

## Corals and coral reefs of India

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**Abstract.** This paper summarises the present state of knowledge on the ecology, productivity and resources of Indian coral reefs. In Indian waters, reef-building corals occur at Palk Bay, Gulf of Mannar, Gulf of Kutch and central west coast along the mainland India, Andaman and Nicobar islands in the Bay of Bengal, and Lakshadweep islands and Gaveshani Bank in the Arabian Sea. Coral formations at Palk Bay, Gulf of Mannar, Andaman and Nicobar islands are of fringing type. Patch reefs occur along the central west coast, on the Gaveshani Bank and around Gulf of Kutch islands. Lakshadweep islands are well developed atoll reefs. Diversity of coral genera is greatest in the Nicobar islands, with 42 genera followed by Lakshadweep islands (28), Gulf of Mannar (26), Andaman islands (25), Palk Bay (21), Gulf of Kutch (20), central west coast (9) and Gaveshani Bank (5). *Acropora* is the most diverse genus in Indian reefs whereas *Porites* is the most important reef builder.

Gross primary production of Indian reefs vary from 2.4 to 9.1 gC m<sup>-2</sup> d<sup>-1</sup> which are in the range known for world reefs. All reefs studied are autotrophic with the exception of one reef in the Andaman islands. Bulk of the primary production is contributed to by benthic autotrophs, and phytoplankton production is negligible. Nannoplankton is an important fraction of phytoplankton in reef waters. The corals recycle and conserve nitrogen very efficiently accounting for the high primary productivity of the reefs located in oligotrophic waters. Production of particulate organic aggregates is an important pathway of energy transfer in coral reefs and can be as high as 20% of gross production.

Food fishes and aquarium fishes constitute the pelagic resources of coral reefs. The potential food fish yield from all Indian reefs is about 0.2 million tonnes yr<sup>-1</sup>. Potential yield and export value of aquarium fishes, however, are not known. Corals are the most important of benthic resources and are exploited in commercial quantities from the Gulf of Mannar reefs. Coral sands to the extent of about a million tonnes are dredged annually from the Gulf of Kutch. Pearl oyster and chank constitute the major molluscan fisheries in Gulf of Mannar reefs. Trade for ornamental shells is also an important industry in many of the Indian reef areas.

Overexploitation of coral resources is a serious threat to Indian reefs. Calcareous sand mining in the Gulf of Kutch has led to the destruction of more than 50% of coral life. In Gulf of Mannar, selective overexploitation of massive corals has adversely affected several reefs. Coral mining also leads to shore erosion, as in the Lakshadweep islands. The increasing trade in corals for ornamental purposes is also a contributing factor to the decline in coral resources.

Present management and conservation measures for Indian coral reefs are inadequate. So far, only Gulf of Kutch reefs have been declared as Marine Sanctuary and Marine National Park, and thus enjoy legal protection. Proposals to declare other reef areas as Marine National Parks are yet to be implemented. In certain reef areas, protection for overexploited species exists; however, its enforcement is not strict. Proper management of space and species of coral reefs, and creation of an awareness among the public of the importance of the coral reef ecosystem, are the measures urgently needed for the conservation of our coral reefs.

**Keywords.** Coral reefs; Indian Seas; diversity; productivity; resources availability; exploitation; conservation; management.

### 1. Introduction

Coral reefs are shallow water, tropical marine ecosystems known for the high rates of

biological productivity, exceptionally diverse fauna and flora, and the complex food web and trophic organization. In addition, reefs are sites of rich living and non-living resources. The fish yield from coral reefs is comparable to most other productive marine ecosystems, and the potential fish harvest from the coral reefs of the world would be in the order of 9 million tonnes  $\text{yr}^{-1}$  (Munro 1984), equivalent to 12% of the current world fish harvest of 75 million tonnes  $\text{yr}^{-1}$ . The non-living resources include large mineral and lime stone resources; potential yield of calcium carbonate from the world reefs amounts to 600 million tonnes  $\text{yr}^{-1}$  (Smith 1978), and annually several million US dollars are realized by way of trade in ornamental corals and shells alone (Wells 1981). Aquarium fish from reefs yields a revenue of more than one million US dollars per year (Ex. The Philippines, Sri Lanka), and tourism to reefs is one of the major revenue sources to several countries (Ex. Great Barrier Reef of Australia, Oceania, Carribbean islands, Polynesian islands of Pacific etc.).

Such rich resources of coral reefs render them highly susceptible for overexploitation. As corals are highly specific in their requirements of temperature, salinity or water clarity for their growth, any attendant environmental changes consequent to improper exploitation, will seriously impede the recovery of the reefs. Many world reefs are already in this state, and Indian reefs are no exception. The objective of this communication is, therefore, to describe the biology and productivity of coral reefs in general, outline the studies on Indian coral reefs, and discuss the exploitation of their resources and the measures for a rational use of the reefs.

## 2. Ecology and distribution

The term 'coral' refers to coelenterates secreting a massive calcareous skeleton, particularly of the order Scleractinia (class: Anthozoa). It is further possible to divide the Scleractinian corals into two groups: the ahermatypic or non-reef building and the hermatypic or reef building corals. While structurally these two groups are similar, major differences between them lie in the presence of endosymbiotic zooxanthellae in the hermatypic corals, and the extent of their distribution in the seas.

The ahermatypic corals are widely distributed at all latitudes, down to several thousand metres depth, whereas the hermatypic corals are stenotypic, limited to warm saline waters, essentially between the tropics of Cancer and Capricorn, where minimum water temperatures do not fall below  $20^{\circ}\text{C}$ . However, some coral reefs occur at higher latitudes, probably as a result of tongues of water currents of tropical origin (Crossland 1981). Requiring normally clear waters with uniform conditions of temperature and salinity, hermatypic corals have however been recorded from turbid waters with muddy bottom (Goreau and Yonge 1968), and from waters where the temperature is as low as  $10^{\circ}\text{C}$  (MacIntyre and Pilkey 1969; Zibrowius 1974), or salinity decreases to  $<20\%$  (Qasim and Wafar 1979) for several months in a year. The depth distribution of reef-building corals is restricted to illuminated layers of the sea, a condition clearly associated with the endosymbiotic zooxanthellae of the coral polyps which require light for photosynthesis.

A coral reef can be defined as 'a ridge or mound of limestone, the upper surface of which lies, or lay at the time of its formation, near the level of the sea, and is

predominantly composed of calcium carbonate secreted by organisms, of which the most important are corals' (Vaughan 1911). As this definition clearly shows, corals are primary reef frame-builders. Secondary frame-builders include other calcareous organisms, notably the encrusting coralline algae, which greatly assist in the strengthening of frame-work. Reef-building is an interaction between biological and geological processes, the former represented by primary and secondary reef framework growth, and the latter by sedimentation and early cementation. The destructive processes operating on a reef are mechanical and biological erosions.

Coral reefs can be classified into 3 main types:

- (i) *Fringing reefs (shore reefs)*: Fringing reefs develop nearshore where environmental conditions are suitable i.e. firm bottom, favourable temperature and salinity and low turbidity. Ex. fringing reefs adjoining the shores of Red Sea.
- (ii) *Barrier reefs*: Barrier reefs are linear separated from the shore by a lagoon. The width of the lagoon varies considerably and along some coasts, with a progressive narrowing of the lagoon, a barrier reef may become fringing. Ex. Great Barrier Reef.
- (iii) *Atolls*: Atolls are annular reefs that develop at or near the surface of the sea. These can be further sub-divided into deep-sea atolls and shelf atolls. Deep-sea atolls are isolated, varying considerably in size. Ex. many Indo-Pacific atolls. Shelf atolls are those found on the continental shelf. Ex. atolls on the shelf off the NW coast of Australia.

The minor types of coral reefs include table reefs, faros, microatolls, knolls and patch reefs.

The coral reefs of the world cover an estimated area of  $6 \times 10^5$  km<sup>2</sup>, equivalent to 0.17% of the world ocean area. Over half of this (54%) lies in the Asiatic Mediterranean and Indian Ocean. Of the remaining, Pacific reefs account for 25%, Atlantic reefs for 6%, Caribbean reefs for 9%, Red Sea reefs for 4% and Persian Gulf reefs for 2% (Smith 1978). Majority of the coral reefs are concentrated in the western parts of the 3 major oceans (Scheer 1984).

The abundance and diversity of hermatypic corals is greatest in the Indo-Pacific region. 88 genera and subgenera occur in the Indian Ocean, of which 11 are endemic. In the Pacific, 86 genera and subgenera occur, of which 9 are endemic. 77 genera are common to both the Indian and Pacific Oceans, and 65 of these can be found in most of the reefs of the central areas of the Pacific and Indian Oceans (Scheer 1984). In contrast to the Indo-Pacific region, the Atlantic reefs have lesser diversity. Only 48 species of hermatypes, distributed among 25 genera, are known from the Caribbean region (Goreau and Wells 1967). Along the west African coast, the hermatypes are much less diverse, comprising only 8 genera, probably as a result of a combination of conditions associated with heavy river drainage, and compressed thermal structure characteristic of eastern boundary currents (Glynn 1973). The Indo-Pacific Reef Region can be considered as a single entity, because of the commonness of occurrence of a majority of corals in the Indian and Pacific Oceans, but the Atlantic Reef Region is distinctly different, with only 5 hermatypic coral genera being common to both the regions (Scheer 1984).

It is not known exactly how many hermatypic coral species occur in the reefs of the world. This is largely because many of the remote reefs and atolls are still not extensively sampled, nor do the collections extend to deeper waters. In localized reefs where collections have been more intensive, the number of genera or species known from that area has increased dramatically. For ex. after the 'Xarifa' expedition to the

islands of Great Nicobar and Tillanchong, the number of genera known from the Nicobars rose from 3 to 43 (Scheer 1984). Again, intensive collections in the Philippines' reefs resulted in a record of 400 species belonging to 65 genera, of which one genus and 103 species are believed to be new to science (Nemenzo 1981). In Jamaican reefs, 4 new species of hermatypic corals were found to occur at a minimum depth of 25 m or greater (Goreau and Wells 1967) and not recorded during previous shallow water collections. The lack of systematic collection is further compounded by the extreme difficulty in accurately identifying the corals. Many of the species described are only 'ecomorphs', resulting often in a long list of synonyms, and the classification keys up to the species level are yet to be standardized.

### 3. Indian coral reefs

Figure 1 shows the known locations of coral formations in Indian territorial waters. It can be noted that inspite of the long coastline and warm temperature of the coastal waters, coral growth along the mainland India is limited to a fringing reef in Palk Bay, a chain of islands bordered with fringing reefs in the Gulf of Mannar, many islands in the Gulf of Kutch around which are shallow reefs, and to patches in intertidal zones along the west coast of India. The scarcity of reefs on Indian coast is principally due to major river systems and the sedimentary regime of the continental shelf (Ahmad 1982). However, most of the shoreline of India still remains unexplored,

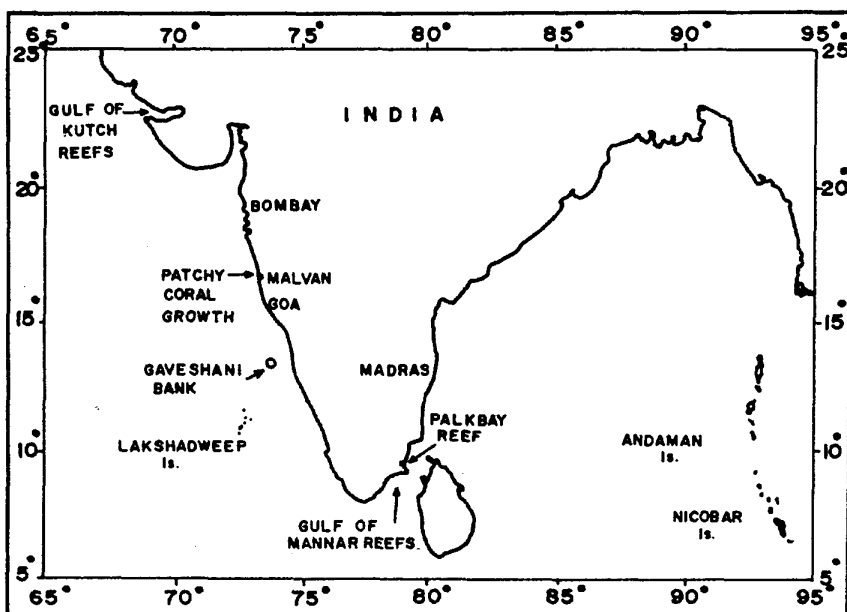


Figure 1. Locations of occurrence of reef-building corals and reef-formations in Indian waters.

and the occurrence of corals along Indian coasts may be more widespread than known so far (Qasim and Wafar 1979). On the other hand, the Lakshadweep archipelago in the Arabian Sea, has a chain of well developed atoll reefs, and the Andaman and Nicobar islands have extensive well developed fringing reefs.

### 3.1 Southeastern Indian reefs

3.1a *Palk Bay reef*: There is only one reef in the Palk Bay, which lies in an east-west direction along the mainland at Mandapam and the Rameswaram island (figure 2). The reef extends from  $79^{\circ}8'$  to  $79^{\circ}20'E$  along the latitude of  $9^{\circ}17'N$ . The reef is discontinuous at the Pamban Pass, and on the western side the reef is again divided into two halves by a narrow navigational channel. A detailed description of the structure and fauna of the portion of the reef which lies along mainland is given by Pillai (1969).

This reef is one of the few Indian reefs where systematic and ecological investigations of the hermatypic corals have been carried out (Pillai 1967a, b, c, 1969, 1971a, 1972; Wafar 1974; Balasubramanian and Wafar 1974). 63 species belonging to 22 genera have been recorded from this reef (Pillai 1969). However, the species diversity of this reef is less than those recorded in other Indian Ocean reefs (Pillai 1971a), a result of the collections being limited to a maximum depth of 2 m only. The dominant genera are *Favia*, *Acropora*, *Leptastrea*, *Porites*, *Pocillopora*, and *Goniastrea*. The genera *Acropora* and *Montipora*, of the family Acroporidae are the most diverse with 25 species, whereas *Porites* is the most important genus in terms of abundance and reef building.

The only detailed study on distribution and zonation of corals in India was carried out on this reef by Pillai (1969). A 1 m width transect was chosen, and the sampling was done at every 5 m over a line-transect length of 450 m from the shore to the outer edge of the reef. The results do not demonstrate any distinct zonation; however, the shoreward and seaward sides of the reef showed marked differences in their coral fauna, the former with mostly the massive, encrusting, large-polyped corals, and the latter with small-polyped ramose forms dominating.

3.1b *Gulf of Mannar reefs*: The reef formation in the Gulf of Mannar is of fringing

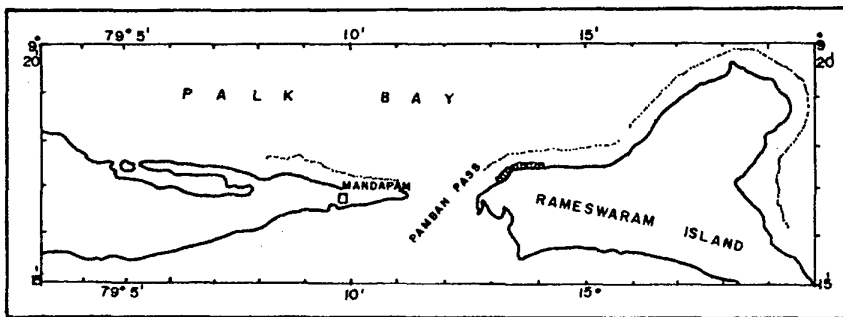


Figure 2. The fringing reef at the Palk Bay.

type developed around a chain of 20 islands from Tuticorin (8°48'N; 78°9'E) to Shingle island (9°14'N; 79°14'E), lying at an average distance of about 8 km from the mainland (figure 3). In addition, a 2 km shore reef, the only one known so far in the Gulf of Mannar (figure 3), exists at Kilakkarai (Reddiah *et al* 1974). Rajendran and David (1972) have made a preliminary underwater survey of the extent and state of the reefs in 19 of these islands. Their survey shows that the eastern side of all these reefs support active coral growth, whereas the western and northern shores are quarried for coral blocks. Physiography of 3 northern (Manauli, Hare and Pulli), and 4 southern (Van, Kasuwar, Karaichalli and Vilanguchalli) islands are given in detail by Mergner and Scheer (1974) and Venkataramanujam *et al* (1981), respectively. The Appa island and its fringing reef have been described in detail by Reddiah (1970).

Detailed systematic collections have been carried out by Pillai in some of the northern-most islands (Shingle, Krusadai, Pullivasal, Pulli, Manauli, New and Hare) over a period of several years (Pillai 1971a, 1972). He recorded 88 species, and together with those of the Palk Bay reef, the total number of species known for Mandapam area is 117 distributed among 32 genera, of which 110 species belonging to 25 genera are hermatypic. *Acropora* is the most diverse genus with 24 species, followed by *Montipora* (20 species) and *Porites* (12 species). 5 species under 3 genera are new to science and 25 species under 4 genera are new records (Pillai 1967a, b, c). 21 species under 19 genera were also from collections at Tuticorin which were not as intensive as in the northern islands.

### 3.2 Gulf of Kutch reefs

The Gulf of Kutch reefs (22°15'N–23°40'N and 68°20'–70°40'E) are the northern most of the Indian Ocean (figure 4). Most of the islands in the Gulf support fringing reefs, and coral patches are also found between islands. The reefs are generally restricted to areas exposed to strongest tidal currents, and living corals are confined to northern and western sides of the islands where the currents are strongest. Pillai *et al* (1980) describe these reefs as patchy coral growth rather than reefs, as they are supported by intertidal sandstones or wavecut, eroded shallow banks.

The diversity of coral species in the Gulf of Kutch is the lowest of all Indian reefs. Pillai *et al* (1980) record only 26 species of hermatypic corals, under 20 genera, from these reefs; there appears to be a total absence of ramose corals, and genera such as *Acropora*, *Pocillopora*, *Stylophora* and *Seriatopora* have not been found. However, recently Patel (1985a) has recorded 44 species of Scleractinian corals and 12 species of soft corals from the Gulf of Kutch.

### 3.3 Central West Coast

Qasim and Wafar (1979) have recorded the occurrence of coral patches in the intertidal regions of Ratnagiri, Malvan and Redi (figure 1). The corals collected belonged to the genera *Coscinarea*, *Turbinaria*, *Favites*, *Porites* (*P. lutea* and *P. lichen*), *Pseudosiderastrea*, *Cyphastrea*, *Goniastrea* and subgenus *Synaraea*. Of these, the genus *Pseudosiderastrea* is a new record for Indian waters. *Porites* was the dominant form at all the 3 sites, followed by *Goniastrea* and *Pseudosiderastrea*. *Favites* was observed only at Malvan with very few colonies. Small-polyped ramose forms were totally absent.

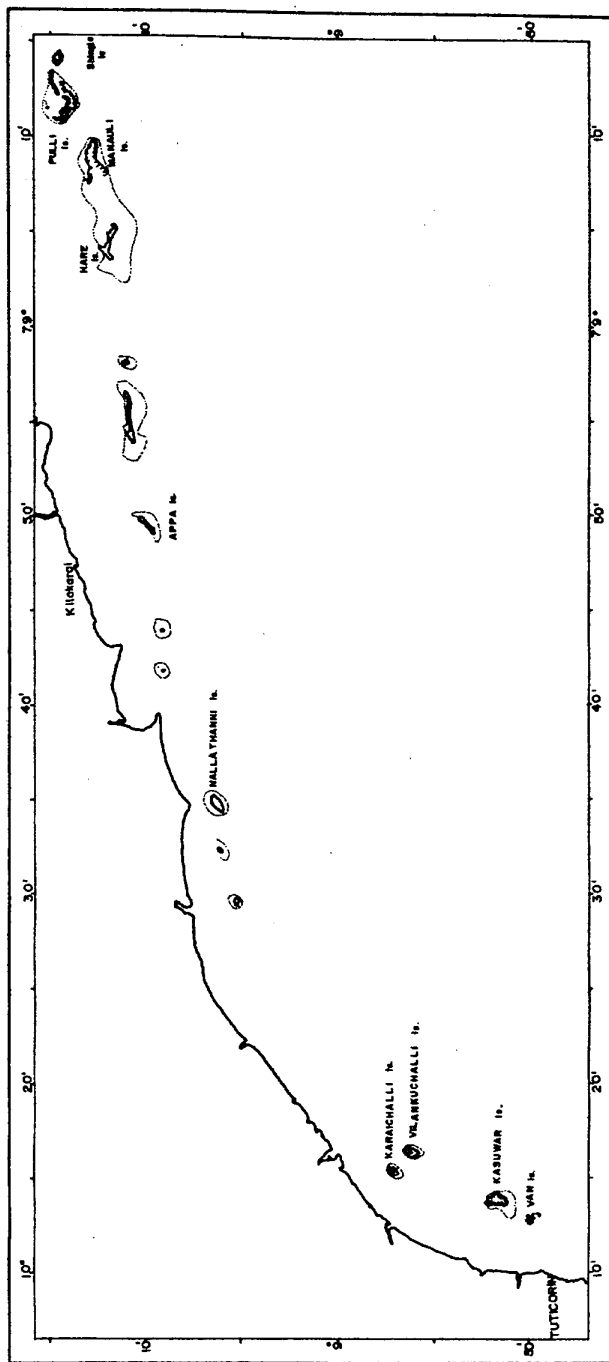


Figure 3. The Gulf of Mannar islands and their reefs.

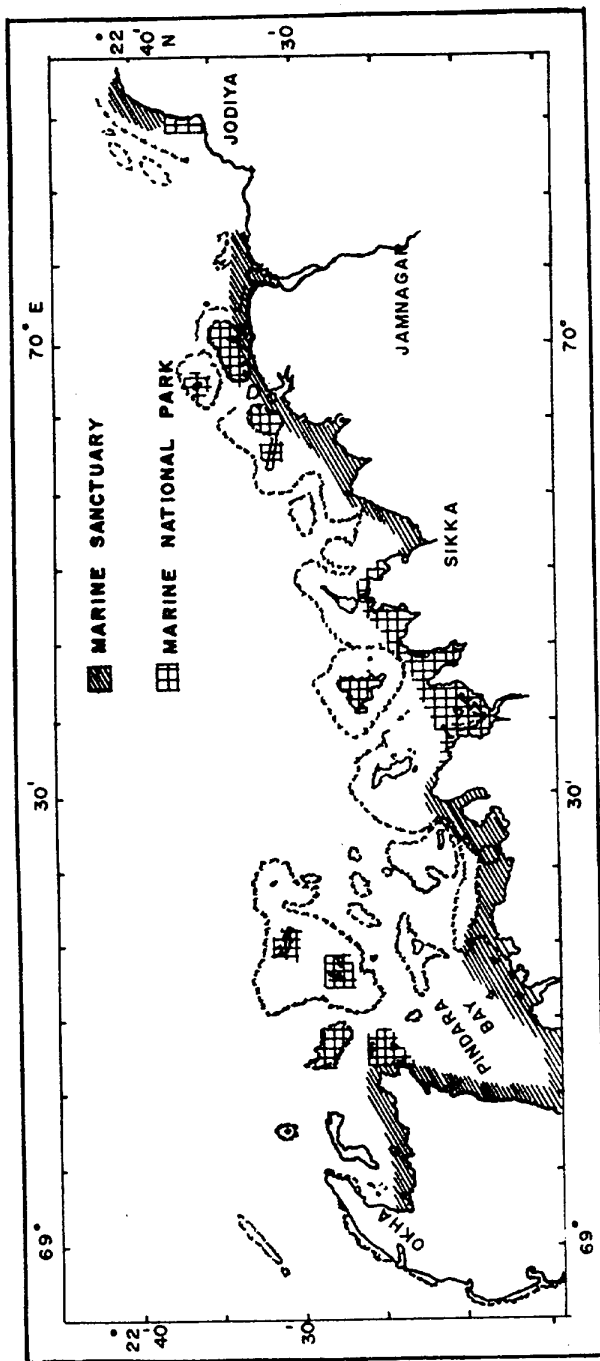


Figure 4. Gulf of Kutch reefs.



The occurrence of reef-building corals along the central west coast is of considerable ecological interest, since during monsoon months (June–August), these coastal waters are characterized by low salinity (20–25%), very high turbidity, silting, and strong wave action. Nevertheless, the corals thrive here and, judging from the size of the colonies, have been growing for many years, thus demonstrating greater adaptability to environmental changes than known hitherto. The tolerance of reef corals is further attested to by the occurrence of *Pseudosiderastrea* and *Porites* in Bombay waters which, besides experiencing monsoon effects, are also subjected to heavy oil, sewage and industrial pollution (Khadilkars, unpublished results).

In the shelf waters, off the west coast of India, a submerged bank with living corals, named as 'Gaveshani Bank', at 13°24'N and 73°45'E, about 100 km offshore to Mangalore (figure 1) and at about 38 m depth, was discovered in 1977 (Nair and Qasim 1978). The corals recorded from this bank were *Euphyllia fimbriata*, *Leptoseris papyracea*, *Stylocoeniella armata*, *Porites lichen* and *Cyphastrea serialia*. Two genera, *Porites* and *Cyphastrea* are common between Gaveshani bank and the intertidal areas of the central west coast.

#### 3.4 Lakshadweep archipelago

The Lakshadweep archipelago consists of 12 atolls, 3 reefs and 5 submerged banks (Anonymous 1984). Of its 36 islands, only 10 are inhabited. Excluding Minicoy, all the other atolls are located within the geographical limits of 10°–12°N and 71°40'–74°E (figure 5). Minicoy at 8°18'N and 73°E is the southernmost atoll, separated from the rest by the 9 degree channel; it is also the largest atoll in the Lakshadweep archipelago. Almost all the atolls have a NE-SW orientation, with the low-lying island on the east, a broad well developed reef on the west, with a lagoon in between, connected to the open ocean by one or more channels (figure 6). The width of the lagoon varies from 1 to 4 km, and most of the lagoons have also coral knolls arising from the lagoon floor.

Systematics, diversity and zonation studies of Lakshadweep corals are limited only to Minicoy island. Pillai (1971b) recorded 70 species of hermatypic corals representing 26 genera from the shallow waters of the Minicoy reef and lagoon. Of these, 36 species are new records for Minicoy. However, the systematics and diversity of other coral reefs in Lakshadweep archipelago have not been studied in detail nor the deep water species, even from Minicoy, are known. An extensive survey of other reefs, planned by NIO using a team of SCUBA divers, may probably reveal the presence of many more species.

#### 3.5 Andaman and Nicobar islands

The Andaman islands (10°30'–14°N; 92–93°E) are the emerged part of a mountain chain and lie on a ridge which extends southward from the Irrawaddy delta area of Burma (figure 7). The Nicobar islands (6°30'–9°30'N; 93–94°E) are high islands forming part of an emerged mountain chain, continuing that of the Andamans (figure 8). The coral reefs of these islands are of fringing type, often separated from the shore by a lagoon; however, Sewell (1935) reported a barrier reef to the west off Andamans. A survey of the Andaman and Nicobar islands was carried out by Reddiah (1977) who described briefly several types of reefs.

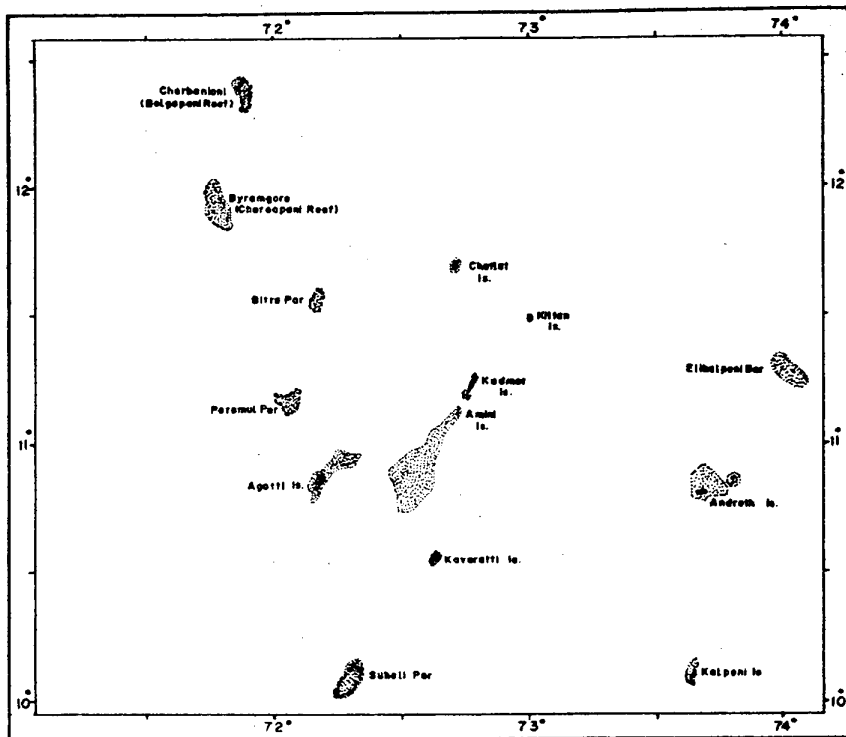


Figure 5. Coral reefs in the Lakshadweep. Minicoy (8°18'N; 73°E) is not included in this figure. Dotted portions represent coralline shelves and reefs.

Coral systematics and diversity are poorly known from these islands. Pillai (1972) has recorded 68 species belonging to 31 genera from Andamans, of which 57 species and 23 genera are hermatypes. Reddiah (1977) recorded *Stylophora* and *Alveopora* also from the Andamans; this raises the number of hermatypic genera known from these islands to 25. The recent synthesis by Scheer (1984) records 39 hermatypic genera from the Nicobar islands. Adding *Psammocora*, *Leptoseris* and *Alveopora* recorded by Reddiah (1977) to these, a total of 42 genera are known so far from the Nicobar islands.

Table 1 lists the known genera of hermatypic corals from the seas around India.

#### 4. Productivity of coral reefs

Coral reefs are the most productive marine ecosystems, with annual gross production rates in the range of 2000–5000 gC m<sup>-2</sup> (Mann 1982). A summary of gross production and respiration rates (community metabolism) of several atolls and fringing reefs may be found in Qasim *et al* (1972), Sourmia (1977) and Lewis (1977).

Primary producers in the coral reefs are very diverse. These include zooxanthellae

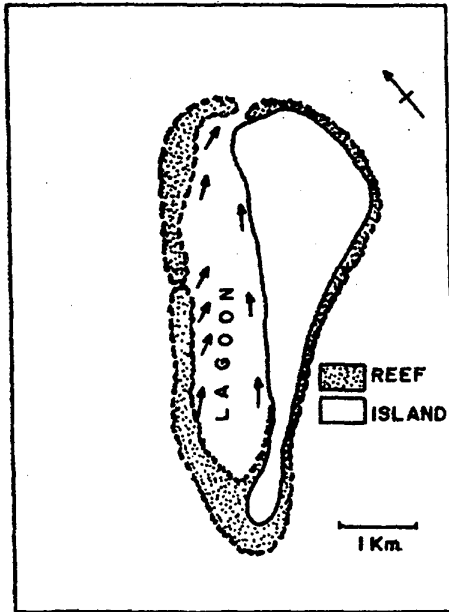


Figure 6. Structure of a typical atoll (Kavaratti) in the Lakshadweep.

symbiotic with coral polyps, coral-boring filamentous algae, calcareous algae, benthic macroalgae, microalgae in sands and periphyton and phytoplankton, each of which is briefly examined below.

(i) *Zooxanthellae*: The endosymbiont is a dinoflagellate, described as *Gymnodinium microadriaticum*. In coral polyps, zooxanthellae occur in enormous numbers, ranging from  $0.9$  to  $2.48 \times 10^6$  cells  $\text{cm}^{-2}$ , with a mean of  $1.45 \times 10^6$  cells  $\text{cm}^{-2}$  (Drew 1972). The chlorophyll content of zooxanthellae varies from  $5$  to  $15 \mu\text{g}$   $10^{-6}$  cells (Titlyanov 1981) and their production rate is around  $0.9 \text{ gC m}^{-2} \text{ d}^{-1}$  (Scott and Jitts 1977), about 3 times higher than phytoplankton production on unit area basis.

(ii) *Boring filamentous algae*: Belonging predominantly to the genus *Ostreobium*, these symbiotic algae live buried below the coral tissue and skeletal matter. Production by these algae is less than 10% of the total productivity of the coral (Kanwisher and Wainwright 1967), due to low light energy level reaching this algae (Halldal 1968).

(iii) *Calcareous algae*: These (Rhodophyceae—*Lithothamnion*, *Porolithon* and other corallinaceae) are the most important secondary frame builders in a coral reef. The net production rates of the coralline algae vary between  $0.66 \text{ gC m}^{-2} \text{ d}^{-1}$  (Marsh 1970) and  $5.7 \text{ gC m}^{-2} \text{ d}^{-1}$  (Littler 1974).

(iv) *Benthic macroalgae*: These are among the major groups of primary producers on a reef, and include seaweeds and seagrasses. Very often, the seagrasses form extensive beds in shallow lagoons, and the net production of such beds is in the order of  $400\text{--}4000 \text{ gC m}^{-2} \text{ yr}^{-1}$  (Lewis 1977). The importance of these algae in reef

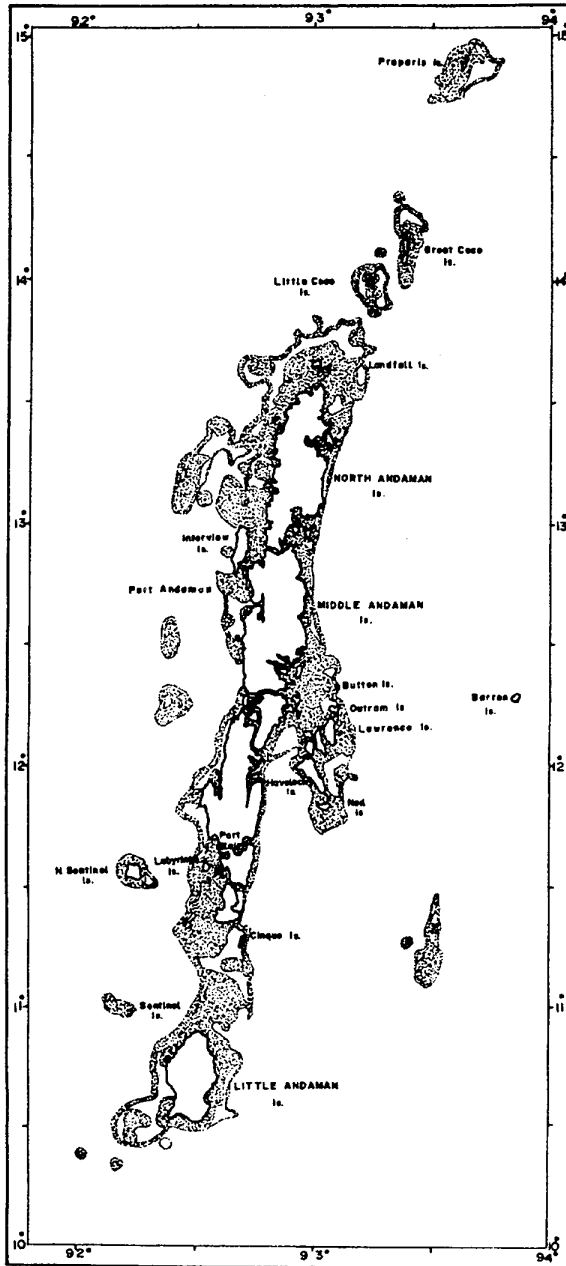


Figure 7. The Andaman islands and their fringing reefs. Dotted portions represent coralline shelves and reefs.

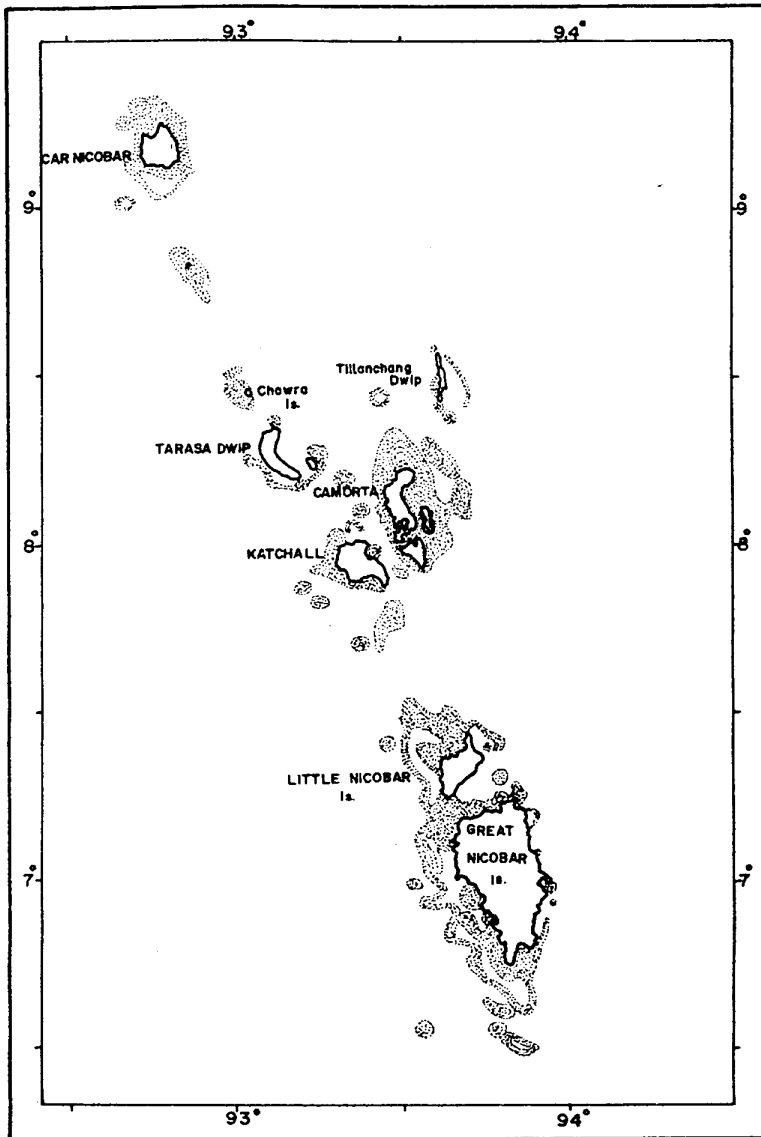


Figure 8. The Nicobar islands and their fringing reefs. Dotted portions represent coralline shelves and reefs.

productivity will become evident when the production of different components on a reef are compared; in Kavaratti atoll, the gross production of the seagrass bed was  $12.0 \text{ gC m}^{-2} \text{ d}^{-1}$  (Qasim and Bhattathiri 1971) whereas that of the reef was  $6.15 \text{ gC m}^{-2} \text{ d}^{-1}$ , and of the seaweeds,  $3.84 \text{ gC m}^{-2} \text{ d}^{-1}$  (Qasim *et al* 1972).



Table 1. (Contd.)

	1	2	3	4	5	6	7	8	9
<i>Oulophyllia</i>						*			
<i>Platygyra</i>		*	*	*	*	*	*		
<i>Leptoria</i>			*	*		*	*		
<i>Hydnophora</i>		*	*	*	*	*	*		
Sub family Montastreinae									
<i>Diploastrea</i>				*		*			
<i>Oulastrea</i>					*				
<i>Leptastrea</i>		*	*	*		*	*		
<i>Cyphastrea</i>		*	*			*	*	*	*
<i>Echinopora</i>			*	*	*	*			
<i>Plesiastrea</i>		*	*	*		*			
Trachyphyllidae									
<i>Trachyphyllia</i>						*			
Oculinidae									
<i>Galaxea</i>		*	*	*	*	*			
Merulinidae									
<i>Merulina</i>		*	*	*	*	*			
<i>Scapophyllia</i>						*			
Mussidae									
<i>Acanthastrea</i>				*			*		
<i>Lobophyllia</i>				*	*	*	*		
<i>Symphyllia</i>		*	*	*	*	*	*		
Pectiniidae									
<i>Mycedium</i>		*				*			
<i>Pectinia</i>						*			
Caryophylliidae									
<i>Euphyllia</i>				*		*			*
<i>Plerogyra</i>						*			
Dendrophylliidae									
<i>Turbinaria</i>		*	*			*	*	*	
Genera Total		21	26	28	25	42	20	8	5
Subgenera		2	4	9	8	9	1	2	1

Source: Pillai (1971b, 1972); Reddiah (1977); Patel (1978); Nair and Qasim (1978); Qasim and Wafar (1979); Pillai *et al* (1980); Scheer (1984).

(v) *Benthic microalgae*: These algae have increasingly come to be known as important primary producers on a reef. Sournia (1976) found that the photosynthetic pigments and productivity of lagoon sands can be 1000 and 50 times more respectively, than those of phytoplankton per unit area. From his studies on several Pacific and Indian Ocean reefs, Sorokin (1981) concluded that the production of benthic microalgae (sand flora and periphyton) can be as high as  $2-6 \text{ gC m}^{-2} \text{ d}^{-1}$ , a figure comparable to gross production in many reefs.

(vi) *Phytoplankton*: Primary production by phytoplankton and its contribution to reef productivity, have been extensively studied. The consensus of these studies, is that the phytoplankton production in coral reefs does not assume any importance, but represents only the production rates of the surrounding waters, being often only a few tens of  $\text{mgC m}^{-2} \text{ d}^{-1}$ . On unit area basis, phytoplankton production is only about 1% of the total benthic production (Sournia 1977).

#### 4.1 Productivity of Indian reefs

Primary productivity studies on Indian coral reefs are rather few, limited to two fringing reefs in the Gulf of Mannar, one each in Palk Bay and Andaman Sea and two atolls, Kavaratti and Minicoy, in the Lakshadweep (Nair and Pillai 1972; Qasim *et al* 1972; Balasubramanian and Wafar 1974). Results of these studies are summarized in table 2. Gross production ranged from 2.4 to 9.1 gC m<sup>-2</sup> d<sup>-1</sup>, and with the exception of Andaman reef, all reefs are autotrophic or self-supporting. In the Palk Bay reef, where measurements were carried out for 6 months, a clear seasonality was observed, with the production increasing nearly two-fold from March to August, in phase with progressive favourable environmental conditions (Balasubramanian and Wafar 1974). Phytoplankton production in all these reefs was negligible, and in the oceanic atolls, 60–90% of phytoplankton production was contributed to by nannoplankton (Wafar 1977).

An apparent contrast, between the characteristically high primary productivity of coral reefs and the low nutrient concentrations in surrounding waters, would suggest that the reefs and corals have means of conserving and efficiently recycling the nutrients within the ecosystem. This was investigated recently by Wafar *et al* (1985) in Kavaratti atoll using stable isotopes of nitrogen (<sup>15</sup>NO<sub>3</sub>, <sup>15</sup>NH<sub>4</sub> and <sup>15</sup>N-urea). Their results demonstrate that, even at the maximum rate of uptake, the zooxanthellae can obtain all their N requirements directly from coral excretion alone, and that nearly 80% of the N synthesized by zooxanthellae may be translocated back to the corals within 4 h. This tight recycling of nitrogen, as for phosphorus (Pilson and Betzer 1973), can explain the high productivity of coral reefs in the midst of oligotrophic waters.

### 5. Role of detritus

Detritus production is an important pathway in the transfer of energy in reef ecosystems. The major source of detritus is the mucus produced by the corals. This

Table 2. Gross primary production and community respiration in some coral reefs from Indian seas.

Reef	Gross production gC m <sup>-2</sup> d <sup>-1</sup>	Community respiration gC m <sup>-2</sup> d <sup>-1</sup>	Source
Gulf of Mannar			
Manauli Reef	7.3	0.3	Nair and Pillai (1972)
Kurusadai Reef	2.4	2.0	Balasubramanian and Wafar (1974)
Palk Bay Reef	4.9–9.5	2.3–3.3	Balasubramanian and Wafar (1974)
Andaman Reef	3.9	17.1	Nair and Pillai (1972)
Lakshadweep			
Minicoy Reef	9.1	0.1	Nair and Pillai (1972)
Kavaratti Reef	6.2 <sup>a</sup>	2.4 <sup>a</sup>	Qasim <i>et al</i> (1972)
Seagrass bed on Kavaratti atoll	12.0	6.2	Qasim and Bhattathiri (1971)

<sup>a</sup>Not corrected for diffusion.



mucus entraps other detrital particles and are subsequently colonised by heterotrophic microorganisms. Together they form what is commonly known as the 'organic aggregates' of reef waters.

These organic aggregates are important food sources for many reef invertebrates, particularly the zooplankton (Gottfried and Roman 1983). Reef fish and shrimps can also ingest coral mucus (Johannes 1967). The trophic significance of organic aggregates extend beyond the reef too. Organic matter swept continually off the reef would support a greater zooplankton population in the waters outside the reef (Johannes 1967; Qasim and Sankaranarayanan 1970), which otherwise would not be possible, with sparse phytoplankton. Qasim and Sankaranarayanan (1970) measured the production of particulate organic carbon in organic aggregates over the Kavaratti atoll; production was  $95 \text{ mgC m}^{-2} \text{ h}^{-1}$  and was about 20% of gross production by the reef.

## 6. Resources from coral reefs

### 6.1 Pelagic

The pelagic resources in coral reefs are the endemic fish fauna, which comprise of food and aquarium fishes.

6.1a *Food fishes*: Fish production from coral reefs can be quite high, upto 20 tonnes  $\text{km}^{-2} \text{ yr}^{-1}$  (Marten and Polovina 1981) and heavily fished coralline shelves are able to produce sustained harvests of 4–6 tonnes  $\text{km}^{-2} \text{ yr}^{-1}$  (Munro 1984). The estimated potential fish yield from all world reefs varies from 6 million (Smith 1978) to 9 million tonnes  $\text{yr}^{-1}$  (Munro 1984), or 10–15 tonnes  $\text{km}^{-2} \text{ yr}^{-1}$ , equivalent to 9–12% of all oceanic fish caught. These yields are comparable with intensively fished shelf areas in the world.

No figures are available on fishery in Indian coral reefs, though catch data exist for pelagic and demersal fishes in waters around reef areas. Fishing in the reef is generally for sustenance, hence underexploited and the catches remain unrecorded. However, extrapolating the above fish yield to reef areas, it would be possible to calculate the potential yield from the Indian reefs. These are shown in table 3. In these calculations, the reef area includes reef, lagoon and submerged banks. The Gulf of Kutch was not considered, since the reefs here are extensively damaged due to coral mining and coral sand dredging. The potential yield from all reef areas would

Table 3. Potential fish yield from Indian coral reefs.

Reef location	Reef area ( $\text{Km}^2$ )	Potential yield $\times 10^6$ tonnes $\text{yr}^{-1}$
Lakshadweep islands	4200	0.04–0.06
Andaman islands	11000	0.11–0.17
Nicobar islands	2700	0.03–0.04
SE coast of India (Gulf of Mannar and Palk Bay)	100	0.001–0.0015
Total		0.18–0.27

be about 0.2 million tonnes  $\text{yr}^{-1}$  or about 10% of the total marine fish production in India.

6.1b *Aquarium fishes*: Commercial exploitation of aquarium fishes from coral reefs has gained importance only recently. However, the potential for revenue from this industry is great, as shown by the Philippines, where the revenue from aquarium fish trade increased from 120,000 US \$ in 1970 to 2.5 million US \$ in 1979 (Albaladejo and Corpuz 1981). Though our Indian reefs sustain an abundant variety of aquarium fishes, no organized effort has yet been made to exploit these resources; we do not even know how many species of aquarium fish exist, nor their biology and potential yield.

## 6.2 Demersal

6.2a *Corals*: Corals are mainly used as building-blocks, in the construction of roads and as lime in cement industries. Smith (1978) has estimated that the world reefs precipitate about  $6 \times 10^{12}$  mol of  $\text{CaCO}_3$   $\text{yr}^{-1}$ , equivalent to an annual production of  $6 \times 10^8$  tonnes.

Commercial exploitation of corals, coral debris and coral sands is well documented from the Gulf of Mannar and the Gulf of Kutch reefs. A conservative estimate for the Gulf of Mannar reefs (Mahadevan and Nayar 1972) indicates an annual removal of 25,000 tonnes (60,000  $\text{m}^3$ ). Pillai (1973) estimated the annual exploitation from Gulf of Mannar reefs as about 90,000  $\text{m}^3$ . A recent detailed study by Venkataramanujam *et al* (1981) shows that annually about 15,000 tonnes of coral stones are removed from four Tuticorin coral islands alone; this is a 3-fold increase over that in the late 1960s. To this must be added the coral debris exploitation of about 10,000 tonnes which is nearly a 10-fold increase within a decade. In the Gulf of Kutch, coral sands are dredged for use in cement industry. Estimates of the quantity dredged vary from 0.6 (Patel 1985b) to 1 million (Rashid 1985) tonnes  $\text{yr}^{-1}$ .

Coral removal in the Andaman, Nicobar and Lakshadweep islands is mainly for local needs, such as building, construction or laying of the roads, as no commercial industry exists in these islands. It has been estimated that in the Lakshadweep lagoons, about 2000 million tonnes of calcareous sand and boulders are available, of which about 700 million tonnes can be safely extracted (Anonymous 1984).

6.2b *Molluscan resources*: Molluscs, a major group of invertebrates on coral reefs, are exploited largely for food and shell resources. While molluscan fishery in many reef areas is only a sustenance fishery, especially for the meat, in terms of shell resources these are of commercial importance. The well known example is the *Trochus niloticus* (buttonshell) fishery in the Indo-Pacific; annual shell production of this snail has a dockside value of approximately 3 million US \$ and an export value of roughly twice that amount (Heslinga 1981).

Commercial molluscan fisheries in Indian reefs exist for pearl oysters and chanks from the Gulf of Mannar. Fishing for pearl oysters is done at irregular intervals. The last fishery in 1961 yielded a revenue of about 30,000 US \$. This covers only the revenue for the government, though the actual value including cost of pearls, could be twice that amount (Mahadevan and Nayar 1973). The chank fishery for the sacred chank *Xancus pyrum* is a regular one and the sale of shells fetches every year about

20,000 US \$ (Nayar and Mahadevan 1973). In addition, the trade for ornamental shells, such as *Trochus* spp., *Strombus gigas*, *Nautilus* spp., *Cyprea tigris* and for a variety of other cowrie, cone and helmet shells, is an important industry in the Gulf of Mannar and Andaman and Nicobar islands; the revenue figures for these are however, lacking.

## 7. Constraints in the sustainability of reefs

### 7.1 Pollution

Because of stenotypic nature, the corals and coral reef organisms are highly susceptible to environmental stress i.e. pollution. Until recently, pollution threat to reefs was minimal but increase in industrialization in coastal areas, offshore mining and oil transport have increased the risks of large scale pollution.

Among the several, oil pollution is of serious concern and there is growing evidence for the detrimental effects of oil pollution on coral reef communities. Loya and Rinkevich (1980) summarize the field reports following oil spills on the impact of oil on reef organisms; the impact varied from no damage to severe damage. However, chronic oil pollution was conclusively detrimental to reef corals. Similarly, because of their low thermal tolerance, the reef corals are also vulnerable to thermal pollution. For example, the thermally enriched discharge waters from a power plant in Guam have destroyed a reef flat and margin area of 20,000 m<sup>2</sup> (Neudecker 1976). Sewage pollution, on the other hand, is not generally directly toxic, but leads to eutrophication and favours the growth of other algae which effectively compete with corals for space and light (Marszalek 1981a).

### 7.2 Man-made changes

These come under different forms such as mining, dredging, building activities, shell and coral collection, recreational uses etc.

Mining of reefs for CaCO<sub>3</sub> and, in the adjacent areas for other minerals, affect the reefs directly and indirectly. While coral mining is directly detrimental to reefs, effects of coastal mining are indirect but equally serious, as the discharge of mine tailings and effluents, reduces salinity and increases turbidity, both of which are detrimental to coral survival, as was the case in Phuket Bay (Chansang *et al* 1981). Dredging also affects the coral reefs adversely by increasing turbidity, modifying the reef topography and causing mechanical damage to corals (Marszalek 1981b).

Building activities are mainly construction and extensions of harbours and factories. Their primary impact on corals would be through chronic pollution, particularly by oil and toxic effluents. Constructions can also modify water circulation pattern and can cause poor flushing and excessive sedimentation. Overexploitation of shells and corals for ornamental trade and amateur collection is another serious threat to many reefs. The magnitude of this problem can be judged by the fact that the annual trade in sea shells is in the order of several million US dollars (Wells 1981).

## 8. Threats to Indian reefs

The most serious threat to Indian reefs is the excessive and indiscriminate exploitation of corals, coral debris and sands, which leads to irreversible ecological damage. In the Gulf of Kutch, dredging of coral sands for the cement industry has caused substantial destruction of the natural habitat. The most important consequence of dredging is an increase in suspended silt and this is probably the cause for considerable decline in fauna and flora of the Gulf (Anonymous 1978). Patel (1985b) described the calcareous sand mining in the Gulf of Kutch and its deleterious effects on marine life. As a consequence of mining, about 50% of the coral life has already been destroyed (Rashid 1985) and this may even be as high as 70% (Bhatt 1983).

The situation is no better in the Gulf of Mannar reefs. Quarrying of corals has resulted in near-total destruction of several reefs (Pillai 1973). The species most selectively quarried are the massive forms such as *Porites* and *Favia*, which are the principal reef builders and the most abundant. A detailed study by Venkataramanujam *et al* (1981) in Tuticorin islands shows that the exploitation of corals, in particular quarrying of massive forms, has increased at an alarming rate over the past 10 years and despite being banned, continues clandestinely. The net result is that the growth rate of corals hardly matches the rate of their removal (Pillai 1973) and as the present-day exploitation is largely confined to waters less than 1 m deep, the destruction of live corals is extensive, upto even 100% in localised sites.

Though large scale mining of corals is not known from island reefs, localized removal of corals and dredging of the lagoon floor, has resulted in erosion of shorelines. This problem is well evident in Kavaratti atoll, where the population pressure has led to increased construction activities and consequently, quarrying of corals. This exploitation is mainly on the oceanic side of the island and as a consequence, strong wave action has led to extensive shore erosion in many places (figure 9). Another disturbance is through the removal of corals as souvenirs. The observations made by NIO during the last 10 years in Kavaratti clearly show that the lagoon, once abundant with all varieties of branching corals, is now completely denuded (Qasim and Wafar 1985) and this problem is slowly spreading to other islands also. In the high islands of Andamans, widespread and uncontrolled deforestation has resulted in soil erosion, washing off sediments by river run off and massive siltation on the fringing reefs.

## 9: Management approaches for conservation

The management approaches for the conservation of coral reefs are diverse and have been discussed in detail by Kenchington and Hudson (1984). These can be grouped into management of space, management of species and instilling a sense of awareness about the importance of coral reefs among local population and tourists.

### 9.1 Management of space

The management of reefs can best be achieved by establishing marine parks. The motivation behind this is conservation, promotion of tourism and recreational and



**Figure 9.** Erosion of the sea shore at Kavaratti atoll after coral quarrying. The tripods check further erosion

cultural uses. At present, there are 58 established marine parks of coral reefs in 17 out of 100 countries in the intertropical zone (Salvat 1981) and 18 more have been planned for the future.

The only reefs of India that have officially been declared as Marine National Park and Marine Sanctuary are the Gulf of Kutch reefs. The Marine Sanctuary covers an area of 455.92 km<sup>2</sup>, from Okha to Jodiya and a core area of 162.89 km<sup>2</sup> has been declared as the Marine National Park (figure 4). The enforcement staff includes a Director, two range officers and a dozen assistants. Three boats are available for surveillance and the immediate task of the enforcement staff is to book offenders under the Preservation of Wildlife Act and involve local people in an intensive afforestation of mangroves (Bhatt 1983).

Proposals to declare the Gulf of Mannar reef area as a Marine National Park have been made (Silas *et al* 1985). The Government of Tamil Nadu has already banned quarrying of massive corals and collection of marine organisms from the reefs. No island reef has been declared as a Park or Sanctuary yet, though the Pitti island (in Lakshadweep) has been declared as a Sanctuary for birds. In Andamans, the Nandur Marine National Park was established in the Little Andamans, but there is no management or protection at present. It has been recommended that the Malvan coast, from Vengurla in the south to Sindudurg Fort in the north, also may be declared as protected and a Marine Park be established at Malvan (Anonymous 1980).

### 9.2 Management of species

Management of species includes control and regulation of commercial fisheries and amateur collection of corals and other reef organisms, particularly the molluscs. Legislations governing the exploitation of several species already exist in many countries, such as for marine turtles, precious coral and trochus shells. Protection of species by declaring them as endangered is also helpful. More recently, the emphasis on the protection of species is through a total ban or regulation of the export and import of corals and shells considered to be overexploited.

Legal protection for species and their management in Indian reefs, in general, does not exist and where it exists, its enforcement is not intensive, though there is an awareness of the depletion of many species. In the Gulf of Kutch, the only declared Marine National Park, protection extends over all marine life. In the Lakshadweep islands, collection of corals is banned, but is to be enforced strictly.

### 9.3 Extension service

Management measures would undoubtedly be effective, at least partially if not wholly in conserving reefs, but it is important to create public awareness regarding the delicateness and the fragility of the coral reef ecosystems. This can be done by educational and extension programs. Non-formal education of the local population can be a useful tool in cultivating environmental awareness among local inhabitants (Cabandan and White 1981) and would certainly lead to lasting results than rigid legal conservation programs. The awareness and concern created by television serials and movies of Jacques Cousteau are pointers in this direction, as they served a better purpose than the hundreds of books and articles written on coral reefs and their conservation.

The present status of our reefs can best be summarized with reference to the following sequence of human impact on marine resources: discovery, exploitation, overharvest, decline and recognition of the need for conservation and management (Kenchington and Hudson 1984). Most of our reefs have already declined and in the case of others, overharvest and decimation of fauna and flora, appear to be common. We have no alternative but to seek conservation and the sooner this is done, the better are the prospects of protection for our reefs.

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