc. Symp. Corals and Coral Reefs: Mar. Biol. Ass. India, 33-42.

NAIR, P.V.R., A.V.S. MURTY, C.P. RAMAMIRTHAM, D.S. RAO and **V.K. PILLAI** 1986a. Environment features in the sea around Lakshadweep. Mar. Fish. Infor. Serv. T&E, Ser., **68:** 10-13.

NAIR, P.V.R., G. SUBBARAJU, K.J. MATHEW, V.K. PILLAI and **V.K. BALACHANDRAN,** 1986b. Productivity of the seas around Lakshadweep. Mar. Fish. Infor. Serv. T&E., Ser., **68:** 13-15.

NEUDECKER, S. 1981. Effect of substratum orientation, depth and time on coral recruitment of Guam. Proc. Fourth Int. Coral Reef. Symp. Manila, **2:** 376 (Abstr.).

NEUMANN, A.C. 1966. Observations on coastal erosion in Bermuda and measurements of the boring rate of the sponge Cliona lamps. Limnol. Oceanogr., **11**: 92-108.

NIELSEN, C. 1976. Notes on boring bivalves from Phuket, Thailand, Ophelia, **15**: 141-148.

NISHIHIRA, M. and **K. YAMAZATO,** 1974. Human interference with coral reef community and Acanthaster infestation at Okinawa. Proc. Second Int. Coral Symp. Brisbane, **1**: 577-590.

ODUM, H.T. and **E.P. ODUM,** 1955. Trophic structure and productivity of a windward coral reef community of Eniwetok Atoll. Ecol. Monogr. **25**: 291-320.

OGDEN, J.C. 1977. Carbonate-sediment production by parrot fish and sea urchins on Caribbean reefs. In: S.H. Frost, M.P. Weiss and J.B. Saunders (Eds.), Reefs and Related Carbonates - Ecology and Sedimentology. Am. Assoc. Petrol. Geol., Stud. Geol., **4**: 281-288.

OGDEN, J.C., R.A. BROWN and **N. SALESKY,** 1973. Grazing by the echinoid Diadema antillarum Philippi: formation of halos around West Indian patch reefs. Science, **182**: 715-717.

* **OHLHORST, S.L.** 1980. Jamaican coral reefs important biological and physical parameters. Ph.D. thesis. Yale Univ. New Haven, Conn.

ORMOND, R.F.G., N.J. HANSCOMB and **D.H. BEACH,** 1976. Food selection and learning in the crown-of-thorns starfish, Acanthaster planci (L.). Mar. Behav. Physiol., **4**: 93-105.

ORR, A.P. 1933. Variations in some physical and chemical conditions on a near Low Isles reef. Sci. Rep. Great Barrier Reef Exped., **2**: 87-98.

OTT, B. and **J.B. LEWIS,** 1973. The importance of the gastropod Coralliophila abbreviata (Lamarck) and the polychaete Hermodice carunculata (Pallas) as coral reef predators. Can. J. Zool., **50**: 1651-1656.

OTTER, G.W. 1937. Rock destroying organisms in relation to coral reefs. Sci. Rep. Great Barrier Reef Exped., **1:** 323-352.

PATIL, M.R. and **C.P. RAMAMIRTHAM,** 1963. Hydrography of Laccadive off shore waters. A study of the winter conditions. J. Mar. Biol. Ass. India, **5**(2): 159-169.

PEARSE, J.S. 1969. Preproductive periodicities of Indo-Pacific Invertebrates in the Gulf of Suez. II. The Echinoid Echinometra mathaci (De Blainville). Bull. Mar. Sci., **19:** 580-613.

PEARSON, R.G. and **R. ENDEAN,** 1969. A preliminary study of the coral predator Acanthaster planci (L.) (Asteroidea) on the Great Barrier Reef. Fisheries Notes, Queensl. Dep. Harbours and Marine, Brisbane, **3:** 27-55.

PETER, E.C. and **M.E.Q. PILSON,** 1985. A comparative study of the effect of sedimentation on symbiotic and asymbiotic colonies of the coral Astrangia danae (Milne-Edwards and Haime 1849) J. Exp. Mar. Biol. Ecol., **92:** 215-230.

PEYROT-CLAUSADE, M. 1974. Ecological study of coral reef Cryptobiotic communities: An analysis of the Polychaete Cryptofauna. Proc. Second Int. Coral Reef Symp. Brisbane, **1:** 269-283.

PICKARD, G.L. 1986. Effect of wind and tide on upper layer currents at Davies Reef, Great Barrier Reef, during MECOR (July-August 1984). Aust. J. Mar. Fresh. Res., **37:** 545-565.

PILLAI, C.S. GOPINADHA, 1971. Distribution of shallow-water corals at Minicoy Atoll in the Indian Ocean. Atoll. Res. Bull. Wash., **141:** 1-12.

PILLAI, C.S. GOPINADHA, 1971a. Composition of the coral fauna of the south eastern coast of India and the Laccadives. Symp. Zool. Soc. Lond., **28:** 301-328.

PILLAI, C.S. GOPINADHA, 1971b. The distribution of corals on the reefs at Mandapam, Palk Bay. J. Mar. Biol. Ass. India, **11** (1&2): 62-72.

PILLAI, C.S. GOPINADHA, 1972. Stony corals of the seas around India. Proc. Symp. Corals and Coral Reefs. Mar. Biol. Ass. India, 191-216.

PILLAI, C.S. GOPINADHA, 1973. Regional variation in Indian Ocean Coral Reefs. Edited by D.R. Stoddart and Maurice Yonge (Book Review). J. mar. biol. Ass. India, **14**(2): 895-896.

PILLAI, C.S. GOPINADHA, 1975. An assessment of the effect of environment and human interference on the coral reefs of Palk Bay and Gulf of Mannar along the Indian coast. Seafood Export J., **7**: 1-13.

PILLAI, C.S. GOPINADHA, 1986. Status of coral reefs in Lakshadweep Mar. Fish. Infor. Serv. T&E Ser., **68**: 38-41.

PILLAI, C.S. GOPINADHA, 1987. Structure and generic diversity of recent scleractinia of India. J. mar. biol. Ass. India, **25**(1&2): 78-90.

PILLAI, C.S. GOPINADHA, 1990. The endangered marine and terrestrial habitats of Minicoy Atoll in Lakshadweep. In: J.C. Daniel and J.S. Serrao (Eds.) Conservation in Developing Countries: Problems and Prospects. Bombay Natural History Society, Oxford University Press: pp. 267-276.

PILLAI, C.S. GOPINADHA and **K.K. APPUKUTTAN,** 1980. Distribution of molluscs and around the coral reefs of the southeastern coast in India. J. Bombay Nat. Hist. Soc., **77**: 26-47.

PILLAI, C.S. GOPINADHA and **S. JASMINE,** 1989. The coral fauna of Lakshadweep. Cent. Mar. Fish. Res. Inst. Bull. No.**43**: 179-195.

PILLAI, C.S. GOPINADHA and **MADAN MOHAN,** 1986. Ecological stress in Minicoy lagoon and its impact on tuna live baits. Mar. Fish. Infor. Serv. T&E Ser., **68**: 33-37.

PILLAI, C.S.G. and **G. SCHEER,** 1976. Report on the stony corals from the Maldive Archipelago. Zoologica, **126:** 1-83.

POMPONI, S.A. 1977. Etching cells of boring sponges: An ultrastructural analysis. Proc. Third Int. Coral Reef Symp. Miami, **2:** 485-490.

POR, F.D. 1975. Boring species of Aspidosiphon (Sipuncula) on the coast of Israel. Proc. Int. Symp. on the Biology of the Sipuncula and Echiura, **1:** 301-304.

PORTER, J.W. 1972. Patterns of species diversity in Caribbean reef corals. Ecology, **53:** 745-748.

POTTS, D.C. 1982. Crown-of-thorns starfish-man-induced pest or natural phenomenon? In: R.L. Kitching & R.E. Jones (Eds.). The Ecology of Pests, Some Australian Case Histories, CSIRO, Canberra, Australia, pp. 55-86.

POTTS, D.C. and **P.K. SWART,** 1984. Water temperature on an indicator of environmental variability on a careef. Limnol. Oceanogr., **29**(3): 504-516.

PURCHON, R.D. 1955a. The structure and function of British Pholadidae (rock-boring Lamellibranchia). Proc. Zool. Soc. Lond., **124:** 859-911.

PURCHON, R.D. 1955b. The functional morphology of the rock-boring lamellibranch Petricola Pholadiformis Lamarck. J. Mar. biol. Ass. U.K., **34:** 257-278.

PURCHON, R.D. 1968. The biology of the mollusca. Int. Ser. Monogr. Pure Appl. Biol. Zool., **40:** 1-560.

QASIM, S.Z. and **P.M.A. BHATTATHIRI,** 1971. Primary productivity of a seagrass bed on Kavaratti Atoll (Laccadives). Hydrobiol., **38:** 29-38.

QASIM, S.Z., P.M.A. BHATTATHIRI and **C.V.G. REDDY,** 1972. Primary production of an atoll in the Laccadives. Int. Rev. Ges. Hydrobiol., **57**(2): 207-225.

QASIM, S.Z. and **V. SANKARANARAYANAN,** 1970. Production of particulate organic matter by the reef on Kavaratti Atoll (Laccadives). Limnol. Oceanogr., **15:** 574-578.

RANDALL, J.E. 1955. Fishes of the Gilbert Islands Atoll Res. Bull., **47:** 1-243.

RANDALL, J.E. 1967. Food habits of reef fishes of the West Indies. Stud. Trop. Oceanogr., **5:** 665-847.

RANDALL, J.E. 1974. The effect of fishes on coral reefs. Proc. Second Int. Coral Reef Symp., Brisbane, **1:** 159-166.

RANDALL, J.S., S. HEAD and **A. SANDERS,** 1978. Food habits of the giant hump-head wrasse, Cheilinus undulatus (Labridae). Environ. Biol. Fishes., **3:** 235-238.

RAO, GANGADHARA, L.V. and **R. JAYARAMAN,** 1966. Upwelling in the Minicoy region of the Arabian Sea. Curr. Sci., **35**(15): 378-380.

REDDIAH, K. 1975a. Sipuncular habitats of the Peninsular India. Proc. Int. Symp. on the Biology of the Sipuncula and Echiura, **1:** 297-300.

REDDIAH, K. 1975b. The formation of secondary rock on a reef flat and its effect on reef organisms. Proc. Int. Symp. on the Biology of the Sipuncula and Echiura, **1:** 285-294.

REED, J.K. and **P.M. MIKKELSEN,** 1987. The molluscan community associated with the Scleractinian coral Oculina varicosa. Bull. Mar. Sci., **40:** 99-131.

REESE, E.S. 1977. Coevolution of corals and coral feeding fishes of the family chaetodontidae. Proc. Third Int. Coral Reef Symp. Miami, **1:** 267-274.

RICARD, M. 1977. Phytoplankton contribution to primary productivity in two coral reef areas of Fiji Islands and French Polynesia. Proc. Third Int. Coral Reef Symp. Miami, **1:** 343-348.

RICE, M.E. 1969. Possible boring structures of sipunculids. Am. Zool., **9:** 803-812.

RICE, M.E. 1975. Observation on the development of six species of Caribbean Sipuncula with a review of development in the phyllum. Proc. Int. Symp. on the Biology of the Sipuncula and Echiura, **1:** 141-160.

RICE, M.E. and **I.G. MACINTYRE,** 1972. A preliminary study of spipuncular burrows in rock thin sections. Can. J. Sci., **12:**

RICE, M.E. and **I.G. MACINTYRE,** 1982. Distribution of Sipuncula in the coral reef community, Carrie Bow Cay, Belize. In: K. Rutzler and I.G. Mac Intyre (Eds.). The Atlantic Barrier Reef Ecosystem at Carrie Bow Cay, Belize, I. Structure and communities. Smithsonian Institution Press, Washington, pp. 311-320.

RISK, M.J. and **J.K. MACGEACY,** 1978. Aspects of bioerosion of modern Caribbean Reefs. Rev. Biol. Trop., **26:** 85-105.

ROGERS, C.S. 1979. The effect of shading on coral reef structure and function. J. Exp. Mar. Biol. Ecol., **41:** 269-288.

ROGERS, C.S. 1983. Sublethal and lethal effects of sediments applied to common Caribbean reef corals in the field. Mar. Pollut. Bull., **14:** 378-382.

ROGERS, C.S. 1990. Responses of coral reefs and reef organisms to sedimentation. Mar. Ecol. Prog. Ser., **62:** 185-202.

ROUGHGARDEN, J. 1975. Evolution of marine symbiosis - a simple cost-benefit model. Ecology, **56:** 1201-1208.

RUSS, G. 1984a. Distribution and abundance of herbivorous grazing fishes in the Central Great Barrier Reef, 1. Levels of variability across the entire continental shelf. Mar. Ecol. Prog. Ser., **20**: 23-34.

RUSS, G. 1984b. Distribution and abundance of herbivorous grazing fishes in the Central Great Barrier Reef. II. Patterns of zonation of mid-shelf and outershelf reefs. Mar. Ecol. Prog. Ser., **20**: 35-44.

RUSSELL, B.C., G.R.V. ANDERSON and **F.H. TALBOT**, 1977. Seasonality and recruitment of coral reef fishes. Aust. J. Mar. Fresh. Res., **28**: 521-528.

RUSSO, A.R. 1977. Water flow and the distribution and abundance of echinoids (Genus: Echinometra) on an Hawaiian reef. Aust. J. Mar. Fresh. Res., **28**: 693-702.

RUSSO, A.R. 1980. Bioerosion by two rock boring echinoids (Echinometra mathae and Echinostrophus aciculatus) on Enewetak Atoll, Marshall Islands. J. Mar. Res., **38**: 99-110.

RUTZLER, K. 1974. The burrowing sponges of Bermuda. Smithson Cont. Zool., **165**: 1-32.

RUTZLER, K. 1975. The role of burrowing sponges in bioerosion. Oceologia, **19**: 203-216.

RUTZLER, K. 1978. Sponges in coral reefs. In: P.R. Stoddart and R.E. Johannes (Eds.). Coral Reefs: Research Methods. UNESCO, pp. 299-314.

RUTZLER, K. and **G. RIEGER**, 1973. Sponge burrowing: fine structure of Cliona lampa penetrating calcareous substrate. Mar. Biol., **21**: 144-162.

SALE, P.F. and **B.J. SHARP**, 1983. Correction for bias in visual transect censuses of coral reef fishes. Coral Reefs, **2**: 37-42.

SALIM, R.V. and **R.A. KENCHINGTON,** 1988. The need for management. In: R.A. Kenchington and B.E.T. Hudson (Eds.). Coral Reef Management Handbook. UNESCO. pp. 9-13.

SAMMARCO, P.W. 1980. Diadema and its relationship to coral spat mortality: grazing, competition and biological disturbance. J. Exp. Mar. Biol., **45:** 245-272.

SAMMARCO, P.W. 1982. Echinoid grazing as a structuring force in coral communities: whole reef manipulations. J. Exp. Mar. Biol. Ecol., **61:** 31-55.

SAMMARCO, P.W., J.S. LEVINTON and **J.C. OGDEN,** 1974. Grazing and control of coral reef community structure by Diadema antillarum Philippi (Echinodermata: Echinoidea): a preliminary study. J. Mar. Res., **32:** 47-53.

SANKARANARAYANAN, V.N. 1973. Chemical characteristics of waters around Kavaratti Atoll (Laccadives). Indian J. Mar. Sci., **2:** 23-26.

SANO, M., M. SHIMIZU and **Y. NOSE,** 1987. Long-term effects of destruction of hermatypic corals by Acanthaster planci infestation on reef fish communities at Iriomote Island, Japan. Mar. Ecol. Prog. Ser., **37:** 191-199.

SATYAMURTI, S.T. 1956. The mollusca of Krusadi Island (in Gulf of Mannar), Scaphopoda, Pelecypoda and Cephalopoda. Bull. Madras Govt. Mus. New. Ser., **1:** 1-202.

SCHROEDER, P.C. and **C.O. HERMANS,** 1975. Annelida: Polychaeta. In: A.C. Giese and J.S. Pearse (Eds.). Reproduction of Marine Invertebrates, Vol.III. Annelids and Echiurans. (Academic Press: New York) pp. 1-213.

SCHULTZ, L.P. 1958. Review of the parrot fishes, family Scaridae. Bull. U.S. Nat. Mus., **214:** 1-143.

SCOFFIN, J.P., C.W. STEARN, D. BOUCHER, P. FRYDL, C.M. HAWKINS, I.G. HUNTER and **J.K. MACGEACHY,** 1980. Calcium carbonate budget of a fringing reef on the west coast of Barbados. Bull. Mar. Sci., **30:** 475-508.

SEIBOLD, E., L. DIESTER, D. FULTERER, H. MULLER and **F. WERNER,** 1973. Holocene sediments and sedimentary processes in the Iranian part of the Persian Gulf. In: B.H. Purser. (Ed.) The Persian Gulf Springer-Verlag, New York, 537 pp.

SEN GUPTA, R., CAROLINE MORAES, T.N. KUREISHY, V.N. SANKARA-NARAYANAN, T.K. JANA, S.W.A. NAQVI and **M.D. RAJAGOPAL,** 1979. Chemical oceanography of Arabian Sea. Part IV - Laccadive Sea. Indian J. Mar. Sci., **8:** 215-221.

SHEPPARD, C.R.C. 1980. Coral cover, zonation and diversity on reef slopes of chagos Atolls, and population structure of the major species. Mar. Ecol. Prog. Ser., **2:** 193-205.

SHIBATA, K. and **F.T. HAXO,** 1969. Light transmission and spectral distribution through epi and endozoic algal layers in the brain coral, Favia. Biol. Bull. mar. Biol. Lab., Woods Hole, **136:** 461-468.

SHIPLEY, A.E. 1903. Sipunculoidea, with an account of a new genus Lithacrosiphon. In: J.S. Gardiner, (Ed.). Fauna and Geography of the Maldive and Laccadive Archipelagoes, **1:** 131-140.

SIVADAS, P. 1977. Report on the occurrence of Acanthaster sp. in Lakshadweep waters. Mahasagar, **10:** 170-180.

SLOAN, N.A. 1982. Size and structure of Echinoderm populations associated with different coexisting coral species at Aldabra Atoll, Seychelles. Mar. Biol., **66:** 67-75.

SMITH, C.L. and **J.C. TYLER,** 1972. Space resource sharing in a coral reef fish community. In: B.B. Collette and S.A. Earle, (Eds.) Results of the Tektite Program: Ecology of Coral Reef Fishes. Nat. Hist. Mus. Los Angeles County Sci. Bull., **14:** 125-170.

SMITH, R.L. and **A.C. PAULSON,** 1974. Food transit times and gut pH in two Pacific parrotfish. Copeia, **3:** 769-799.

SMITH, R.L. and **A.C. PAULSON,** 1975. Carbonic anhydrase in some coral reef fishes adaptation to carbonate ingestion ? Comp. Biochem. Physiol., **50**A: 131-134.

SMITH, S.V. 1973. Carbondioxide dynamics. A record of organic carbon production, respiration and calcification in the Enewetak Reef flat community. Limnol. Oceanogr., **18:** 106-120.

SMITH, S.V. 1978. Coral-reef area and contribution of reefs to processes and resources of the world's oceans. Nature, **273:** 225-226.

SMITH, S.V. and **P.L. JOKIEL,** 1975. Water composition and biogeochemical gradients in the Canton Atoll Lagoon: 2. Budget of phosphorus, nitrogen, carbondioxide and particulate materials. Mar. Sci. Comm. **1:** 165-207.

SOLIMON, G.N. 1969. Ecological aspects of some coral-boring gastropods and bivalves of the northwestern Red Sea. Am. Zool., **9:** 887-894.

SOROKIN, Y.I. (1990). Plankton in the reef ecosystems. In: Z. Dubinsky (Ed.). Ecosystems of the world 25 - Coral Reefs Elsevier, pp. 291-327.

SOROKIN, Y.I., V.S. TYAPKIN, and **NGUEN TAK AHN,** 1982. Primary production in coastal waters of the central Vietnam. Mar. Biol. (Vladivostok), **6:** 12-17.

SOURNIA, A. and **M. RICARD,** 1976 Phytoplankton, and its contribution to primary production in two coral reef areas of French Polynesia. J. Exp. Mar. Biol. Ecol., **121:** 121-140.

STEARN, C.W. and **T.P. SCOFFIN,** 1977. Carbonate budget of a fringing reef, Barbados. Proc. Third Int. Coral Reef Symp. Miami, **2:** 471-476.

STEPHEN, A.C. 1941. Sipunculids and echiurids of the Sir John Murray Expedition to the Red Sea and Indian Ocean 1933-1934. Scient. Rep. John Murray Exped., **7:** 401-409.

STEPHEN, A.C. and **S.J. EDMONDS,** 1972. The Phyla Sipuncula and Echiura. British Mus Nat. Hist., London, pp. 1-528.

STEPHENSON, W. and **R.B. SEARLE,** 1960. Experimental studies on the ecology of intertidal environments at Heron Island. Aust. J. Mar. Fresh. Res., **11:** 241-267.

STODDART, D.R. 1966. Reef studies at Addu Atoll, Maldive Islands. Atoll Res. Bull., No. **116:** 122 pp.

STODDART, D.R. 1969. Ecology and morphology of recent coral reefs. Biol. Review, **44:** 433-498.

STRAUGHAN, D. 1972. Ecological studies of Mercierella enigmatica Fauvel (Annelida: Polychaete) in the Brisbane River. J. Anim. Ecol., **41:** 93-136.

STRICKLAND, J.D.H. and **T.R. PARSONS,** 1968. A practical handbook of seawater analysis. Bull. Fish. Res. Bd. Can., **167:** 1-311.

SUKARNO, 1984. A review of coral reef survey and assessment methods currently in use in Indonesia. In: Comparing Coral Reef Survey Methods. UNESCO Reports in Marine Science, **12:** 74-82.

SURESH, V.R. 1991. Studies on the Coral Reefs of Lakshadweep. Ph.D. Thesis, Cochin University of Science and Technology, 123 pp.

THOMAS, P.A. 1979a. Boring sponges destructive to economically important molluscan beds and coral reefs in Indian seas. Indian J. Fish., **26** (1&2): 163-200.

THOMAS, P.A. 1979b. Demospongiae of Minicoy Island (Indian Ocean) Part 1. Orders - Keratosida and Haplosclerida. J. Mar. Biol. Ass. India, **21**(1&2): 10-16.

THOMAS, P.A. 1980a. Demospongiae of Minicoy Island (Indian Ocean) Pt. 3 - Orders Halichondrida, Hadromerida, Epipolasida and Choristida. J. Mar. Biol. Ass. India, **22**(1&2): 8-20.

THOMAS, P.A. 1980b. Demospongiae of Minicoy Island (Indian Ocean) Pt. 2-Order Poecilosclerida. J. Mar. Biol. Ass. India, **22**(1&2): 1-7.

THOMAS, P.A. 1983. Some pathological aspects akin to sponge boring in molluscan shells. Proc. Symp. Coastal aquaculture. Mar. Biol. Ass. India, **2**: 671-676.

THOMAS, P.A. 1988. Sponge generated bioerosion in Lakshadweep. Mar. Fish. Infor. Serv. T&E Ser., **86**: 20-26.

THOMAS, P.A. 1989. Sponge Fauna. Cent. Mar. Fish. Res. Inst. Bull. No.**43**: 150-161.

THOMAS, K.K. APPUKUTTAN, K. RAMADOSS and **S.G. VINCENT**, 1983a. Calabiocavitological investigations. Mar. Fish. Infor. Serv. T&E. Ser., **49**: 1-13.

THOMAS, P.A., K.K. APPUKUTTAN, K. RAMADOSS and **S.G. VINCENT,** 1983b. Calcibiocavitological investigations. 1. Mar. Fish. Infor. Serv. T&E Ser., **55**: 12-13.

* **THOMASSIN, B.A.** 1976. Feeding behaviour of the felt, sponge, and coral-feeder sea stars, mainly Culcita schmideliana. Helgol. Wiss. Meeresunters, **28**: 51-65.

* **THOMPSON, J.H. Jr.** 1979. Effects of drilling mud on seven species of reef building corals as measured in field and laboratory. Final Report to the U.S. Geological Survey. Grant No.14-08-001-1627.

THOMPSON, T.E. and **P. SLINN,** 1959. On the biology of Pleurobranchus membranaceus. J. Mar. biol. Ass. U.K., **38:** 507-524.

* **THORSON, G.** 1946. Reproduction and larval development of Danich marine bottom invertebrates. Medd. Dan. Fisk. Havunders, **4:** 1-523.

TRANTER, D.J. and **JACOB GEORGE,** 1972. Zooplankton abundance at Kavaratti and Kalpeni Atolls in the Laccadive Sea. Proc. Symp. Corals and Coral Reefs. Mar. Biol. Ass. India, 239-256.

TREVOR, J.H. 1976. The burrowing activity of Nephtys cirrosa Ehlers (Annelida Polychaeta). J. Exp. Mar. Biol. Ecol., **24:** 307-319.

TRUDGILL, S.T. 1976. The marine erosion of limestone on Aldabra Atoll, Indian Ocean. Z. Geomorphol., **26:** 164-200.

TRUDGILL, S.T. 1983. Measurement of rates of erosion of reefs of erosion of reefs and reef limestones. In: D.J. Barnes, (Ed.). Perspectives on coral reefs. Australia Institute of Marine Science, Townsville, pp. 256-262.

TUNNICLIFFE, V. 1979. The role of boring sponges in coral fracture. Int. Cent. Nat. Rech. Sci., **291:** 309-315.

TURNER, R.D. and **K.J. BOSS,** 1962. The genus Lithophaga in the Western Atlantic. Johnsonia, **4:** 81-116.

VAUGHAN, T.W. 1918. The temperature of the Florids coral reef tract Carnegie Inst. Wash. Publ., **213:** 319-340.

VAUCHAN, T.W. 1919. Corals and the formation of coral reefs. Annu. Rep. Smithson Inst. **17:** 189-238.

VICOTR, A.C.C., A. CHELLAM and **K. RAMADOSS,** 1989. Underwater observations in the lagoons. Cent. Mar. Fish. Res. Inst. Bull., No.**43:** 227-242.

VINE, P.J. 1970. Densities of Acanthaster planci in the Pacific Ocean. Nature, **228:** 341-342.

VINE, P.J. and **J.H. BAILEY BROCK,** 1984. Taxonomy and ecology of coral reef tube worms (Serpulidae, Spirorbidae) in the Sudanese Red Sea. Zool. J. Linn. Soc., **80:** 135-156.

VITTOR, B.A. and **P.G. JOHNSON,** 1977. Polychaete abundance, diversity and trophic role in role coral reef communities at Grand Bahama Island and the Florida Middle Ground. Proc. Third Int. Coral Reef Symp. Miami, **1:** 163-168.

WARBURTON, F.E. 1958. The effects of boring sponges on oysters. Prog. Rep. Atlant. Cst. Stns., **68:** 3-8.

WARBURTON, F.E. 1958a. Control of boring sponges on oyster bed. Prog. Rep. Atlant. Cst. Stns., **69:** 7-11.

WARBURTON, F.E. 1958b. The manner in which the sponge Cliona bores in calcareous objects. Can. J. Zool., **36:** 555-562.

WARD, J. 1965. The digestive tract and its relation to feeding habits in the stenoglossan prosobranch Coralliophila abbreviata (Lamarck). Can. J. Zool., **43:** 447-464.

WALLACE, C.C. and **G.D. BULL,** 1982. Patterns of juvenile recruitment on a reef front during a spring-summer spawning period. Proc. Fourth Int. Coral Reef Symp. Manila, **2:** 344-350.

WARME, J.E. 1975. Boring as trace fossils, and the processes of marine bioerosion. In: R.W. Frey, (Ed.), The study of Trace Fossils. Springer, Berlin Heidelberg, New York, pp. 181-229.

WEBB, K.L., W.D. DE PAUL, W.J. WIEBE, W. SOTTILE and **R.E. JOHANNES,** 1975. Enewetalk (Enewetok) Atoll: Aspects of the nitrogen cycle on a coral reef. Limnol. Oceanogr., **20:** 198-210.

WEBB, K.L. and **W.J. WIEBE,** 1975. Nitrification on a coral reef. Can. J. Microbiol., **21:** 1427-1431.

WEBER, J.N. and **P.K.J. WOODHEAD,** 1970. Ecological studies of the coral predator Acanthaster planci in the South Pacific. Mar. Biol., **6:** 12-17.

WESENBERG LUND, E. 1957. Sipunculoidea from the coast of Israel. Bull. Res. Counc. Israel., **6**B(3-4): 193-200.

WIEBE, W.J. 1976. Nitrogen cycle in a coral reef. Micronesiea, **12:** 23-26.

WIEBE, W.J., R.E. JOHANNES and **K.L. WEBB,** 1975. Nitrogen fixation in a coral reef community. Science, **88:** 257-259.

WILKINS, S.C. 1979. Culcita novaeguinea coral food preference and behaviour, Piti Bay, Marine Biogeography, Marine Laboratory, University of Guam, 11 pp.

WILLIAMS, A.H. 1979. Interference behaviour and ecology of threespot damselfish (Eupomacentrus planifrons), Oecologia, **38:** 223-230.

WILLIAMS, A.H. 1981. An analysis of competitive interactions in a patchy back-reef environment. Ecology, **62:** 1107-1120.

WILLIAMS, D.McB. 1982. Patterns in the distribution of fish communities across the Central Great Barrier Reef. Coral Reefs, **1:** 35-43.

WILLIAMS, D. McB. 1986. Temporal variation in the structure of reef slope fish communities (Central Great Barrier Reef): Short-term effects of Acanthaster planci infestation. Mar. Ecol. Prog. Ser., **28:** 157-164.

WISELY, B. 1958. The development and settling of the serpulid worm Hydroides norvegica Gunnerus (Polychaeta). Aust. J. Mar. Fresh. Res., **9:** 351-361.

WOLANSKI, E., 1987. Some evidence for boundary mixing near coral reefs. Limnol. Oceanogr., **32**: 735-739.

WOODIN, S.A. 1974. Polychaete abundance patterns in a marine soft-sediment environment: the importance of biological interactions. Ecol. Monogr., **44**: 171-187.

WOODLEY, J.D. 1979. The effects of trap-fishing on reef communities in Jamaica. Proc. Thirteenth Meet Assoc. Is. Mar. Lab. Carib., 27 (abstract).

YAMAGUCHI, M. 1975. Coral-reef asteroids of Guam. Biotropica, **17**: 12-23.

YAMAGUCHI, M. 1986. Acanthaster planci infestations of reefs and coral assemblages in Japan: a retrospective analysis of control efforts. Coral Reefs,**5**: 23-30.

YONGE, C.M. 1931. The Biology of Reef Building Corals. Sci. Rep. Great Barrier Reef Exped., **1**: 48-391.

YONGE, C.M. 1955. Adaptations to rock boring in Botula and Lithophaga (Lamellibranchia, Mytilidae) with a discussion on the evolution of this habit. Quart. J. micr. Sci., **96**: 383-410.

YONGE, C.M. 1963. The biology of coral reefs. In: F.S. Russell (Ed.) Advances in Marine Biology. Academic, New York, Vol.**1**: pp. 209-260.

YONGE, C.M. 1975. A note on mutualism between sipunculans and scleractinian corals. Proc. Int. Symp. on the Biology of the Sipuncula and Echiura, **1**: 305-312.

ZOTTOLI, R. and **M.R. CARRIKER,** 1974. Burrow morphology, tube formation and microarchitecture of shell dissolution by the spionid polychaete Polydora websteri Mar. Biol., **27**: 307-316.

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* Not referred to originals