# DISTURBANCE AND CORAL COMMUNITY STRUCTURE IN THE INTERTIDAL CORAL REEFS OF THE SOUTHERN GULF OF KUTCH

DISSERTATION SUBMITTED TO SAURASHTRA UNIVERSITY, RAJKOT,
IN PARTIAL FULFILMENT OF THE MASTER'S DEGREE IN
WILDLIFE SCIENCE,
JULY 1995

ROHAN ARTHUR

UNDER THE SUPERVISION OF
Dr. Y.V. JHALA

WILDLIFE INSTITUTE OF INDIA, DEHRADUN

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

**CERTIFICATE**

This is to certify that Rohan Arthur of the Wildlife Institute of India has carried out a piece of original research work entitled "Disturbance and coral community structure in the intertidal coral reefs of the southern Gulf of Kutch" in partial fulfilment of M.Sc. (Wildlife Science) degree of Saurashtra University, Rajkot. These investigations were carried out under my supervision at the Wildlife Institute of India from November 1994 to July 1995. I also certify that this work has not been submitted for any other degree of any other university.

Jhala.

DR. Y. V. JHALA

SCIENTIST - SE, FACULTY OF WILDLIFE BIOLOGY

DATE: JULY 3RD, 1995

PLACE: DEHRA DUN

**Post Box No. 18, Chandrabani, Dehradun - 248 001. India**
EPABX: 620912 to 620915; Fax: 0135-620217; Gram: WILDLIFE

for

**Smita Krishnan**

who belongs to the reef

**CONTENTS**

## LIST OF TABLES AND FIGURES

**Acknowledgements**

I know, I know. I've heard it a hundred times if not more. A thesis is like a good Agatha Christie novel; anyone in their right mind will only read the first fifteen pages, and the denouement of the plot. The acknowledgements is the place where the reader still has a smile on his or her face, and a genuine desire to read this little piece of original work from cover to cover. If you want to create a good impression, here is the place to do it.

Yet, right now, a hectic, crazy night of panic and typewriter keys is drawing to a close and the smell of the coffee Dr. Jhala prepared for us fills the room with the sweet stale smell of the succour it provided us. I am at a creative low right now and the only really creative strategy of writing this prayer of thanksgiving is this:

**From the bottom of my heart, I thank you all.**

But that's no go. A thesis, even a M.Sc. thesis, is still the end result of the goodwill, love, and sheer dogged persistence of so many people who do not appear on the title page to take responsibility. So here I am, holding the baby and the least I can do is thank the many who made it happen.

Dr. Jhala, guide and mentor, for agreeing to work with me on this project and then suffering the haphazardness of my work-style without too much complaint. I spent several very enjoyable hours poaching puffer in Pirotan with him. B.C. Choudhary was ever ready to help, reading drafts, providing much-needed reference material and clearing up my thinking about the problems of mangagement in the coastal zone. Ravi, good guy and comrade who told me that it's alright to be unconventional so long as I conform. Dr. Johnsingh who was always supportive and concerned. Qamar, ever ready to educate us lesser mortals, provided great insight into those rarified realms of the multvariate world. The entire Biology faculty provided me with support and encouragement. Dr. Renée Borges, always encouraging, assured me that all would be well.

The Field Experiece deserves those capitals. It was a growth experience, a lesson in life and in living.

Vimal Bhuva taught me basic survival skills in Gujarat and settled me in in fine form. My philosopher-fool field assistant Adam (Dada) and his wife Ayesha (Dadi) did more than carry my equipment into the reef and cook my food. They taught the true meaning of that old cliche - the simple life - how to fish and catch crabs; if I learnt nothing else in the past months, these are enough.

I thank the Chief Wildlife Warden of Gujarat, without whose support the project would not have happened. All the forest Department staff and the staff of the Educational Camp, treated me like a freindly alien and showed me off to all the earthlings of Jamnagar. The ACF Mr. Baleja was always ready to help if the need arose.

The staff of the Lighthouse and the Jamvijay Launch staff provided strong tea and light conversation along the mangrove creeks to Pirotan.

Dr. M. I. Patel of the Gujarat Fisheries Department identified the coral species and I am eternally grateful to him.

The hostelites at the WII, understood (or tried to understand) my weird ways. I bow to them, respecting their insanity as sacred to them as they recognized that mine is sacred to me. Aparajita, Vidya, Divya, Christy, Nima, Shomita, Azra, without them life would have been infinitely simpler but a lot less fun. Aparajita provided sorely needed help in the run-up to the deadline doing all the dirty work of tidying up graphs, creating tables, and using SPSS wizardry to do last minute analysis. Diwakar was of immense help in sorting out the intricacies of CANOCO and TWINSPAN.

My classmates, more than any other group of individuals had to suffer me (not always in silence) and they deserve a round of applause. Will every body stand up please. They bashed my ideas to bits, laughed at my accent, laughed at my mannerisms, were exasperated by my mindlessness, never took me seriously and I love them dearly.

The computer and GIS room staff were always there to rescue me from my worst scrapes with the software. The Rizo room wizards helped make this thesis look presentable. I bless them both, Mahesh and Ishmael .

I would like to express my deep appreciation for the helpfulness and concerned efficiency of the library staff at the National Institute of Oceanography. Without their help, most of my referencing would have been impossible.

The engineers at the Indian Oil Corporation were extremely friendly and I thank them for providing the crude for the experimental treatments.

For taking the time to visit me in Pirotan and helping to alleviate the lonliness, I thank Rajiv, Aparajita, Smita, Natasha, Deepali, Rishi and my parents who braved the terrors of the reef just to see what their son was actually upto. Deepani, who carried maggoty specimens to Ahmedabad to get them identified requires a special word of thanks. With the hectic schedule I was running, I would never have been able to do the job myself.

Smita, teacher, friend, confidante showed a faith in me that I did not have in myself.

Natasha, understood and understands.

My parents who always allowed me to have my head in the clouds and only occasionally made attempts to make sure my feet touched the ground. The support they provided during the entire field-work and report-writing stage was huge.

That's about it I guess. Ah, yes, I would also like to thank a little green, dogeared notebook with information on 110 community quadrats in them. It is lurking somewhere in the infinite universe of possibilities that exist between the computer room and my hostel cell. It taught me a lesson very hard in the learning, that I am not totally in control of everything and some things have to be left to higher beings.

**Summary**

I quantified the coral community structure using quadrat sampling in two intertidal coral reefs off the island of Narrara and Pirotan in the Southern Gulf of Kutch. These areas are subject to heavy disturbance from industries, and anthropogenic pressures on the reef are considerable. Species richness and indices of diversity indicate the reefs are of low diversity. Species diversity values indicate that Narrara has a lower species diversity (H'= 2.822, SE 0.139) than Pirotan (H'= 3.95, SE 0.126) (t-test, d.f. = 236, $p < 0.001$). However, environmental data collected from both areas indicate that the levels of disturbance, measured as the mean percentages of dead coral, sediment load on live coral, algae cover and bleaching, was generally higher in Pirotan than in Narrara. Multivariate techniques of analysis were used to elucidate these trends. Community clustering using the statistical package TWINSPAN and direct ordination using Canonical Correspondence (statistical package CANOCO) were carried out. Axis I correlated well with the percentage of boulders in the reef and the density of algae, and Axis II correlated well with sediment load on the coral. Species showed clear patterns of distribution along these axes.

I set up experiments to test the effect of crude oil and bittern, a salt manufacturing by-product, on two common reef Scleractinidia, *Porites compressa* and *Favia favus*. Significant effects were seen with both pollutants. Most of the replicates showed some level of recovery though this recovery did not result in any of the coral regaining total health. Indices of coral sensitivity and coral recovery was developed and this proved a valuable means of comparing the response of different species.

Bittern and crude oil stressed the corals and resulted in sediment depostion. The immediate cause of mortality was caused by sediment deposits on the coral boulders. In highly turbid reefs, coral species might be affected more by high sedimentation levels than by other environmental stressors.

# 1. Introduction

## 1.1. *General introduction*

Coral reefs are ecosystems that have, in their brief evolutionary existence, been moulded by the forces of disturbance into highly complex, highly diverse ecosystems that are characterized by high rates of primary productivity and are in a constant state of flux (Petraitis *et al. 1993*). The pressures of living in a near-shore environment with all its variability and unpredictability make coral reefs extremely plastic and they can generally withstand a lot of disturbance from natural forces without disastrous effects.

Our natural systems bear the brunt of man's activity and many survive on the brink of disaster. The coral reef is an ecosystem that has suffered the activities of man ever since the vast possibilities of the reef were realised. Reefs create calm waters where they form and are the richest fishing grounds in the sea. They are an abundant source of raw material for industry: coral sands and coral skeletons are excellent sources of calcium carbonate for the cement. Coral and sand mining, strip large areas of rich reef bare and promote coastal erosion. The high levels of sedimentation caused by this erosion process is detrimental to all reef organisms (Rogers 1990), and sedentary species like coral are worst affected.

Fringing reefs such as the reefs of the Red Sea, the Caribbean and the Gulf of Kutch survive in areas that are also heavily used by man as sea ports, fishing waters and for recreation. Because of this the reef is subject to a host of other disturbances through physical destruction from trampling and breakage by ship keels and anchors, and through physiological stresses in the form of oil, thermal pollution, sediment load and effluent releases (Johannes *et al.* 1972, Salm 1983, Hawkins and Roberts 1993, van Katwijk *et al.* 1993).

The Southern Gulf of Kutch is a centre of heavy industrial activity fast increasing in its economic value to the region. The number of private concerns handling the storage and transport of crude and petroleum products have increased in recent years (H.S. Singh, *pers. comm.*). Besides this, the gulf is dotted with many other industries that include thermal power plants, a cement factory, an ammonia plant and numerous small scale and mega-industrial salt manufacturing works (Naik *et al.* 1985).

The reefs of the Gulf possess a naturally low diversity of corals. They still support a wide variety of marine life in the intertidal regions and beyond, as well as some extensive mangrove patches. This study aimed at describing and quantifying the coral community structure in the intertidal zones of two disturbed reefs of the area. In order to examine the effect of crude oil and "bittern" on important coral species, I carried out a series of field experiments, that simulated the conditions of an oil spill on two intertidal coral species *Porites compressa* and *Favia favus*. Similar experiments were carried out using "bittern".

## 1.2. *Stress Effects on Scleractinidian Coral: A Review*

### 1.2.1 Oil pollution studies on corals and Reefs

Ecological disasters like the *Torrey Canyon* (in 1967) and the *Santa Barbara* (in 1969) catastrophes which caused extensive damage to marine life, concern about the effect of oil and other pollutants affecting these important environmental and economic areas has been high ever since the 1970's. The 70's and early 80's saw a significant amount of work emerging on the effect of oil and oil-based products on corals and coral reefs. Much of this work consists primarily of experiments carried out within the controlled but much simplified environment of marine aquaria. The literature available from the field consist primarily of reports of oil spills and a qualitative assessment of damage and recovery (Spooner 1970, Loya 1975, Shinn 1976). The conclusions of all these studies is often contradictory and no clear picture emerges of the effect corals sustain during an oil spill. In one experiment, Lewis (1971) exposed the corals *Porites porites*, *Agaricia agaricites*, *Favia fragum* and *Madracis asperula* to Barbados crude in totally enclosed aquaria. All the coral were severely affected by the oil at low concentrations and showed no significant recovery. They suffered ruptured tissue, nematocyst discharge and other signs of distress, such as abnormal feeding and tactile responses.

Loya (1975) criticized these experiments, pointing out that the conditions under which the coral were exposed to oil were extremely unnatural and never met with in the field. Coral death, says Loya, may have resulted from toxic lower hydrocarbons that, being very volatile, evaporate very quickly in the wake of a spill. This was confirmed when Elgershuizen and Kruijf (1976), conducting very similar experiments on *Madracis mirablis* in open aquaria, found little disastrous effect. Oil on the surface of the water caused negligible disturbance to the coral and recovery was noticed after 24 hours of exposure. Mixed with the sea water, the oil produced a marginally increased effect, though recovery once again, was almost total. Both studies show a more significant effect on corals of chemical dispersants used to clean up the spill. Elgershuizen and Kruijf (1976) hypothesize that dispersants, by emulsifying the oil into smaller and more abundant globules, increase the potential surface of contact the oil can have with the coral. Furthermore, their experiments suggest that the dispersants themselves are toxic to coral. Still in the laboratory, Loya and Rinkevich (1979) reported physiological stress to corals exposed to crude oil expressed as an abnormal reproductive behaviour which they term the "abortion effect". The coral *Stylophora pistillata*, exposed to oil and sea water mixtures at different concentrations, showed an immediate mouth opening response and a premature expulsion of planulae. These planulae, they speculate, would be ill-equipped to deal with the vagaries of sea, less likely to settle in favourable areas, be less competitive in the reef and more prone to predation. The extrusion of planulae was accompanied by an expulsion of zooxanthallae, a well-documented sign of stress. Loya and Rinkevich also noted that this abortion effect is manifest with many other physical disturbances such as sediment load, fluctuations in temperature, storm winds and, in laboratory conditions, on the application of chemicals such as ethyl alcohol.

Other physiological signs of distress have been noted by a number of researchers in the laboratory. Oil pollution causes indirect damage to coral by stimulating excessive mucous secretion Mitchell and Chet (1975), coagulation necrosis in coenosarc tissues (Peters *et al.* 1981), damage to feeding mechanisms (Reimer 1975) besides effecting other changes in coral behaviour (Cohen *et al.* 1977)

Coral researchers tend to agree that the best measure of stress on a reef is reflected in alterations of growth rates in corals. The growth rate encapsulates a variety of physiological processes and a change in any of them will be manifest as a change in the growth rate of the species (Brown and

Howard 1985, Birkeland *et al.* 1976). However, it is also common knowledge that the growth of corals is an extremely variable factor, changing from species to species, reef to reef, between reef zones and even between individual colonies. The work of Birkeland and his colleagues (Birkeland *et al.* 1976) is one of the few studies that looks at the effect of oil on the growth of corals. In the laboratory, the general trend noticed is that oil causes scarce little damage to the physical structure of corals except under extremely harsh conditions. Birkeland showed that while mortality did not occur under petrochemical stress (Bunker C oil, exposure for 2.5 hours), specimens of *Porites furcata* showed decreased mean growth increments 61 days post-exposure.

As Grigg and Dollar (1993) and other reviewers (see Brown and Howard 1985, Loya and Rinkevich 1980,1987) have made clear, laboratory experimentation should be evaluated with extreme care for their simplifying assumptions and unnatural environments can very easily lead us to equally simplistic results which are seldom seen in the field themselves. The dearth of field experimentation however means that we have to fall back largely on this body of laboratory work to form any theory of oil pollution on coral reefs.

Reports from the field are generally opportunistic observations on a reef after an oil spill has occurred. The Gulf of Eliat in the Red Sea is perhaps a notable exception where sustained and intensive work was carried out on oil pollution effects (Loya 1975, Rinkevich and Loya 1977, Loya and Rinkevich 1979, Loya 1980). They worked on the effect crude has on the reproductive patterns of *Stylophora pistillata* Loya and Rinkevich 1979) in the field, comparing the mortality rates of colonies, number of ovaries per polyp, number of planulae per coral head, and the settlement rate of planulae of chronically polluted sites with sites not polluted with crude. They showed a significant lowering of function in all the observed criterion of corals in polluted waters. Their work is of particular interest because they corroborated their field results with more controlled experiments in the field using Iranian crude (see above).

The report of Shinn (1976) suggests on the other hand that corals are generally not affected much by oil and pose a minor threat to the reef. His conclusions were based on observations of polluted reefs in Persian Gulf. These results however should be viewed with the same caution that

Grigg and Dollar (1993) applied to laboratory work for his results are based on a qualitative assessment of the reef, reporting total recovery within 6 years without actually measuring the rate of recolonization or knowing the coral community structure of the pre-catastrophe reef. Johannes *et al.* (1975) warns that when a reef community is destroyed, the ecological conditions that follow cannot be expected to coincide with those which preceded the initial development of the community. Thus it can never be guaranteed that, in the wake of a major disturbance, the reef will ever replace itself. Loya (1976) carried out a long term study on the effect of oil pollution on a reef which suffered a catastrophic low tide, comparing it with a 'clean' reef which suffered the same low tide. The low tide killed off 90% of all Scleractinidian coral in both reefs and while, after three years, the undisturbed reef was flourishing with a high diversity of coral species, the polluted reef showed almost no recolonization at all. Even after 10 years of the event, the polluted reef showed no signs of recolonization (Loya unpublished, quoted in Loya and Rinkevich 1980).

Of particular interest to this study is the report of Johannes *et al.* (1972) that corals exposed to air can be severely affected by crude oil pollution. In an experiment designed to support this claim they exposed one or two specimens of 22 species of coral to crude oil and left them out of water for 90 minutes before placing them back in the reef. They noticed a complete breakdown of coral tissue in many species where the oil had come in contact with the animal. Though none of the colonies were totally killed, no regeneration was observed on affected boulders.

What does emerge from all the conflicting reportage is the fact that corals respond in rather unpredictable ways to oil. Each species will no doubt have its own characteristic range of tolerances depending on the its resistance to stress in general. More evidently, in the event of a spill, the effects observed will be greatly determined by the time of the year that the spill occurs in, the atmospheric conditions at the time of the spill (see Johannes *et al.* 1972), the microhabitat characters of the reef, the tidal flux and a plethora of such environmental variables. It is perhaps a futile task to try and work out a generalized model for oil pollution on coral species yet it is not necessarily true that no guidelines or precautionary notes can be drawn from the body of work on the subject. Most reviewers (Brown and Howard 1985, Grigg and Dollar 1993) for instance agree that chronic oil pollution, while it receives less attention both from researchers as well as from the public at large, is much more detrimental than the high-profile mega-spills that everybody hears about. It is also pretty well documented and corroborated that the dispersants used in cleanup operations are more detrimental to Scleractinidian corals as well as to other reef organisms. Corals are resistant, it would appear, to pollution from petroleum hydrocarbons, but that by no means that they are not affected by them.

### 1.2.2 *Effects of Sedimentation*

The physical alteration of coastlines has very serious effects not only on coastal ecosystems. It is one of the common and pressing problems for coral reefs and other near-shore ecosystems as well (Grigg and Dollar 1993). It is caused by a host of anthropogenic activities that include the cutting of mangroves, sand mining, land reclamations and other such activities. The upshot of this activity is an increased sediment load on coral reefs and this severely disrupts reef functioning. Sediment loads can also arise from construction activities in and around the reef, dredging of coral for construction and cement, increased run-offs from rivers and increased vehicular traffic around reef areas.

Sedimentation as a disturbance factor in coral reefs has garnered much interest and concern from scientists. Johannes (1975), Bak (1978) and Rogers (1990) have reviewed quite extensively the effects of sediment on reef environments, and the responses of reef dwellers to increased sediment load. Sediment stress generally has more predictable a response on coral species than oil pollution. Corals, living as they do, in the sediment-rich waters of the continental waters, have an inherent ability to deal with sediment (see Endean 1976). They have an efficient ciliary mechanism which serves primarily as a food-garnering mechanism, but also serves the additional function of keeping the skeleton clean of all sediment. Corals can also deal with sediment load with tentacular movement, stomodeal distension through the uptake of water and with the entanglement of sediment with mucus secretion that later sloughs off the coral. However, most coral are intolerant to great increases in the sediment load in the water.

Sometimes dredging and other activities seem to cause only negligible damage to corals (Brown and Howard 1985). The dumping of 2200 tons of kaolin clay from a freighter grounded on a reef, produced large plumes of suspended clay but not much damage was seen beyond a 50 m radius of the site (Grigg and Dollar 1993). Sheppard (1980) reported that the effect of dredging and blasting in Diego Garcia Lagoon in the Indian Ocean was a low coral cover but little change in coral diversity. Rogers (1990) suggests that the presence of strong currents might be an alleviatory factor in reefs with high sediment loads. It is not surprising that sediment levels can determine the distribution and abundance of species in a reef. In the reef crest areas, where the currents are strongest, highly turbid reefs show the highest diversities, though the size of coral species in these areas is limited by the battering of waves (see Morelock *et al.* 1977, Hubbard *et al.* 1987). Highly sedimented areas of reefs have been shown to have lower rates of coral recruitment, lower growth rates, lower coral cover, lower species diversity and a greater abundance of sediment-resistant coral species (Rogers 1990). As with crude oil, the studies suggest that, more than large single doses of sediment, small scale, chronic turbidity is more deleterious to coral species in particular and the reef in general (Johannes *et al.* 1972, Grigg and Dollar 1993).

### 1.2.3 *Effects of Salinity*

Corals, it is known, thrive in a narrow range of salinity (Endean 1976). Not many studies have looked at the effect of salinity changes on coral species but a few qualitative reports do exist. These are largely in relation to the drastic lowering of salinities that accompanies heavy tropical storms. When these storms occur during the period of the low water, the salinity conditions are even more severely exacerbated and corals in the intertidal zone, more affected (Goodbody 1961, Banner 1968). These effects are hard to separate from the effects of mechanical destruction that these catastrophic events wreak on the coral (Stoddart 1963). Besides, during these events, siltation levels also increase significantly and the response observed could well be a result of this disturbance. The loss of zooxanthallae commonly reported as a result of decreased salinities results in a phenomenon called bleaching. Recovery in most cases was very variables (Kinsman 1964, Brown and Howard 1985,). Heightened levels of salinity also have a significant deleterious effect on coral (Brown and Howard 1985 but see Kinsman 1964). No experiments have been conducted in the field on the effect of heightened salinities, and in the light of effluent releases from nearshore industries like salt-pans, such work is sorely needed.

### 1.2.4 *Community structure and disturbance*

Disturbance has been a topic of active research in coral reefs and intertidal communities and much important theorizing has resulted from this interest. Ever since Connell's (1978) path-breaking intermediate disturbance hypothesis of ecological diversity in coral reefs and tropical rainforests, scientists have found that several ecosystems are steered quite significantly by the hand of disturbance. The intertidal region of the sea in particular is an area in which disturbance levels are very significant and communities there are limited by disturbance (Sousa 1979). The individual organisms that dwell in these areas have peculiarities of behaviour and natural history that make them resilient to the various stress factors that they have to face. Coral ecologists have found that corals surviving in intertidal areas of the sea are generally much hardier than those living in deeper waters. Much of the community ecology work on these systems look at the effect of specific disturbances on the coral (Loya 1975, Öhman et al. 1993, Hawkins & Roberts 1993, van Katwijk *et al.* 1993) and on the recovery of coral communities from such disturbances (Loya 1976). Oil pollution has been shown to have some (if confusing) effects on coral communities (see above) while sedimentation has been shown to have significant effects on coral diversity (van Katwijk *et al.* 1993). The effects trampling by people on the reef communities has also been a topic of research in recent years in the light of the new rush of ecotourists and pleasure seekers to coral reef areas.

# 2. STUDY AREA

## 2.1 *The Gulf of Kutch: Coral Communities in a disturbed reef*

The Southern Gulf of Kutch in Gujarat lies between the latitudes 22°15' and 23°15' N and the longitudes 69°00' and 70°40' E. The Gulf covers an area of 735 km$^2$. with forty-two small islands in it. Only one island, Ajad, has a small population living on it. Annual temperatures vary from 7°C to 40°C and the area receives an average of 300 mm of rainfall, most of it in the months of July and August.

Of the little work done on the flora and fauna of the region, the available literature is confined chiefly to inventories of the species, which, though not intensive, are extensive (see Naik *et al.*, 1985). Over hundred species of algae were found in the past though recent records list about seventy four. There are small pockets of excellent mangrove forests comprising primarily of *Avicennia alba*, *Rhizophora micronata* and *Ceriops tagal* on the islands of Khara Chusna and Pirotan.

Among the fauna recorded from the area are some 150 species of fish, large numbers of sponges, arthropods, molluscs and other invertebrates. Thirty-two species of hard (Scleractinidian) and 12 species of soft (Alcyonarian) coral have been recorded, found as fringing reefs and numerous coral boulders upto a water depth of 30 meters (Scott 1989). To stem the alarming loss of biodiversity and habitat that was resulting from industrial activity, the Marine National Park was set up and this covers an area of 163 km$^2$., the Marine Sanctuary enclosing a 45,6 km$^2$. area (Rashid 1985). This was quite a landmark in Indian conservation history for it was the first Marine National Park to be established in India.

There are many reasons why corals and coral reefs should not thrive in the waters of the Southern Gulf of Kutch. Coral reefs are a purely tropical phenomenon and the Tropic of Cancer on which the Gulf lies is very near the 20°C isotherm, the accepted temperature barrier to coral formation (Endean 1976). The west coasts of continents do not generally harbour coral life because of the cold polar currents that wash against their shores. The west coast of India in particular is not conducive to the growth of coral primarily due to the high sedimentation loads that the continental seas are subjected to by the rivers that empty their silt into them (Wafar 1985). The levels of sedimentation is particularly high in the gulf waters, turbidity being as high as 1m depth (Naik *et. al* 1986).

A tectonic uplift made much of the gulf a very lowlying area, and the area therefore experiences an unusually large tidal fluctuation (Naik *et al.* 1988). The ample intertidal zone that results from this tidal fluctuation ensures that the coral have a much greater probability of being exposed to air during the low tide and few coral can tolerate this constant exposure.

Despite all this, coral reefs do survive in the Gulf of Kutch. They are an important ecological feature for the area and support large commercial and artizanal fisheries. Managed with care they can also form an abundant storehouse of raw material for industrial, pharmacological and research purposes. The fishers use the reef an its many islands not only to fish but as safe, calm water for harbouring small boats and as a rich source of octopus, a valuable bait for large scale hook-and-line fishing. The mangrove is often illegally lopped for fuelwood and the plants themselves were subject to heavy camel grazing in the past.

The waters of the Gulf have historically been an important link with the countries across the Arabian Ocean, and, in recent times, have also served as a vital and busy trade route between India, Africa and the Middle East. There is a heavy industrial dependence on the Gulf particularly for oil supplies that is ferried over in the form of crude from Iran, Kuwait and other oil producing nations. Naturally then the pressure on the reef is high with the high traffic of large cargo ships constantly plying the waters. Minor oil spills are a constant feature in the area with crude and engine oils generally finding their way onto the nearby islands, polluting the sands and poisoning the reef. The coral reefs and mangrove forests are most threatened by this chronic spillage of oil.

The entire coast of the Southern Gulf of Kutch is also dotted with many tiny salt manufacturing industries. These pans release a byproduct of salt manufacture called 'bittern' into the gulf waters that increases the salinity of the surrounding area. This has virtually killed off the reefs found off the coast of Okha. Many other industries also depend on the reef including cement industries which mined coral directly from the reef before the National Park was declared (Singh 1995) and several fertilizer and chemical plants. All these apply their own pollution pressures on the coral reef and the battle to try and protect this area from their influence is perhaps a vain one.

**2.1.1. Narrara Beyt:** Narrara Beyt is now a mere strip of sand where once an island stood. The heavy sand mining and coral dredging that the island withstood has taken a heavy toll on the area and the reefs are extremely restricted in their formation and low in diversity. The island is connected to the mainland by a jetty that serves as a thoroughfare for the existing Indian Oil Corporation pipeline that carries crude oil to repository tanks and thence to Mathura. The oil is offloaded from waiting ships via the Single Buoy Mooring located a few kilometres from the shore. Accidental spills sometimes occur in this area from the waiting tankers but more alarming is the chronic spillage of crude from the delivery point which goes largely unnoticed. A large area of the near shore has been modified into extensive pans for salt manufacturing and these also pose a threat to the reef because they release bittern into the sea waters either directly or when the high tide inundates the pans with bittern in them.

Stunted mangrove are present on the landward side of the beyt while sparse mangroves, vestiges of failed plantation experiments line the seaward side of the island. The site serves as an ideal roosting spot for many shore birds, chiefly crab plovers, oystercatchers, sand plovers and egrets.

**2.1.2 Pirotan:** The island of Pirotan is the northernmost island of the 42 present in the Gulf. Located around ten kilometres from the nearest port, Jamnagar, it is a mere 1.5 sq kilometres in size. It has some of the last good mangrove patches in the Gulf and this was, till very recently subject to unrestrained lopping and camel grazing. The island was also dredged for cement along with Narrara. The island has a non-reproducing population of six individuals, most of them lighthouse personnel. Besides the lighthouse and its associated structures, a "Pir" (a Muslim shrine) is also present. Pirotan (*Pir-no-sthan* or the place of the Pir) is held as sacred by the primarily muslim fishing communities of the southern Gulf and a heavy load of pilgrims visit it year round.

The reefs of the area are extensive but prone to high levels of siltation caused by rapid coastal erosion on it as well neighbouring islands. Coral diversity is higher than it is in Narrara. The island serves as a dense breeding ground for grey herons and several egret species.

## 3. METHODS

### 3.1. Community structure

To quantify the community structure of the sedentary reef organisms, quadrat sampling was used (Naik *et al.* 1985, van Katwijk 1993), borrowing a method often used by plant ecologists. 1 X 1 m quadrats (divided into a hundred 0.1 m cells) were used. The reef was divided into strata based on distance from the shore and the quadrats were cast along a random walk parallel to the shore within the strata. The quadrat constituents were noted as follows:

1. All coral species present were listed along with the percentage of the quadrat that they occupied. This was estimated by counting the total number of 0.1 mt squares that the coral occupied within the quadrat. A cell was considered to be occupied when more than 50% of cell was occupied. Any coral with a percent cover of less than 1 % (one quadrat cell) was noted as a presence.

2. Other quadrat constituents were also noted. The most important and dominant group noted here were the various algae species. Besides this, sponge species, molluscs, cephalopods, and others were also noted.

3. Wherever possible, the boulders were lifted as gently as possible so as not to disturb the marine organisms living under them, to record the species found below the boulders. Species were recorded as frequencies. This was abandoned later on because most of the boulders in the later sampling were too large to attempt to lift without effort and the sampling would be uncontrollably biased towards small and medium sized boulders. It must be noted however, that a great diversity of invertebrate species were found below these boulders and the true richness of the reef is evident in this diversity.

Habitat parameters as a general rule are very difficult to measure accurately without expensive and time consuming methods, yet, some attempt was made to collect these environmental variables.

1. The exposure of the corals in the quadrat to wave action was estimated subjectively depending on the microhabitat characteristics of the corals in the quadrat and the relationship of this microhabitat character with the surrounding areas. If the coral boulders around the quadrat were visibly higher and proctecting the corals from waves, the exposure was considered to be low. Similarly, an area bereft

of protecting boulders around was classified as a high exposure area. If the boulders around were not visibly higher or lower than the quadrat corals, the quadrat was ranked as an intermediately exposed quadrat.

2. van Katwijk, *et al.* (1993) considers all uncolonized boulders to be an index of disturbance to the reef as they represent areas where colonizataion could, and generally would, occur and the fact that they are uncolonized is testimony to the fact that the reef is functioning at a level below its potential diversities. In Narrara and Pirotan, additionally, all the boulders found were coral boulders killed by some historic stress and later covered over by sand and sediments and in themselves represent a good index of disturbance on the reef. The percentage of dead coral boulders in the quadrat was noted.

3. If the live coral had visible portions of it covered by sediment, the percentage of sediment on the coral was noted. Sediment load is a major destructive force in disturbed reefs (see Rogers 1990) and though intertidal coral are generally more resistant to disturbances like sedimentation (Brown and Howard 1985), corals can be heavily stressed by heavy loads of sediment.

4. Bleaching is a phenomenon often noted when a coral is under stress (see Introduction for details). The stressed coral immediately expells it's symbiotic zooxanthallae and this is seen visibly as a discoloration of the area known as bleaching. It should be noted that the surrounding unbleached areas of the animal soon take over the bleached portions. The amount of bleaching present on a coral is a good indicator of coral stress and I recorded this as the percentage of the quadrat it occupied.

5. Algae has been used as an index of disturbance to the reef. This is justified for several reasons. For one, many algae species, particularly the larger, attached algae such as those of the *Sargassum* genus, pose a major problem to reef-building *Scleractinidian* corals. They shade the coral on which they grow from the sunlight, and thus restrict the photosynthetic activity of the zooxanthallae, which in turn restricts the growth of the coral (Katwijk 1993). Besides, most algae species are opportunistic, and will grow only on disturbed coral boulders which have some attachable substrate on which to grow. This is a direct result of siltation on the coral. Notable exceptions to this are the species of coralline algae found abundantly in many reefs. These are very much a part of the undisturbed reef community being very active reef builders, supplementing, in no small measure, the reef-building activities of the

*Scleractinidia* (Endean 1976). The percentage of algae present in the quadrats was noted and used as an environomental stress factor. Coralline algae, where encountered, was excluded from this index.

6. Identification of species: Coral species are notoriously difficult to identify in the field, partly because of the high amount of variation they show in colour, shape and overall structure. More importantly, taxonomic work on coral has only now gained respectibility (Wallace and Willis 1994) with the latest refinements in molecular techniques. The field researcher still has to depend on field guides which are very often unclear and unspecific (quite literally; most assist in identification only to the genus level). I used the key provided by Wood (1988) to identify the genus and took field notes on the physical characters of all species seen. The individual species were identified later by M. I. Patel of the Gujarat Fisheries Department who has worked on coral in this area for several years.

### 3.2. Experimental procedures

In order to experimentally determine the effect of crude oil and bittern on certain coral species, I set up the following experiments in the field. I used two species of coral, *Porites compressa* and *Favia favus* for the experiments. These were among the most abundant species in the reef and, in case of a spill would be the ones most abundantly affected.

Oil, it is clear from the literature (see introduction), has little effect to coral species when it is floated on the surface of the water. In the eventuality of a spill, this scenario, would be pretty much true to life in most seas. However, the corals of the Gulf survive in areas that come precariously close to total exposure with every low water. The region of the reef crest is particularly prone to emersion from water and the corals in these areas would come into direct contact with the crude during the spill. Since the intertidal region is so vast, a large area of coral would be affected by this exposure. Johannes *et al.* (1972) noted that corals exposed to air may be detrimentally affected by crude oil. This experiment was set up to test whether this was true and to see what the extent of damage would be.

Three boulders each of *Porites compressa* and *Favia favus* were used as experimental boulders. These were collected from a similar area in the reef and kept together under observation for 24 hours in the reef. Care was taken that after that period the corals still appeared to be healthy. The boulders were mapped on waterproof tracing film, and all dead and silted areas were noted. The coral were then exposed to Kuwait crude oil applied evenly to them in a thin layer. The boulders were exposed to air for a period of 30 minutes and then replaced carefully in the water.

The boulders were remapped one day after treatment, seven days after treatment, fifteen days, one month and two months post-exposure. At each remapping the portions bleached, silted or showing signs of recovery were noted.

Three boulders of each species were used as controls for the experiment and were placed in similar area of the reef. They were exposed to air for 30 minutes and mapped as with the experimental boulders to control for the possible effects of exposure to air and stress caused by relocation.

Corals are generally sensitive to extreme fluctuations in salinities. Very low salinities, experienced during rainstorms, can kill a large part of the reef. Similarly, extremely high salinities are also detrimental to coral.

To test the effect that the substance "bittern" has on corals I exposed the corals *Porites compressa* and *Favia favus* to bittern at half its concentration for 30 minutes before replacing them in the reef. The concentrations were determined using a Total Dissolved Solutes instrument. The Dissolved Solutes of the undiluted bittern was $80 \times 10^4$ TDS. This was approximately four times the concentration of the winter sea waters in the Gulf ($19.8 \times 10^4$ TDS).

### 3.3. Data Analysis

To check for adequacy of sampling, a cumulative species diversity graph was plotted using a running mean of the plot-wise Shannon-Weiner species diversity index $-\sum p_i \log_e p_i$ for both Narrara as well as Pirotan. Here $p_i$ is the propotional contribution of each species to the community The index was calculated using only Scleractinidian coral species for the calculation and for all further analysis, only coral species are considered.

Plotwise species diversity was calculated to compare Narrara and Pirotan in terms of their coral species diversities. For this purpose, species richness, as well as the Shannon-Weiner index were used as comparable indices of species diversity. Mean species diversities were also compared in different depth zones, (estimated subjectively in the field) within and between study sites. Because of widely varying sample sizes, this trend could not be tested for significance. Continuing the comparison of the two sites, I compared mean levels of sediment deposits on the boulders, bleaching, algae, uncolonized and dead bouldery substrate in Pirotan and Nararra. Since none of the varibales were normally distributed (K-S one sample test $p < 0.001$), Mann Whitney U tests were used to test these values for significance.

Beyond this initial comparison, I used multivariate statistical techniques to look for species associations and habitat differences between and within the sites. I used the statistical package TWINSPAN (Hill 1979) to elucidate the major coral associations of the reef. This performs a two way indicator analysis on the quadrat and species abundance data using reciprocal averaging to separate the sampling points and the species into recognizable groups or associations. It is more and more being used as a powerful and flexible technique for the clustering of species data (Kent and Coker 1992) and is intuitively easy to comprehend. I found that the default abundances values (the pseudospecies cut levels) were adequate for the kind of abundances of species commonly encountered in the quadrats. I chose to weight the most abundant species to facilitate clumping of associations. I plotted a denrogram using the eigen values calculated by the analysis. The cut off point was determined by the level below which making ecological sense of further divisions was infeasible. For ease of interpretation, I chose not to proceed beyond the third level of division.

In order to relate habitat variables and stress factors to the observed species associations, I used Canonical correspondence analysis with no detrending as the algorithm for analysis. Many researchers have found canonical correspondence analysis as a robust and versatile tool in the direct ordination of community data and it does not produce the observed 'arch effect' that Principal Components Analysis produces, nor does it possess the inelegancies of detrending that Detrended Corespondence has (Kent and Coker 1992). Palmer (1993) found, that even with skewed and non-normal data sets with a lot of environmental noise, the analysis was good enough to extract the two significant environmental axes from a simulated data set. I used the statistical package, CANOCO (Ter Braak 1987) for this. I used non-detrended correspondence analysis as the algorithm for analysis.

A point needs to be made here about distance from shore as a habitat parameter. While the basic structure of the reefs in Narrara and Pirotan was the same, the moat region of the intertidal reef where I concentrated my sampling, was closer to the shore at Narrara than it was at Pirotan. Comparable sites need to be used for any coherent community comparison and equal linear distances from shore do not represent comparable locations in the reef that can be contrasted. Because of this problem of deceptive distance measurements, I ran the canonical correspondence analysis once with distance as a varible and once without it. This was done with the conviction that the removal of this parameter would draw other more ecologically important trends in the community out of the data. The environmental axes I and II were used to analyse the relationship of the environmental variables with the species and sampling point distributions. The signficance of the first environmental axis was tested using the Monte Carlo test of significance with 150 iterations.

The experimental and control boulders were digitized using standard digitization software and areas affected and unaffected before and after the stress at varying intervals was calculated. An area graph was plotted for each boulder, showing the propotion of areas unaffected and the propotions of areas affected by the pollutant against the number of days after treatment. The affected portions of the coral were classified according to the type of response seen. Characteristically, the following classes of stress response and signs of coral disturbance were noted:

1. oil adhering to coral, 2. light bleaching, 3. heavy bleaching, 4. light silt 5. heavy silt, 6. bleaching and siltation.

The changes observed in these categories over time was presented in area graphs of propotion of coral against the number of days after treatment. These serve as a clear and unambiguous graphical means of examining the trends seen in coral decline and recovery after the pollution event.

I was interested in examining the sensitivity of coral species to the pollutant added as well as the recovery of the coral from the disturbance. In order to do this I constructed two indices using propotions of areas affected in order to standardize between boulders and to provide a numerical means of comparing the response of the coral.

**Sensitivity:** This I define as the Maximum propotion area affected divided by the the time the coral took to be thus affected. The higher the value of this index, the greater is the sensitivity of the coral and vice versa. Since the areas of all three replicate boulders was approximately the same, I calculated the mean sensitivity of each species to a particular disturbance. The index was calculated using the proportion:

$$Sensitivity = \frac{E_{\max}}{T_{\max}}$$

Where $\mathbf{E_{max}}$ or Maximum effect is defined as the lowest point on the response area graph expressed as a propotion of the total unaffected coral boulder prior to exposure. $\mathbf{T_{max}}$ is the number of days the coral takes to reach $\mathbf{E_{max}}$.

**Recovery:** The recovery response of a coral boulder from a pollution event determines how resilient a coral is when stressed. I calculated this index of recovery using the following formula:

$$Recovery = \frac{E_{stab} - E_{\max}}{T_{stab}}$$

Where $\mathbf{E_{stab}}$ is the stable point on the area graph, beyond which the coral did not recover. $\mathbf{T_{stab}}$ is the total number of days after $\mathbf{T_{max}}$ that the coral takes to reach $\mathbf{E_{stab}}$.

I used the mean index values of all boulders treated with crude and the mean index value of all bittern-treated boulders to compare the response of corals to the different stressors.

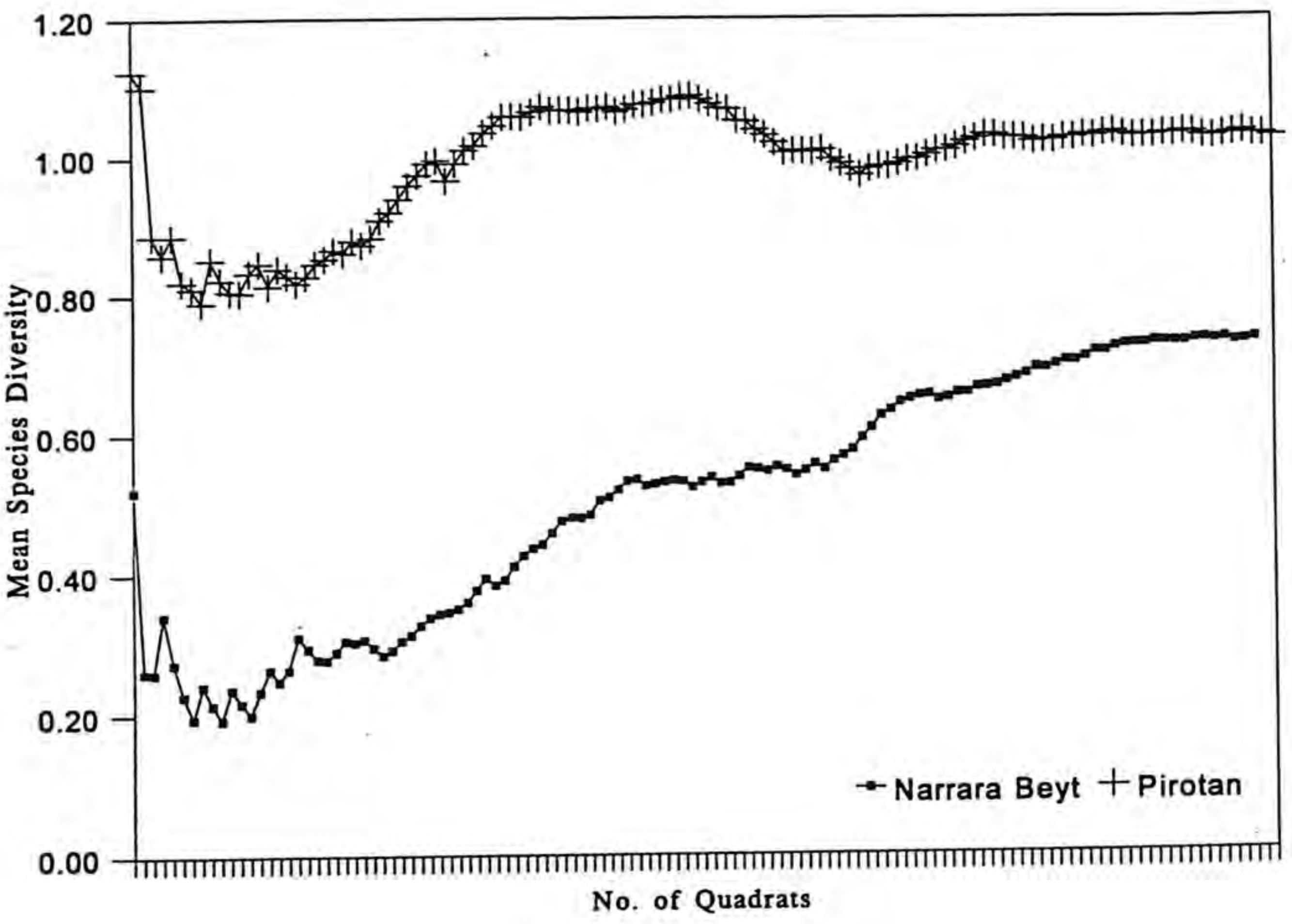
Table 1.

Comparative percent cover of various habitat components in Narrara and Pirotan, Gulf of Kutch, 1995

| | Percent Boulder | Percent Algae | Percent Silt | Percent Bleach |
|---|---|---|---|---|
| Narrara (n = 118) | 1.9% (0.537) | 5.6% (0.765) | 11.8% (0.817) | 1.4% (0.231) |
| Pirotan (n = 120) | 16.4% (1.162) | 16.9% (1.053) | 16.4% (0.985) | 1.2% (0.207) |
| Mann-Whitney U test | $p < 0.001$ | $p < 0.001$ | $p < 0.001$ | $p = 0.66$ |

Standard errors are given in parentheses

Figure 1. Running Mean Species Diversity curves of Narrara and Pirotan, Marine National Park, Gujarat 1994-95



## 4. RESULTS

### 4.1. *Community structure*

#### 4.1.1 Species Diversity:

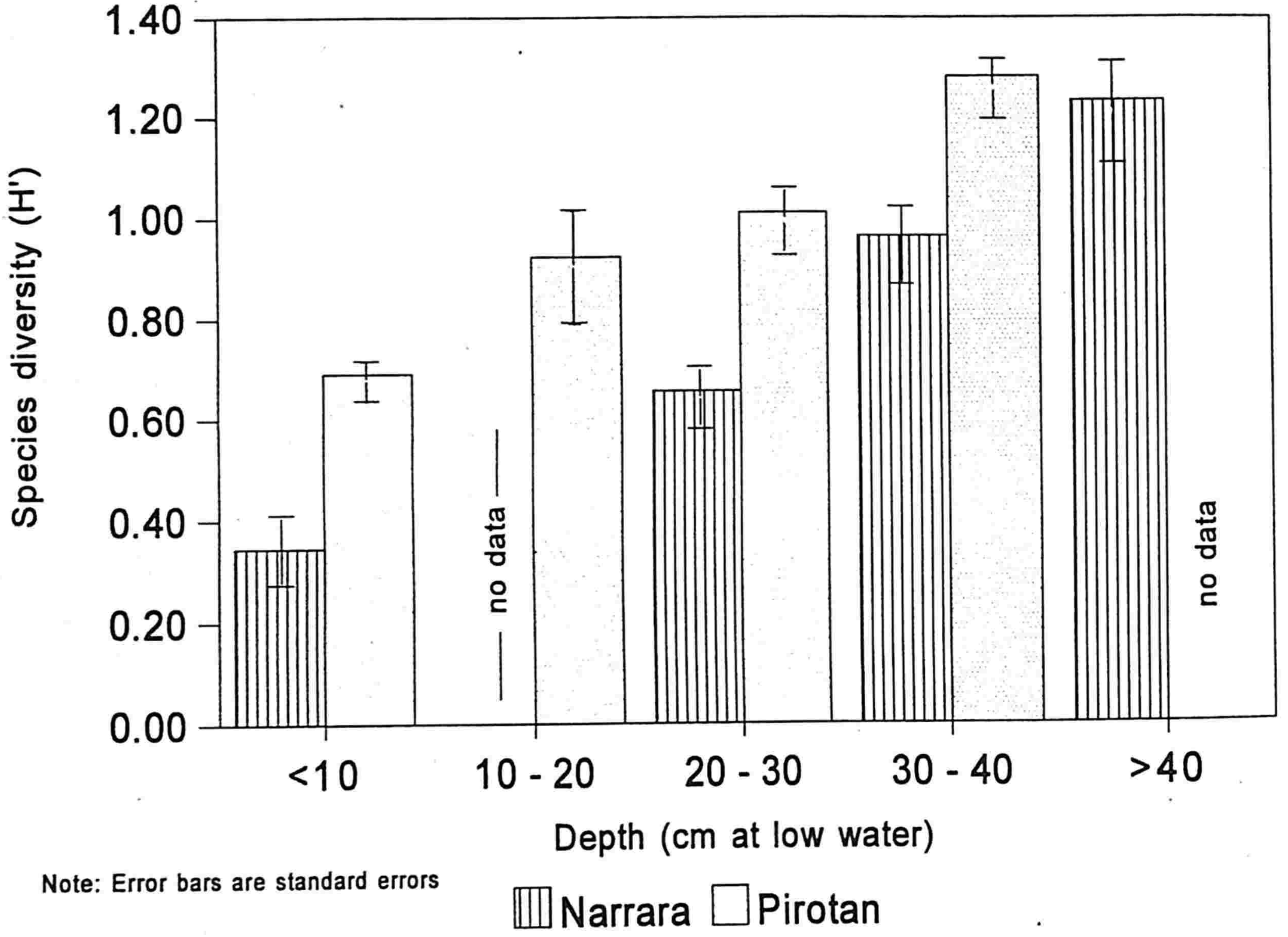
The cumulative species diversity curves were calculated as the running cumulative mean of species diversity of the individual quadrats. The curve for both sites leveled off before the 100th quadrat (Fig 1). In Narrara, I collected information from 118 quadrats whereas in Pirotan data was collected for 120 quadrats.

In terms of species richness, the sites do not seem to be very different. Narrara totals 13 species of coral whereas in Pirotan, 15 coral species were enumerated. There was a significant difference in the mean species richness per quadrat between Narrara (2.822 ± 0.139 SE) and Pirotan (3.95 ± 0.126 SE)(t-test, d.f. = 236, $p < 0.001$). The cumulative species diversity curve plotted depicts the pattern seen between the sites in terms of species richness and diversity. The mean species diversity of the two study sites suggests that Pirotan has at a higher species diversity than Narrara. The diversity for Pirotan was 1.0252 (± 0.036 SE) and for Narrara, was 0.7332 (± 0.044 SE). The t-test is a valid test of comparison for normally distributed species diversity values and the difference between the sites was highly significant (d.f.= 236, $p < 0.001$).

Diversity appears to be correlated with water depth at low tide. Species diversity increased consistently with increase in water depth (Fig 2). against water depth. At all comparable water depths, the coral diversity was higher in Pirotan than in Narrara.

Uncolonized or dead Bouldery substrate was generally higher in Pirotan where as in Narrara, this substrate appeared to be much rarer. Algae cover differed between the two sites (Table 1). In both the reef areas, the substrate most often encountered comprised of sand and boulders with a few areas (chiefly in deeper waters) which were dominated by boulders and some areas closer to shore which were largely sand. The amount of sediment deposited on the boulders in Narrara was slightly lower (11.8 %) from sediment deposits in Pirotan (16.4 %). Bleaching was a physiological stress seen throughout the reef though the percent of bleached areas on the coral was marginally higher in Narrara than it was in Pirotan and was not significantly different. There was a significant difference in percent boulder, algae cover and silt between Narrara and Pirotan (Table 1).

Figure 2. Species diversity at various depth zones in the intertidal coral reefs of Narrara and Pirotan, Gulf of Kutch, Gujarat, 1994-95




Note: Error bars are standard errors

**Table 2 a. Abundance ratings of coral species in the various associations identified by TWINSPAN analysis. (Data are from Narrara and Pirotan, Gulf of Kutch, 1995).**

| *Species* | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| *Porites compressa* | 0-3 | 3-5 | 0-5 | 0-3 | 0-4 | 0-4 | 0-4 |
| *Mycedium sps.?* | 0-3 | 0-5 | 0-4 | 0-3 | - | - | - |
| *Cyphastrea serallia* | 1-5 | 0-3 | 0-4 | 0-3 | - | - | - |
| *Porite lichen* | - | 0-4 | 0-3 | - | - | 0-2 | - |
| *Favia favus* | 0-5 | 0-2 | 0-5 | 0-3 | - | 0-5 | 0-5 |
| *Platygyra sinensis* | - | 0-5 | 0-5 | - | - | 0-4 | - |
| *Favites melicerum* | 0-4 | 0-5 | 0-5 | 0-4 | - | 0-5 | - |
| *Porites lutea* | 0-3 | 0-3 | 0-5 | 3-5 | - | 0-3 | - |
| *Favia speciosa* | - | - | 0-5 | 0-2 | - | 0-3 | - |
| *Sideastrea savigynyana* | - | 0-3 | 0-4 | - | - | - | - |
| *Montipora explanata* | - | 0-3 | 0-4 | - | - | - | - |
| *Favites complanata* | - | 0-3 | 0-3 | 0-4 | - | 0-3 | 0-3 |
| *Goniopora nigra* | 0-3 | 0-4 | 0-4 | 0-5 | 0-3 | 3-5 | 0-3 |
| *Goniopora minor* | - | 0-2 | 0-5 | - | 3-5 | 0-4 | 0-5 |
| *Goniopora planulata* | 0-3 | 0-4 | 0-5 | 0-5 | 0-3 | 0-4 | 3-5 |
| *Turbinaria peltata* | - | - | 0-1 | - | 0-4 | - | - |

Abundance ratings:

**0** 0%, **1** 0-1%, **2** 1-5%, **3** 6-10%, **4** 11-20%, **5** > 20%

Associations:

**A.** *Favites melicerum, Favia favus, Cyphastrea serallia*

**B.** *Porites compressa, Favites melicerum, Porites compressa*

**C.** *Favites melicerum, Favia favus, Favia speciosa*

**D.** *Montipora explanata, Favites melicerum, Favia favus*

**E.** *Goniopora minor, Goniopora planulata Platygyra sinensis*

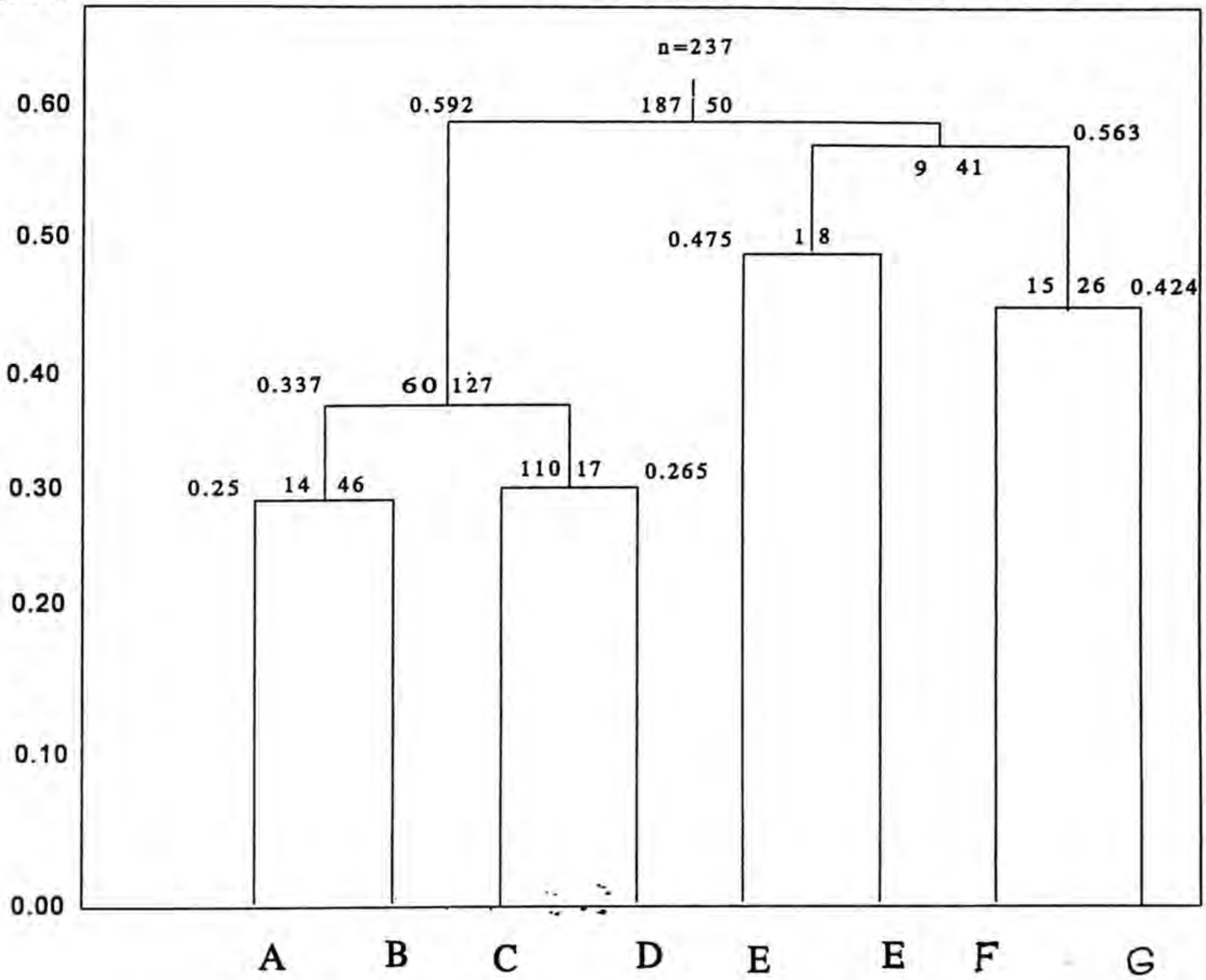
**F.** *Goniopora nigra, Goniopora planulata, Goniopora planulata*

**G.** *Goniopora planulata, Favia favus, Favia favus*

**Table 2 b.**
**Comparative mean quadrat percent cover of some habitat variables across the species associations identified by TWINSPAN in the intertidal coral reefs of Narrara and Pirotan, 1995.**

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Boulder | 8.42 | 9.54 | 11.90 | 10.64 | 0.89 | 3.31 | 2.40 |
| Silt | 11.36 | 17.41 | 14.80 | 13.12 | 9.22 | 14.38 | 9.20 |
| Algae | 20.71 | 15.76 | 11.06 | 10.65 | 6.88 | 4.56 | 5.00 |
| Bleach | 1.57 | 1.58 | 1.38 | 1.35 | 0.55 | 1.81 | 0.72 |

Figure 3. Coral associations in Narrara and Pirotan, Gulf of Kutch, 1994-95




*A. Favites melicerum-Favia favus-Cyphastrea serralia*

*B. Porites compressa-Favites melicerum-Porites compressa*

*C. Favites melicerum-Favia favus-Favia favus*

*E. Goniopora minor-Goniopora planulata-Platygyra sinensis*

*F. Goniopora nigra-Goniopora planulata-Goniopora planulata*

*G. Goniopora planulata-Favia favus-Favia favus*

### 4.1.2. Coral associations (TWINSPAN analysis)

TWINSPAN (ouput summarized in Table 2a) produced the first sampling point division at an eigen value of 0.594. The second division occurred at an eigen value of 0.299. The first division extracted 46 plots of Narrara as a separate group. In the next division, 82 plots of Pirotan separated as a group. I considered divisions upto the third level as ecologically meaningful and the associations they represent along with the abundance of all the species as distributed among these associations is presented in Table 2a. The dendrogram (Fig 3) shows the division of the plots and the eigen values at which they were separated. The following associations are seen:

**A.** *Favites melicerum, Favia favus, Cyphastrea serallia* **(FFC)**

**B.** *Porites compressa, Favites melicerum, Porites compressa* **(PFM)**

**C.** *Favites melicerum, Favia favus, Favia speciosa* **(FFF)**

**D.** *Montipora explanata, Favites melicerum, Favia favus* **(MFF)**

**E.** *Goniopora minor, Goniopora planulata, Turbinaria peltata* **(GGT)**

**F.** *Goniopora nigra, Goniopora planulata, Goniopora planulata* **(GGG)**

**G.** *Goniopora planulata, Favia favus, Favia favus* **(GFF)**

The associations were named on the basis of two dominant and one characteristic species of the association. For example, in *Goniopora planulata - Favia favus - Favia favus* association the first two species are dominants and the last one is a characteristic species of the association. Three of the identified associations were characteristic of Narrara and two were seen mainly in Pirotan.

**A.** The *Favites melicerum - Favia favus - Cyphastrea serallia* association: This community was dominated by *Favites melicerum* and *Favia favus* with *Cyphastrea serallia* being a characteristic species of the association. Algae densities were very high in the region. Dead and uncolonized boulders were common. This was an association exclusively restricted to Pirotan.

**B.** The *Porites compressa-Favites melicerum-Porites compressa* community was a mid reef association of species. It was abundant at both Pirotan as well as Narrara. It was characterized by high levels of sediment loads on the boulders, a large proportion of dead and uncolonized boulders in the community and dense algae growing on the silted region of the boulders. The major algae species in this area was not the branching *Sargassum* species found in deeper waters, but *Ulva lactuca* or the sea lettuce.

**C.** *Favites melicerum-Favia favus-Favia speciosa*: This community was also a mid reef community of species. *Favites melicerum*, the most abundant species in this community, is found in medium to large sized boulders. This is an ideal base for other coral species like some species of *Porites* and *Favia favus* to grow on.

Dead and uncolonized boulders were most abudant in this region of the reef and levels of siltation on the boulders was also extremely high. Algae levels were dense in this community. Exposure to wave force was comparatively low in this association and this accounts for the high levels of siltation seen here. Waves and water currents facilitate the removal of sediment in coral reefs and where currents are low, sediment easily accumulates on the boulders.

The association of *Favites melicerum-Favia favus-Favia speciosa* was a heterogenous community and the most diverse in the intertidal zone. In both Narrara and Pirotan all species were represented in this region of the reef. These were also the deepest regions of the reef with an approximate depth of 40 to 50 cms of water at low tide.

**D.** The *Montipora explanata - Favites melicerum - Favia favus* community was a community found in both Narrara as well as Pirotan as yet another far-shore community of coral. The community is characterised by high algae cover, high sedimentation and a high amounts of uncolonised boulders with a thick growth of *Ulva reticulata* and *Ulva lactuca* on them.

**E.** The *Goniopora minor - Goniopora planulata - Turbinaria peltata* is a small, tight association of species that is found only in Narrara and not in Pirotan. The *Goniopora* genus that dominates this region of the reef represent some of the few diurnal species in the reef with their long polyps seen extended during the day. This is a near shore community of corals and is found in the shallow regions of the moat. Siltation is lower and the density of algae is also considerably less in this region of the moat. The substrate is dominated by sand with small boulders. Mean levels of bleaching are the lowest in this community (only 0.55 % on average; see Table 2 a) . This is a rather species poor community with five species represented here.

**F.** The *Goniopora nigra - Goniopora planulata - Goniopora planulata* community of Narrara is a near-shore association of species. The boulders of coral are small and are heavily stressed with sediment. Algae cover is considerably sparse here and levels of bleaching are higher here than anywhere else in the two sites.

**G.** The *Goniopora planulata - Favia favus - Favia favus* community is another specialist of the Narrara reef. It is found closer to shore and has high exposure to waves. The most abundant substrate is sand with a few boulders. Bouldery substrate and uncolonized dead coral is low at the site, lower levels of siltation and a low amount of bleaching.

Figure 4. First two canonical axes showing distribution of quadrats for coral communites in Narrara and Pirotan, Gulf of Kutch, 1994-95

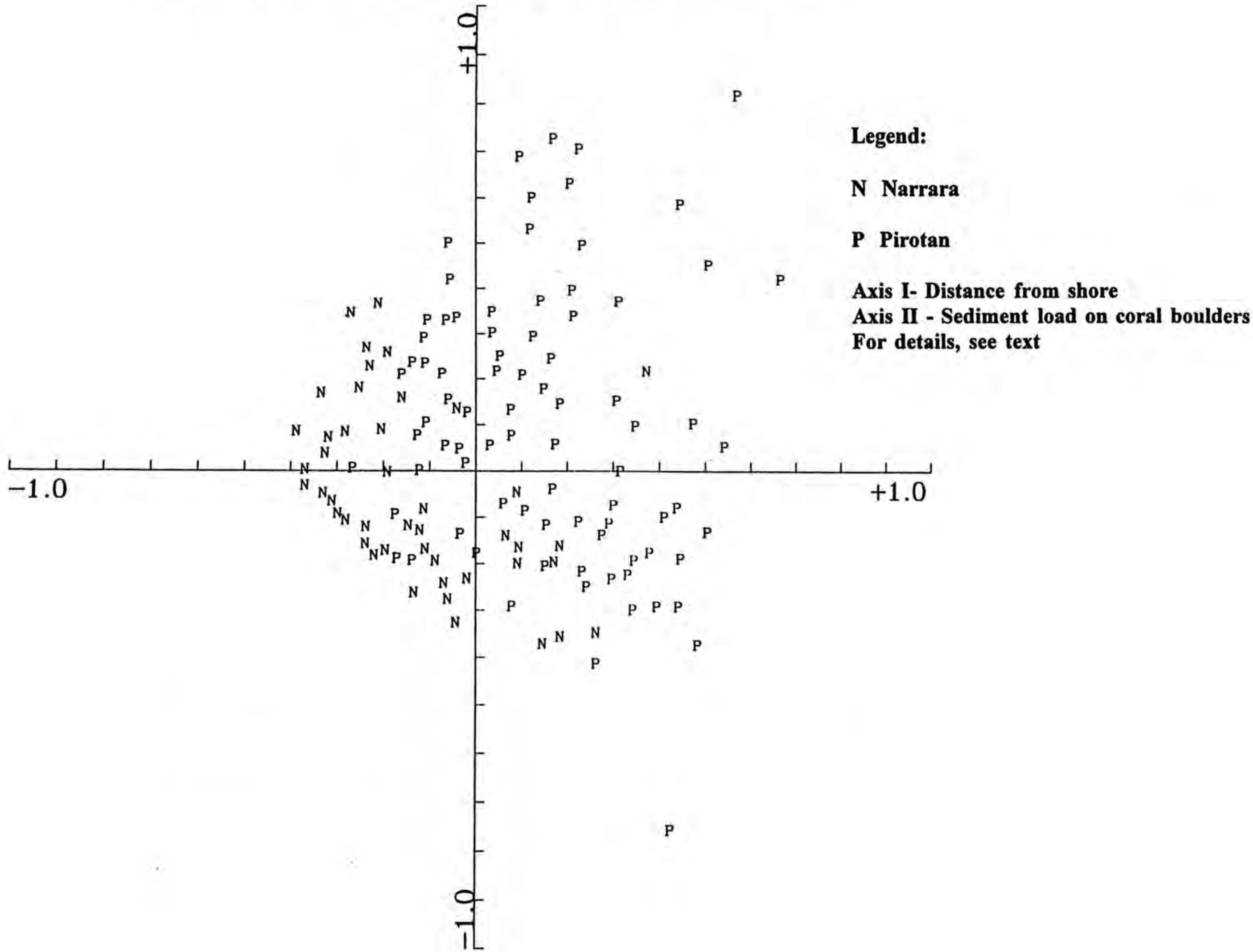


Figure 5. First two canonical axes showing distribution of quadrats for coral communites in Narrara and Pirotan, Gulf of Kutch, 1994-95

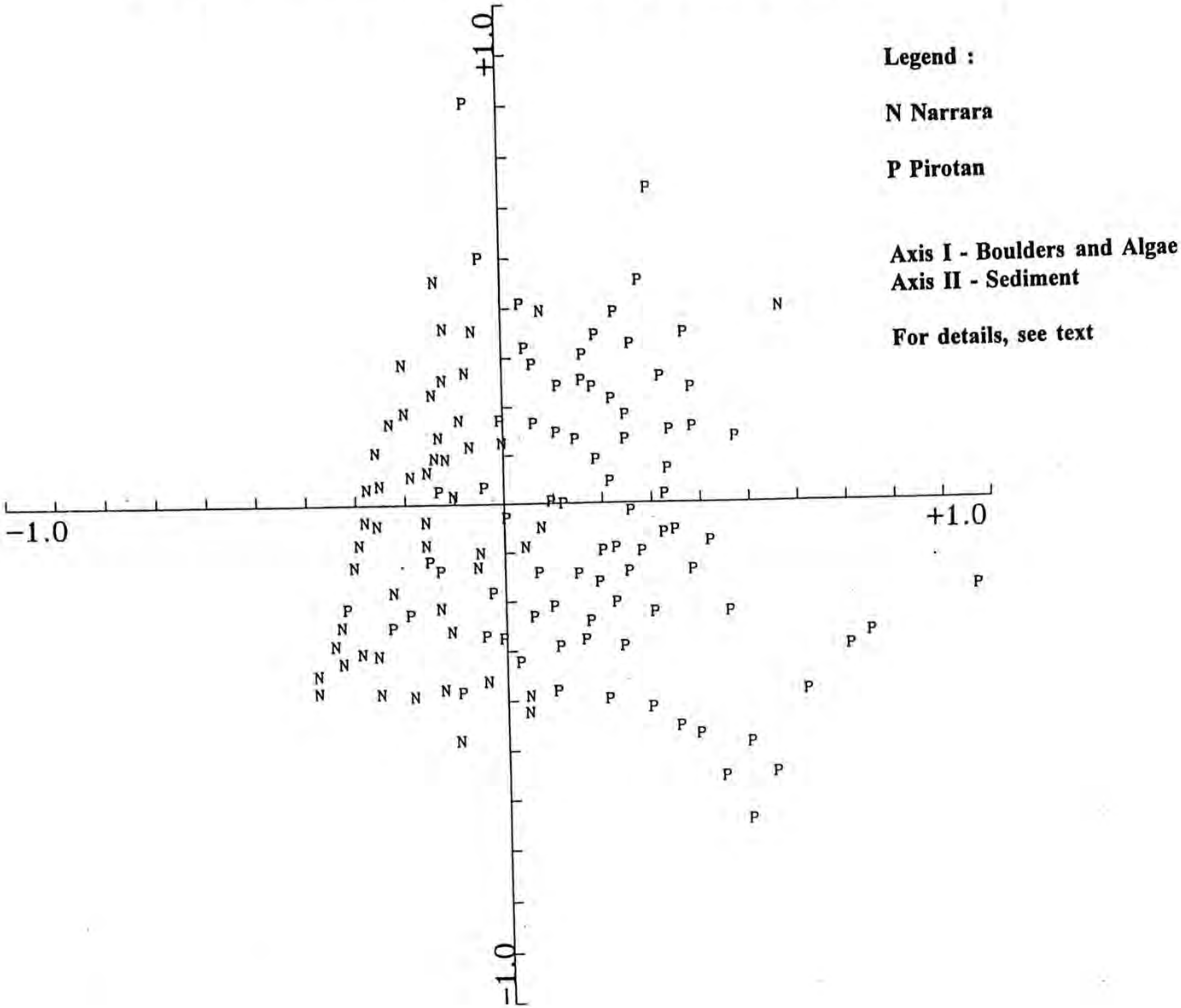
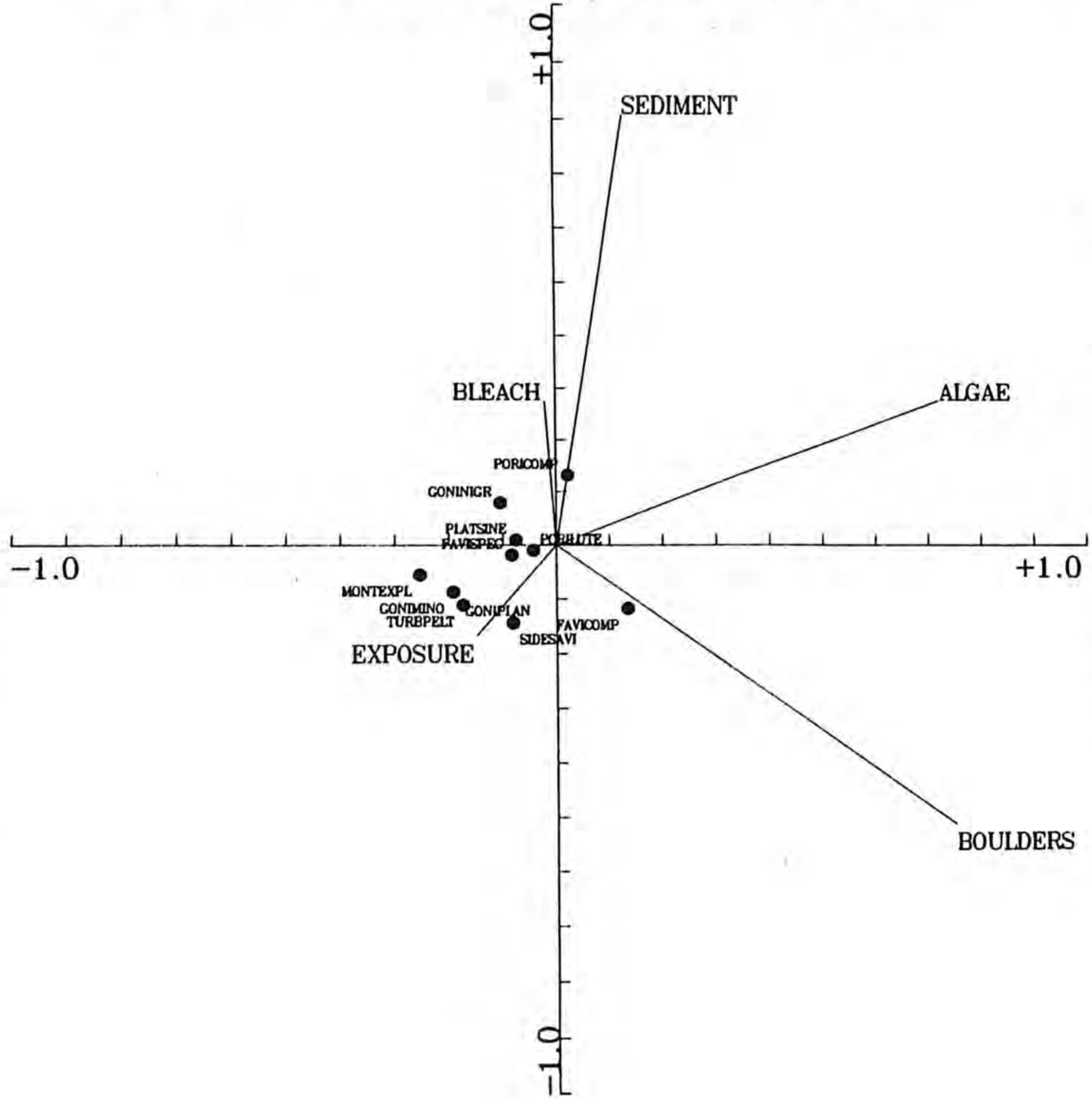


**Figure 6. Species and environmental variables biplot, showing first two canonical axes for coral communities in Narrara and Pirotan, Gulf of Kutch, 1994-95**




**Species labels**

| | |
|---|---|
| *Porites compressa* | PORI COMP |
| *Mycedium* sp.? | MYCE SPS |
| *Cyphastrea serallia* | CYPH SERA |
| *Porite lichen* | PORI LICH |
| *Favia favus* | FAVI FAVU |
| *Platygyra sinensis* | PLAT SINE |
| *Favites melicerum* | FAVI MELI |
| *Porites lutea* | PORI LUTE |
| *Favia speciosa* | FAVI SPEC |
| *Sideastrea savigynyana* | SIDE SAVI |
| *Montipora explanata* | MONT EXPL |
| *Favites complanata* | FAVI COMP |
| *Goniopora nigra* | GONI NIGR |
| *Goniopora minor* | GONI MINO |
| *Goniopora planulata* | GONI PLAN |
| *Turbinaria peltata* | TURB PELT |

#### 4.1.3. *Canonical correspondence analysis (CANOCO)*

Canonical correspondence extracted four axes using the species as well as the habitat variable values. When distance from shore was included in the analysis, the first axis correlated highly (R = 0.789) with distance as well as algae (R = 0.740) and explained 45.6 % of the variation in the data. The second canonical axis correlated with the percent of sediment on the boulders (R = 0.722) explaining a further 37.7 % of the variation. The plot of axis I against axis II showed a distinct separation of the sampling points of Narrara and the sampling points of Pirotan along the first canonical axis (Fig 4). This is perhaps a spurious separation because of the problems of measuring distance mentioned earlier. Analysis was done once again excluding distance as an environmental factor. This analysis resulted in Axis I being highly correlated with both, the amount of dead coral boulders (R = 0.750) in the reef and the density of algae in the reef (R = 0.721) and explained 50.9 % of the total variation. Axis II was highly correlated with the amount of sediment (0.8076) and explained 36 % of the variation. The first axis was tested to be significance (Monte Carlo test, F ratio = 8.53, $p < 0.01$). The plot of sampling points showed Narrara separating to the negative side of the canonical axis and Pirotan separating on the positive side of this axis (see Fig 5). The distribution of individual species along these axes shows the species separating according to their response to the environmental variables (Fig 6).

### 4.2. *Experiments*

#### 4.2.1. Coral responses to Crude oil

All the coral individuals treated showed some amount of response to the crude exposure in a single day. On average, 30.66% (SE 7.55) of the boulders showed visible signs of stress. A direct result of the exposure to crude was sediment accretion on the coral boulder. This silt layer formed a thick coating of sediment that suffocated the coral polyps beneath. Apart from this some areas of the coral showed some amount of bleaching caused by zooxanthalle. Parts of the coral showed a dicoloration where oil still visibly clung to the surface of the boulder. In these areas, mucus production was observed. The unaffected regions of the coral boulders in every case showed no visible signs of distress. Comparing between species, *Porites compressa* was more affected by the pollution event than *Favia favus*. All coral species made some attempt to recover from the disturbance. All the *Favia favus* boulders began to recover one day after the treatment. Over the next fortnight, marginal changes were seen in the boulders, but none of the coral recovered totally from the disturbance. All the *Favia favus* boulders stabilized about a week after the treatment and no further change or alleviation was seen in the amount of sediment deposited on the coral or in the area with oil adhering to it. During the seven days of recovery, changes were seen primarily in the amount of light silt on the coral and small changes were also seen in the amount of heavy silt on the boulder.

*Porites compressa* showed a more pronounced effect to the crude than *Favia favus*. The coral continued its decline for a longer period and a greater propotion of it was affected than *Favia favus*.

### 4.2.2. Coral response to Bittern

All the coral was affected very significantly when treated with a half concentration of bittern. A day after treatment, most of the polyps had retracted into the coral skeleton and nearly the entire boulder was bleached white. A layer of silt had formed on all the boulders and, in some boulders, no visibly unaffected areas could be seen (Fig. 7 a-d).

The recovery was equally rapid in the case of *Favia favus*. All the replicates had begun to recover by the seventh day. Two of the corals had stabilzed in fifteen days and the third, which recovered slower than the others, stabilized in one month, and with much less detriment in the final analysis (92% of the boulder had recovered in this period). The other boulders recovered between 70 and 80 percent of the total area.

*Porites compressa* showed a more variable response to the stressor than *Favia favus*. Whereas one boulder showed a moderate reponse on the first day post-treatment with heavy sediment on a small portion of the boulder, the other replicates showed drastic effects with almost the entire boulder bleached and a layer of sediment on these bleached and other areas. The polyps in these bleached areas were totally rectracted into the skeleton. Replicate two showed a slower response to the disturbance; by the fifteenth day, there was a rapid increase in the amount of area affected by sediment.

The replicates of *Porites compressa* began recovery at different dates. Replicate one and two began recovering on the fifteenth day, stabilizing by the thirtieth day post-treatment while replicate three was already on the upswing by the seventh day, having begun its recovery after the first day post-treatment. It stabilized on the fifteenth day.

The area maps show the response of each individual coral boulder to the stressors. The data for each species was not pooled primarily because of the high amount of variation in the response of each coral. The general pattern of decline and recovery seems to be consistent. The corals were monitored for two months and all the individuals had stabilized within the first month of observation. The graphs presented show only one month of obseravation for neater viewing and comparability. The sensitivity and response index values for the different species and treatments (Table 3) makes it apparent that all treated coral, were sensitive to the treatment. Recovery in every case was low and in some cases did not occur at all. There was an observable difference between the response of the coral species to the two stressors, as well as species-specific trend in this response.

Figure 7a. Responses of three replicates of Porites compressa to 30 minute exposure to crude oil

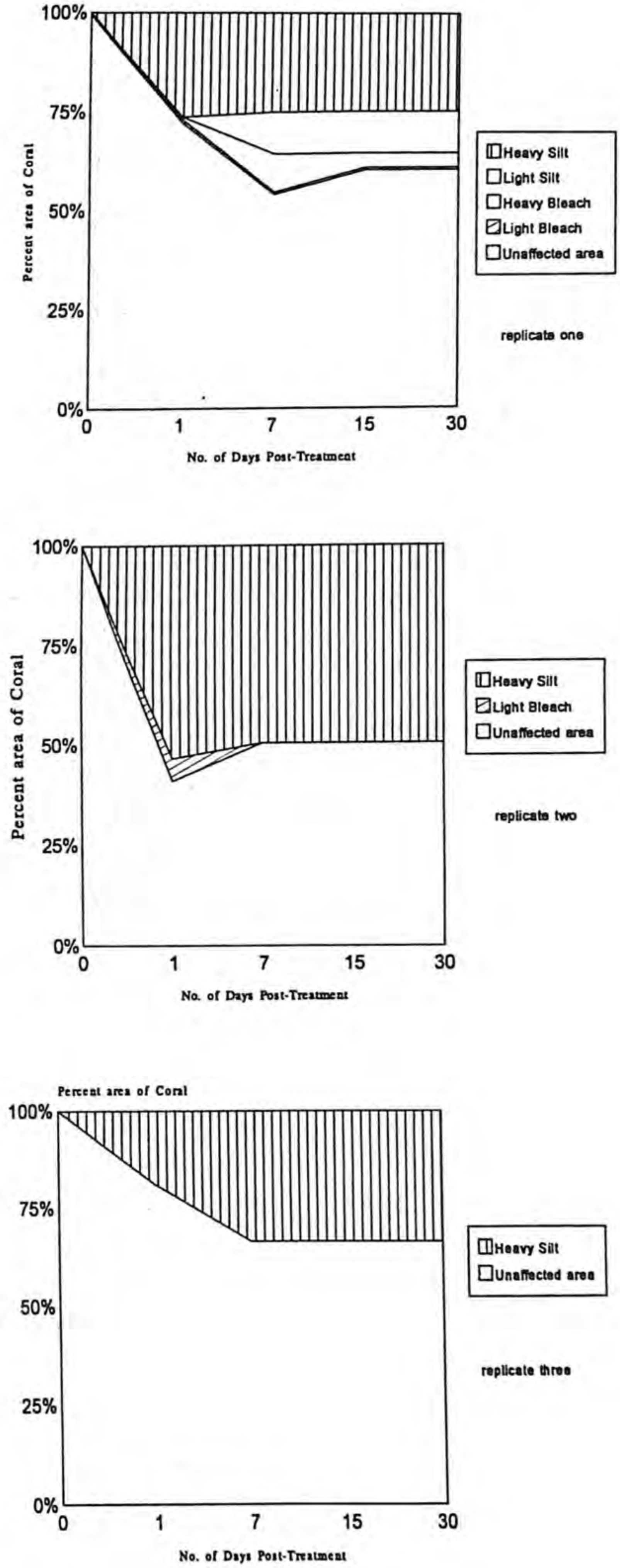
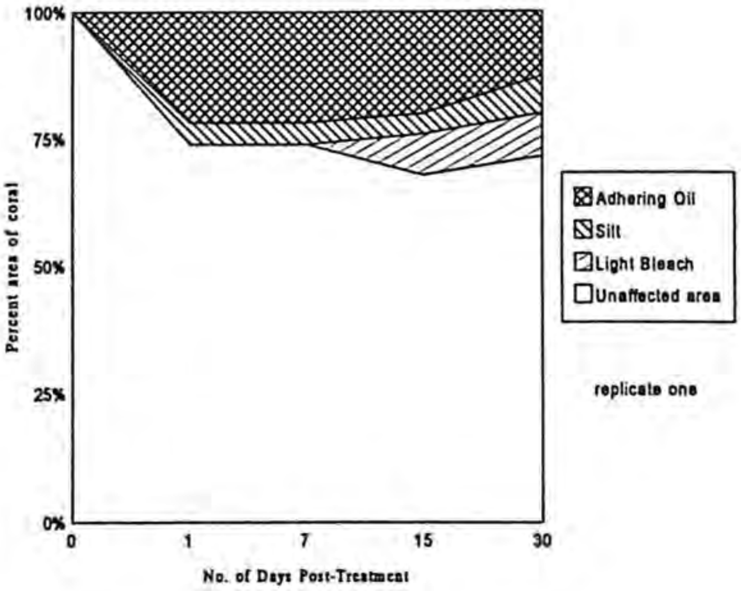
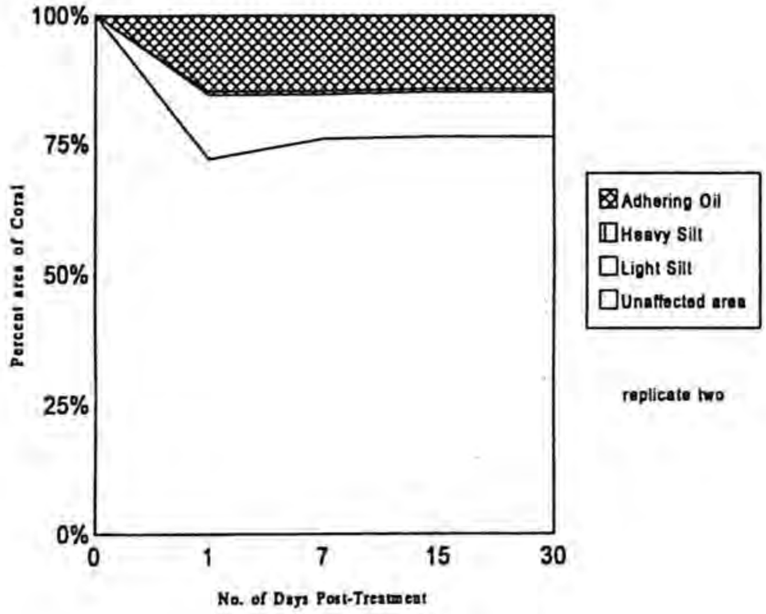


Figure 7b. Responses of three replicates of Favia favus to 30 minute exposure to crude oil



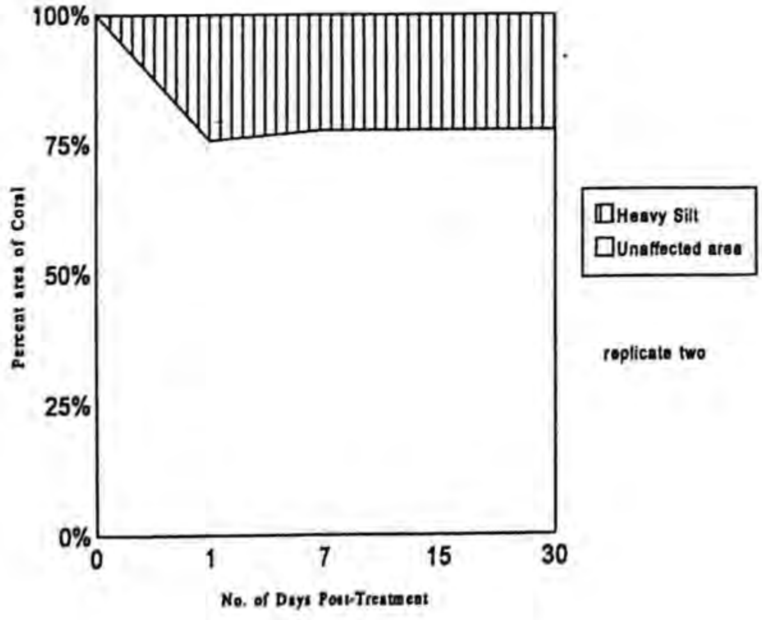



Figure 7c. Responses of three replicates of Porites compressa to 30 minute exposure to bittern

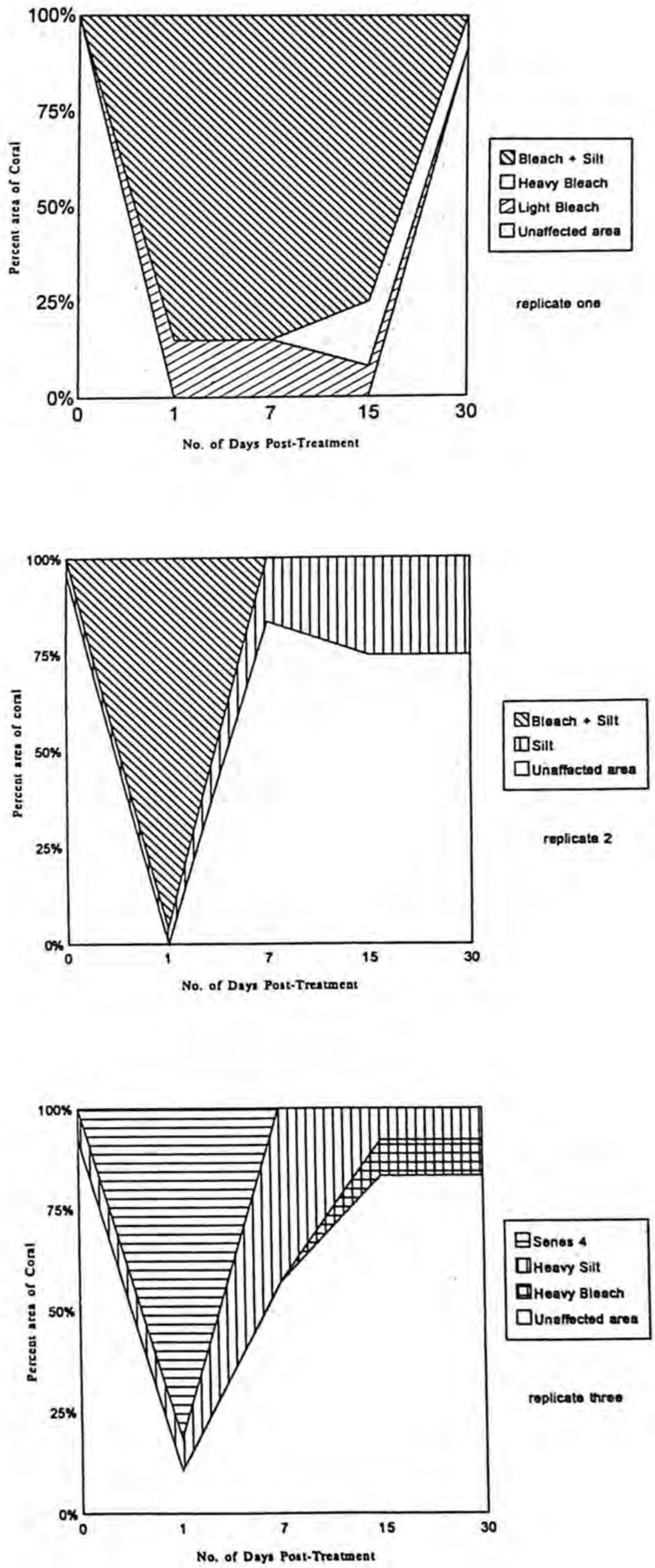
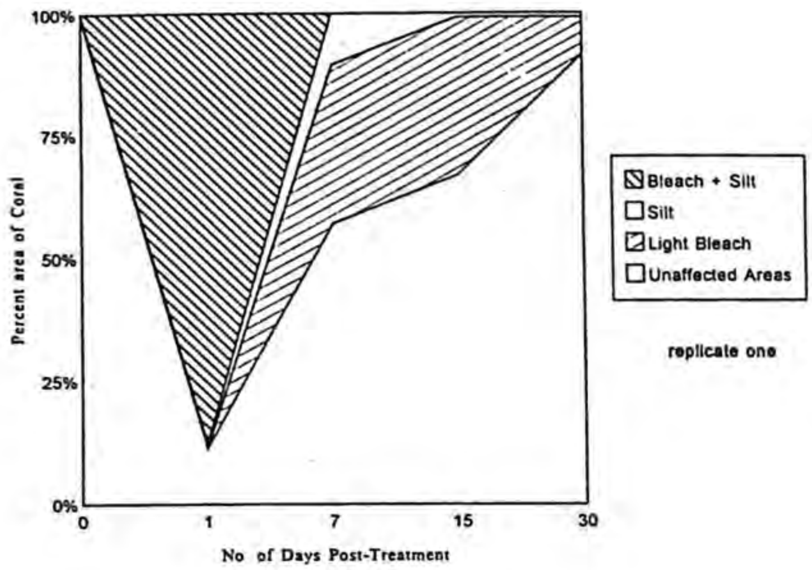
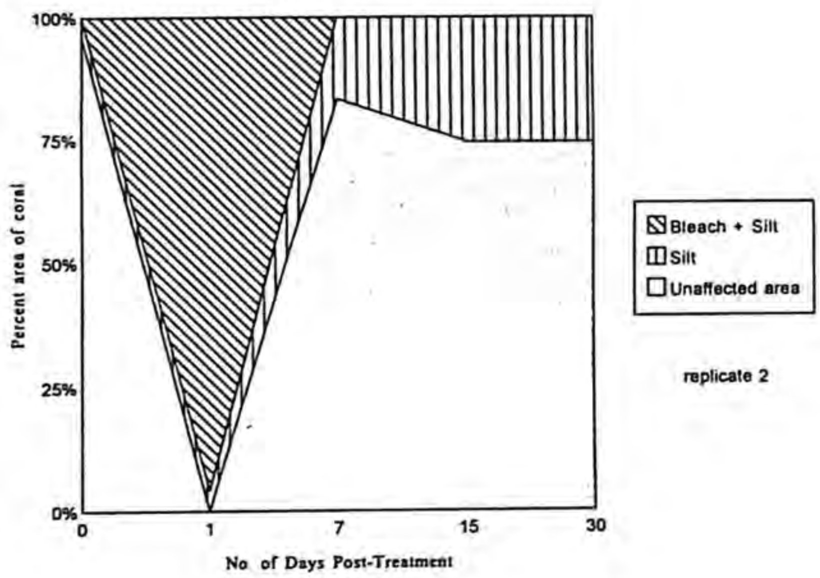


Figure 7d. Responses of three replicates of Favia favus to 30 minute exposure to bittern



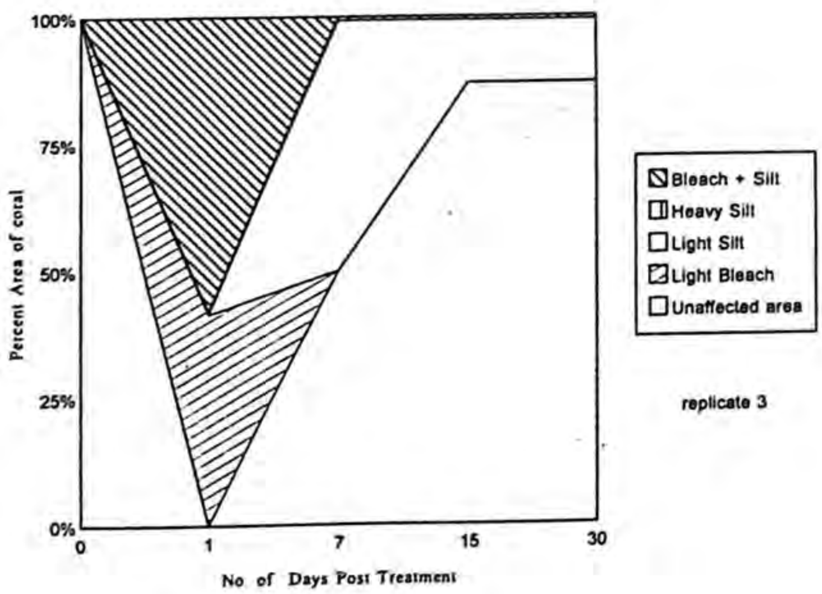
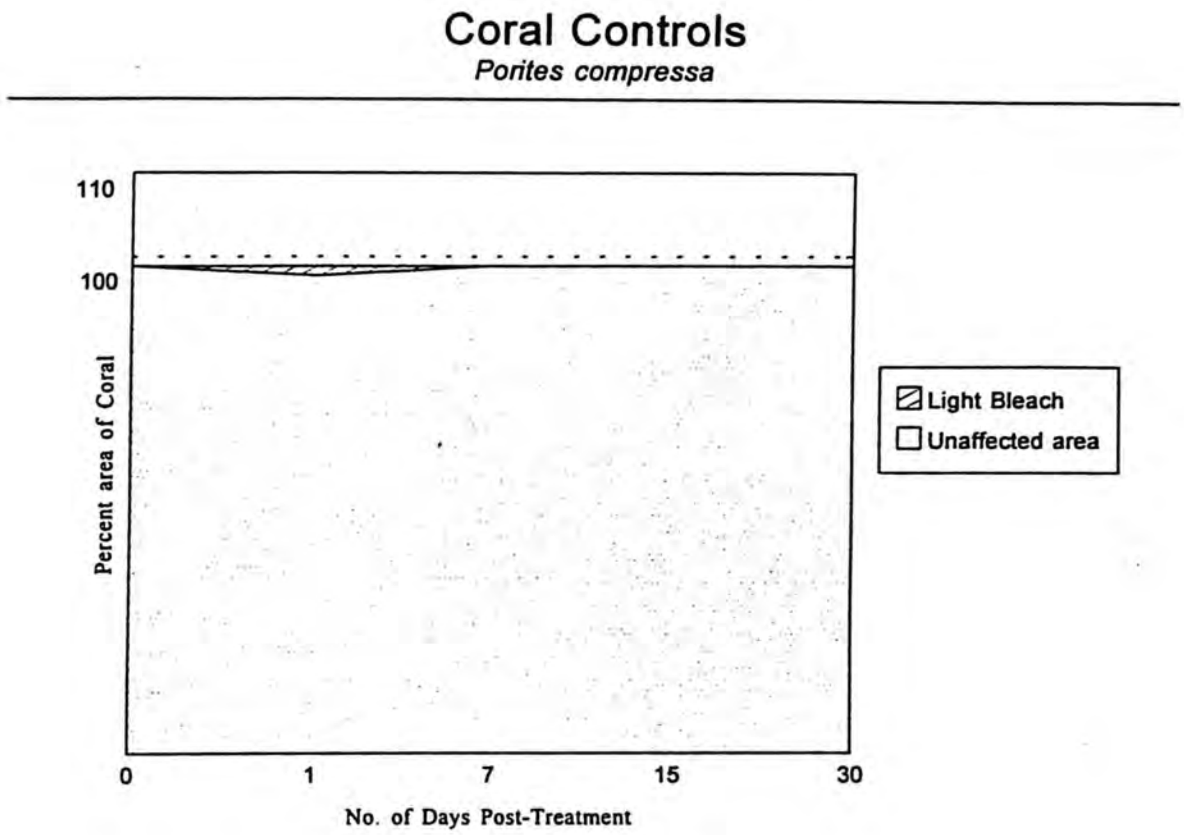



Figure 7e. Response of coral controls to 30 minute exposure to air



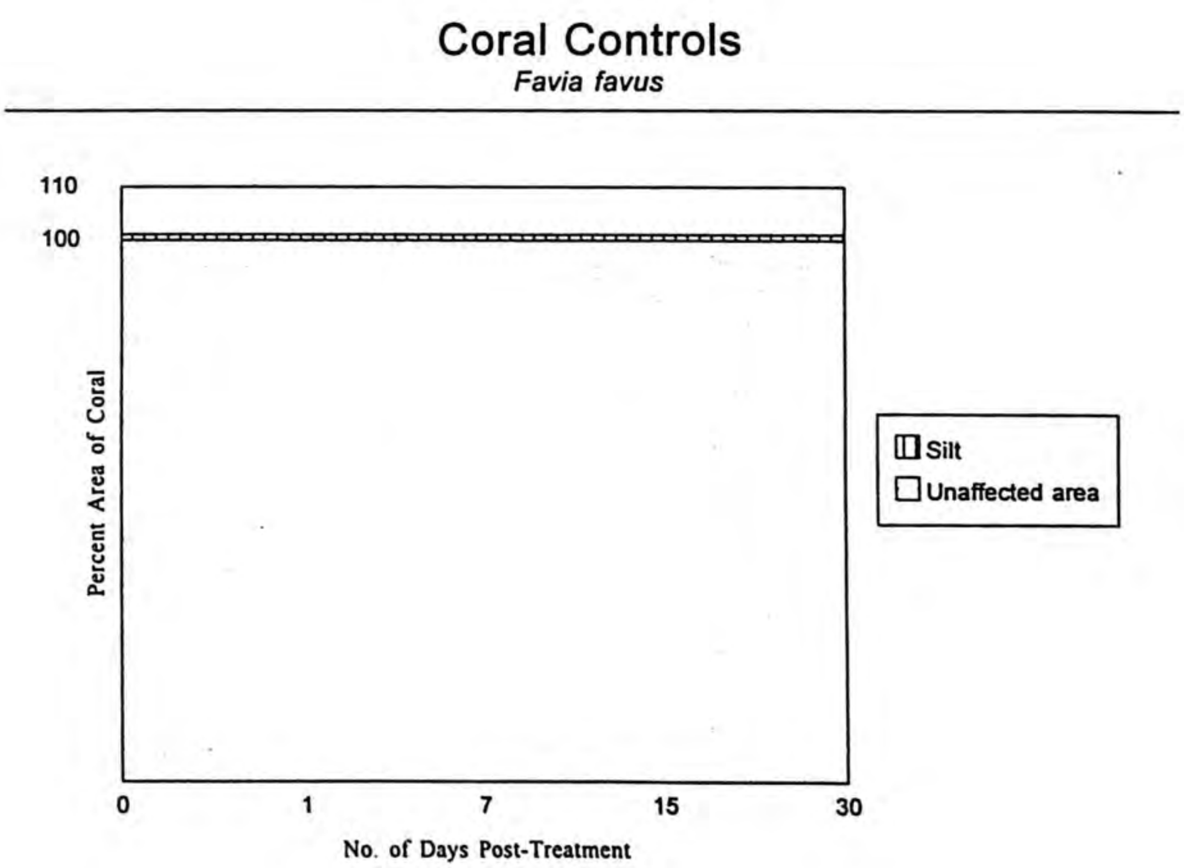



**Table 3.** **Sensitivity and Recovery indices of *Porites* and *Favia* sp. to controlled oil and bittern exposure in the Gulf of Kutch, 1995.**

| | *Porites* Sensitivity Index | *Porites* Recovery Index | *Favia* Sensitivity Index | *Favia* Recovery Index |
|---|---|---|---|---|
| Control | 0.019<br>0.009<br>0.023 | 0.003<br>0.002<br>0.004 | 0.000<br>0.000<br>0.000 | 0.000<br>0.000<br>0.000 |
| Mean ± S.E. | 0.017±.003 | 0.003±.0005 | 0.000 | 0.000 |
| Crude oil | 0.923<br>0.591<br>0.905 | 0.005<br>0.016<br>0.000 | 0.952<br>0.280<br>0.243 | 0.000<br>0.003<br>0.001 |
| Mean ± S.E. | 0.806±.088 | 0.006±.004 | 0.491±.188 | 0.0012±.001 |
| Bittern | 1.000<br>0.996<br>0.887 | 0.031<br>0.042<br>0.056 | 0.910<br>0.948<br>0.928 | 0.029<br>0.000<br>0.047 |
| Mean ± S.E. | 0.961±.030 | 0.043±.006 | 0.926±.009 | 0.025±.011 |

# 5. DISCUSSION

## 5.1. *Community Structure*

The diversity of the reefs in the Gulf of Kutch are characteristically low. A possible reef for comparison would perhaps be the reef of the Gulf of Eliat in the Red Sea (see Loya 1972,1976a). This region is as heavily used by industry and the seas are subject to oil spill often. The diversity in these disturbed reefs as reported by Loya (1972) was 2.206. This is comparable to the diversities of Nararra and Pirotan. Though 44 species of Alcyonarian and Scleractinidian coral have been reported from the entire Gulf, most of them are extremely rare and localized. The reef is dominated by a few hardy species, chiefly *Favia favus*, *Favites melicerum*, and *Porites compressa* (species list see Appendix A). These species thrive in high abundances in the intertidal reef both at Narrara and at Pirotan.

If we compare Narrara and Pirotan in terms of their species richness and diversity, Pirotan is marginally (though significantly) richer and more diverse.

An important limiting factor in the reefs of the Gulf appears to be the depth of water during low tide. Corals cannot survive prolonged exposure to air and the unusually large tidal fluctuations in this area make them extremely susceptible to emergence from the water during the low tide. It is not suprising therefore that as depth at low water increases, the species richness also increases (Fig 2). This has been found to be a general trend in the community organization of corals in most reefs (Sheppard 1982). A point should be noted here about the general growth form of the corals in the reefs of the Gulf. Corals are generally extremely flexible in their growth forms (Wood 1988) yet, in the Gulf waters, only massive and encrusting forms are seen with some semi-massive individuals seen in deeper lagoons. The reefs are characterised by a total lack of any branching forms of coral and the genus *Acropora*, abundant in most reefs of the world, is now extinct in the Gulf (Wafar 1986). I believe that this extinction is a direct result of the lowering of low-water depth in the period after the tectonic uplift that affected the region in the geological past (Naik *et al.* 1988).

Growth form also plays a major role in the response of coral to various disturbance factors. Of particular importance to the reefs of the Gulf is the disturbance caused by sedimentation. Branching forms, it is known, are better equipped to deal with the problem of sediment load (Brown and Howard 1985) while massive forms are among the least resistant to this disturbance. Increased sedimentation is a recent ecological phenomenon in the area and the corals of the reef are ill-equipped to deal with it.

From Table No. 1 it is clear that Pirotan is higher in all the measured disturbance factors except in the amount of bleaching. The presence of uncolonized boulders and dead coral was higher in the reef at Pirotan and represents areas of possible coral colonization that are being limited by some external influence (Katwijk *et al.* 1993). In Pirotan and Narrara, the bouldery substrate represented dead coral boulders, killed by some disturbance in the past, and, in themselves serve, as a sign of past stresses.

In addition to boulders, the amount of algae present in the reef is also higher in Pirotan than at Narrara. Flourishing algae especially the *Sargassum* species most commonly encountered in the Pirotan waters (*Sargassum ilicifalium* and *S. tenerrimum*) adds a significifant amount of stress to corals because they shade the coral from sunlight. Corals are detrimentally affected by shading, (Rogers 1979, Sheppard 1981) presumably because of the lowering in the photosynthetic activity of their commensalic zooxanthallae which are known to facilitate coral growth (Endean 1979). Most algae colonize only dead and sedimented regions of the coral and the amount of algae in the reef is also a direct result of the amount of dead bouldery substrate in the reef. In terms of all these factors, Pirotan appears to be the more disturbed area than Narrara despite the higher species diversity and richness seen in Pirotan.

**5.1.1.Two-way indicator species analysis: communities as indicators of disturbance.**

TWINSPAN (Hill 1979) first proved its worth in the field of plant community ecology. Reciprocal averaging, used by TWINSPAN for the ordering of species data, is an indirect ordination technique that groups the species presence and abundance data into convenient, ecologically interpretable communities. It has since proved a powerful and flexible tool in the interpretation of most ecological communities (Kent and Coker 1993).

The communties identified by TWINSPAN for the reefs at Narrara and Pirotan show a broad trend in their distribution which can are quite instructive.

The *Favites melicerum-Favia favus-Cyphastrea serallia* community (FFC) and the *Porites compressa-Favites melicerum-Porites compressa* (PFM) communities represent associations of species found almost exclusively in Pirotan. It is clear that they thrive in areas where currents are the strongest, on the farshore regions of the reef, close to the reef crest. The waters of Pirotan have high levels of sediment and these communities are best adapted to live in these waters. This is because strong currents help keep coral clean of sediment. Most reefs that are affected by natural or anthropogenic stress will have the concentrations of species in the regions of high currents (Rogers 1990). Rogers (1990) hypothesizes that a high sedimentation reef will have less live coral cover, either only smaller coral communities (because they resist sediment better) or only larger communities (because recruitment is limited by sediment loads). The communities of the Pirotan waters have generally large coral boulders, and a high percent cover of dead (silted) coral boulders. This would suggest that the reef at Pirotan is restricted in its development by high sediment loads.

In contrast, the *Goniopora minor-Goniopora planulata-Turbinaria peltata* (GGT) community, *Goniopora nigra-Goniopora planulata- Goniopora planulata* (GGG) community and the *Goniopora planulata- Favia favus-Favia favus* (GFF) community are all characteristic of Narrara. They are all near-shore communities and present in areas with low sediment and algae, and have a relatively low percentage of dead coral boulders. They represent coral associations at the other end of the spectrum, thriving in much less hostile reef conditions. From my own observations, these areas have a larger spectrum of coral boulder sizes, most of the boulders are medium-sized coral boulders with some large forms (over 1 m in radius) and several smaller boulders. The reef at Narrara appears to be a growing reef while Pirotan seems to be a stagnating ecosystem.

A trend is evident in the order of classification of coral associations (Table 2b). The coral associations represent a declining gradient of distance from shore as well as declining gradient of algae density. Bouldery substrate also decreases down this gradient.

Distance from shore is perhaps the most important explanatory variable in trying to explain the reef. It must be realized however that distance does not really amount to an environmental variable. It is a composite variable trapping the effects of many other varibles in the reef. For instance, the length of exposure to the air during the low-water would be a function of distance from shore, the areas closest to shore being exposed more than sampling points further out in the reef. Depth too is roughly indicated by depth as is the water temperature at low tide and the density of algae. These factors together work to make distance an important factor in the separation of the area.

### 5.1.3. Canonical correspondence analysis (CANOCO): Disturbance and distribution

The first canonical axis was well correlated with distance from shore and algae density. The second canonical axis showed a correlation with the amount of sediment in the reef and, together with the first canonical axis, explained a 83.3 % of the total variation. A plot of Axis I against Axis II shows a clear separation of the plots between Narrara and Pirotan (see Fig 4). This separation however provides very little ecological insight into the workings of the system for reasons discussed in the methods. All it represents is that the plots in Narrara were closer to the shore than the plots at Pirotan. This relationship is so strong that it masks most other environmental trends. The analysis of the data without using distance as a parameter derived two major axes, Axis I which was highly correlated with uncolonized coral boulders and algae cover, and Axis II, which was correlated with the amount of sediment loaded on the coral. When the sampling points are plotted against these axes there is a clear separation of the two sites sampled along the first axis. No clear separation of the sites is seen along axis II.

Axis I and axis II can be considered to be axes of increasing disturbance since they are correlated with disturbance factors in the reef (Boulders and Algae - axis I; Sediment - axis II). The plots of Pirotan are clumped to the right of axis I. This would suggest that the levels disturbance are higher in Pirotan than in Narrara in terms of the the amount of boulders and the density of algae found there. The plots are more or less equally distributed along the sediment axis (axis II) and suggest that there is no clear difference in the sites in terms of sedimentation.

If we look at the plot of evironmental variables and species along Axis I and II, there are definite patterns of community organisation.

*Favites melicerum* is a species found ubiquitously throughout the reef, in every strata. Together with *Favia favus* and *Porites lutea* it is among the most generalist species in the reef. This is adequately elucidated in the XY plot of species and environmental variables. These species are indifferent and are situated very close to the environmental origin, unaffected one way or another by environmental variables.

The positive quarter of the graph represents areas of high bouldery substrate, high algae density and high sedimentation. Species like *Porites compressa Mycedium sps* and *Sideastrea saviagynyana* are found on this, the disturbed quarter of the graph. It is noteworthy that while one (*Porites compressa*) is present all over the reef in varying numbers, the other two species are found exclusively in the Pirotan reef. Most of the species bunch themselves on the opposite quarter of the axis, characterised by low boulders, lower amounts of algae and lower amounts of siltation.

van Katwijk *et al.* (1993) show that for the Malindi-Watamu reefs of the Indian Ocean, the major limiting factors are the amount of terrigenous sediment which is manifest in the reef as a greater amount of coral-free substrate in the reef. Similarly, Öhman *et al.* (1993) showed that in a heavily disturbed reef in Sri Lanka, the amount of dead coral and broken rubble was much higher than in an undisturbed reef. Sheppard (1982) concludes that sedimentation can be a crucial factor in determining the distribution and abundance of corals, reducing light for photosynthesis, sufffocating boulders with sediment and exhausting the corals ability to produce enough mucous to deal with the sediment load.

## 5.2. *Experiments on coral boulders*

### 5.2.1. Response of Corals to Crude and Bittern

The work done thus far on the response of corals to oil is far from consistent in the results obtained (see review). Major differences arise when results from the laboratories and observations from the field are compared. One thing seems to be clear; corals are extremely variable in their response to oil pollution and, in the reef, the extent of damage seen is determined by the interaction of a lot of environmental variables such as the time of year the spill occurs in, the weather conditions, the amount of oil spilled, the frequency with which chronic spills occur and a host of other non-obvious parameters that vary in the environment (Johannes *et al.* 1972).

In the light of all this, it is well nigh impossible to reach a conclusion one way or another from any one study on the effects of oil on corals and the reef. I restricted my experimentation to focus on the effects of crude oil on coral under particular environmental conditions (i.e. extreme low tides during summer months when some of the coral is exposed to air). These are conditions that are natural to the Gulf waters where the tidal fluctuation is high and periods of exposure to the air inevitable during the extreme low day tides in summer.

I chose to treat the organisms with a half-hour exposure because effects seen within this period would give conservative rather than radical results. These are perhaps more useful for generalisation. In the reefs of the Gulf a half hour exposure is experienced very frequently by much of the coral during low tides, particularly the regions closer to shore and in the area around the crest where low-water levels are naturally low.

An important point to be noted is that most of the death was caused by sediment load on the coral which the coral had difficulty cleaning itself of. In normal conditions, the coral have efficient means of dealing with sediments (Rogers 1990). The ciliary flow that moves food particles towards the polyp for ingestion also does the housekeeping duties of keeping the coral clean of all dirt and sediment. This mechanism is capable of dealing quite well with moderate amounts of sedimentation. Besides this, the coral polyp tentacles actively reject larger sediment particles when under their influence. Mucus is often produced when a coral is affected by sediment, this serves to mix the sediment into globules that can later be easily sloughed off (Sheppard 1982).

When oil affected the coral boulders, it formed an adhesive coating over the boulder and attracted sediment deposition in larger quantities than normally would accrue on the surface. The coral is not equipped to deal with these unusually high loads of sediment and the regions affected do not regenerate much.

Studies on the effect of increased salinities on coral are scarce. It is known that lowered salinities cause extensive death (Brown and Howard 1985, Grigg and Dollar 1993) but data on the response of coral to increased salinities is unavailable. Bittern releases pose an important threat to the reefs of the Gulf (Singh, 1995) and the rapidly increasing number of salt pans on the coast makes this an even more urgent worry.

Bittern at half its concentration, produced striking effects on the coral. Both coral species were severely affected within a single day. Almost the entire boulder was bleached white and a layer of sediment had deposited on the bleached areas. The response was variable as can be seen from the area graphs but the trends are readily apparent. The affected areas that persisted two months post-treatment were bleached and silted, either lightly or heavily without any signs of recovery in these regions.

Here too, much of the post-treatment stress was caused by sedimentation. In the pre-recovery phase of the experiment, the polyps remained totally retracted for several days (for a description of the response, see results). Almost no live tissue was seen in this period and presumably all ciliary action was also paralysed or greatly reduced. In the recovery phase the cilia and the polyp tentacles began actively rejecting sediment and much of the sediment was removed. Some areas still remained affected and these did not show signs of recovery even after two months of observation.

That both stressors affected the coral detrimentally is apparent. What is also clear is that the proximal cause of death was sedimentation that acted on the coral by smothering the coral polyps and putting added stress on their cleaning mechanisms. Sediment loading on the coral boulders was definitely facilitated by the stressors as no great changes were seen on the control boulders during the course of the experiment. The nature of this facilitation however was different for two stressors. Crude oil acts, as mentioned before, to make the boulder an adhesive surface. This sticky surface actively attracts sediment that is already abundant in the reef and a thick layer of this smothers the coral boulder. The corals managed to remove only a little of these sedimented portions (Fig.7), most of the sediment being too heavily loaded for the coral cleaning mechanisms to work effectively.

Bittern plays a slightly different role as facilitator in the sedimentation of the coral. At such high concentrations of salinity, the coral tissue is heavily stressed and the polyps retract into the coral slowing down all physiological activities. Heavy bleaching is also a direct result of this stress. This paralysing of coral activity promotes the deposition of sediment on the boulder, which, in normal circumstances would be removed by the ciliary flow. Corals were able to rid themselves of most of this sediment quite readily once physiological activity resumed its normal functioning. The relative ease with which corals rejected sediment loads when stressed with bittern in comparison to oil was likely due to the interaction of sediment with the oil to form an adhesive layer on the coral boulder. Bittern did not facilitate sediment sticking easily to the coral.

There was a lot of variability in the response of *Porites compressa* to both the stressors. In contrast, the response of *Favia favus* was more regular and comparable. It is difficult to draw inferences from sample sizes so low but it is subjectively possible to speculate on reasons for this variability. *Porites compressa* has a very varied growth form (Wood 1983) and it is difficulty to find, even in the same patch of reef, two *Porites* boulders with approximately the same form. This results in considerable variation in surface area of the boulder exposed. *Favia favus* on the other hand is more consistent in shape and size. The boulders never grow very large and the overall shape is of a generalized massive boulder. It is possible to infer that the lack of uniformity of form in *Porites compressa* led to the variability seen in the response of the organism to stressors. Most of the death was caused proximally by sediment loads gathering on the boulders, and a greater surface area would result in a greater propotion of oil adhering on the boulders, (Johannes *et al.* 1972) and a greater propensity of sediment to gather on the affected boulders.

**5.2.2 The coral stress and recovery response index**

The index developed is a useful numerical way of comparing the variable response of the experimental coral replicates to the disturbance factors. It suffers from being a little simplistic in its analysis because it does not distinguish between the type of disturbance seen on the boulder. For instance, the propotion of light silt and the propotion of heavy silt is not considered to be different by the index and are both given an equal weightage. This assumption is rather dubious for corals are certainly less stressed by light siltation than by heavy siltation. The index is still perhaps the best way to compare across species and between stressors in lieu of the considerable amount of additional information required to construct a more elaborate index.

There was a definite species specific response to the different stressors (Table 3). *Porites compressa* is more sensitive to both crude oil pollution as well as bittern stress when compared with *Favia favus*. Both species were more sensitive to stress from bittern but also showed a greater recovery.

It is important to note that though all the experimental boulders showed significant distress when treated with the stressors, most of the boulders also showed some amount of recovery from the stressors. In no case was the entire coral killed and the disturbance resulted in about 75 % of most boulder remaining alive and apparently healthy though, in the case of crude oil, traces of adhering oil could still be seen on the boulder two and half months after the treatment. I can only theorize on the effect of chronic oil spills on coral species but I would predict that small chronic spills, such as occur often enough in the southern Gulf, would have a more serious impact on the reef than a single, large-scale spill. Because of the large intertidal regions in the Gulf, even a small spill can cause, on its own create a lot of damage to the reef. As the reef waters continue their ebb and flow, the spill moves towards the shore. Depending on rate of movement, the oil will continue to affect coral with every subsequent low water and even more damage can be done by this repeated dosing.

### 5.3. Sedimentation as factor in reef decline

All this while I have been discussing community structure and experimental procedures as separate and unconnected. Here I would like to lay stress on the some of the important points of commonality that these two approaches to the problem of stress have in the light of conservation of the reefs of the Gulf.

It is clear from the community ordinations that Pirotan is quite significantly disturbed. One of the major causes of disturbance appears to be sedimentation and the fallouts associated with sedimentation. By a variety of processes the levels of sediment rise to unacceptable levels in the reef and this acts as a major stress to the coral (Brown and Howard 1985). When the sediment rejection mechanisms break down in the organism, tissue necrosis and coral death generally take place.

Sediment acts detrimentally to reduce the available light in the reef, restrict planulae settling rates, increase juvenile mortality and add significantly to the physical and physiological stress on the coral (Rogers 1990).

When additional stressors like crude oil and bittern affect the reef, sediment acts synergistically with these pollutants to exacerbate the stress on the coral. The corals of the Gulf are not well-equipped to deal with the problems of sedimentation. This is largely to do with their growth form determined by the geological history of the reef. The corals in this reef are mostly massive and encrusting forms and are the least resistant to the accretion of sediment on them (Rogers 1990). Branching forms, better able to deal with this stress (Brown and Howard 1985) are extinct in the reef (Wafar 1985).
The high levels of sedimentation in the Southern Gulf is very detrimental to the ecosystem of the reef as it affects one of the chief primary producers of the ecosystem directly.

Excessive sedimentation is the end result of many of Man's activities along the coast. I will restrict myself to a discussion of the problems faced by the Gulf in particular. Here one of the major factors is the increased levels of sediment in the reef is dredging. Though no longer practiced in the Marine National Park and Sanctuary, cement manufacturing concerns dredged large areas of the beach and reef in Pirotan and Narrara (Naik *et al.* 1985). This activity caused destabilisation of the beach and resulted in beach erosion. Large amounts of beach sand deposited on the corals, suffocating them. Very little recovery is seen in these affected areas (Wafar 1985).

Camel grazing and mangrove lopping for fuelwood are also major factors in the destabilization of the coastal zone. These have only recently been stopped and illicit lopping is extremely difficult to control.

Coastal zone development and the conversion of the area into salt pans and sites for industrial development presents a two-pronged attack on the reef. Not only do they result in increased levels of sedimentation in Gulf waters, they also add to the possible threat of effluent releases and thermal pollution that follows in the wake of this development.

Oil pollution is definitely an important stress factor in the reef. It is likely to catalyse greater damage to coral by sedimentation especially when coral are exposed to air during extreme low tides.

Minor spills by and large, go unnoticed in the Gulf yet these probably take a greater toll on the coral reefs of the intertidal zone. With additional oil pipelines and refineries developing very quickly in these areas, the probability of these small spills as well as the danger of a mega-spill is high.

Bittern, at the half-concentration, appears to affect coral quite significantly. The concentration used was rather high and it is interesting to note that none of the coral showed complete death, all of them recovering to some extent. Corals in this intertidal zone are perhaps well adapted to high salinities because of the high levels of evaporation the waters experience during the low tides of the hot summer months. Bittern, when it does have an effect will be a localized affect and reefs like Narrara, close to the mouth of these releases will be more affected by these releases than reefs further away from the mainland. It is an encouraging trend that many of the bigger salt works are now developing Bromine extraction plants alongside their salt works because this uses bittern as the basic raw ingredient for manufacture. This will greatly reduce the stress on the reef.

**5.3.2 Reef decline: A problem for management**

The decline of the reefs of the Gulf presents a formidable task for the ecosystem manager. One factor that limits a marine park manager is the fluidity of the ecosystem's boundaries (Craik *et al.* 1993). The shore line that the manager is trying to protect is affected by many external factors beyond his jurisdictional control. Dumping of waste oil for instance, could be occuring in areas well outside the park boundaries, yet this same oil could, and most often does, find its way to the shore. It is clear that management in isolation is a Sisyphean task in such an area.

Intergrated coastal zone management is an urgent imperative in the Gulf. The many controlling bodies such as the Maritime Board, the Coast Guard, the Indian Air Force and the Fisheries Department need to be drawn into an agreement which binds them to a common direction, development within the bounds of ecosystem tolerance. Unless this happens these organisations will continue to act at cross-purposes with the Forest Department.

Sedimentation and Coastal erosion are major reasons for reef decline (Rashid 1985,1988). If effective ecosystem management has to be effected the current practice of mangrove afforestation should be given more organized drive and importance. Mangrove afforestation is the crucial step to controlling beach erosion as it serves to bind the soil preventing it from escaping into the reef. Further degradation of mangrove through illegal lopping and grazing should be controlled as much as possible.

Detailed and conscientious environmental impact assesment should precede any industrial development, taking into account the effects of effluent releases and physical stress due to construction activities. Declaring areas of ecological importance sacrosanct is crucial as a first step, but this is not enough because of the fluid boundaries of marine ecosystems. This task of impact assesment is scarcely an easy one, but it is urgently important in the wake of increased development interest in the area.

## REFERENCES


AGARD, J. B. R., J. GOBIN AND R. M. WARWICK. 1993. Analysis of marine macrobenthic community stucture in relation to pollution, natural oil seepage and seasonal disturbance in a tropical enviroment (Trinidad, West Indies). Mar. Ecol. Prog. Ser. 92: 233-243.

AZIZ, T. AND H. BARNES. 1993. Reliance Refinery: Endgame for Marine Park. W.W.F. India Quarterly 4(4): 6-11.

BAK, R. P. M. 1978. Lethal and sublethal effects of dredging on coral reefs. Mar. Pollut. Bull. 2: 14-16.

*BANNER, A. H. 1968. A freshwater "kill" on the coral reefs of Hawaii. Hawaii Inst. Mar. Biol. Tech Rep. No. 15, p.1-29.

* BIRKELAND, C., A. A. REIMER AND J. R. YOUNG. 1976. Survey of marine community in Panama and experiments with oil. Environ. Prot. Agency Ecol. Res. Ser. PB 253 409, EPA - 600/3-76 028. Environmental Protection Agency, Washington D.C.

BROWN, B. E. AND L. S. HOWARD. 1985. Assessing the effects of stress in coral reefs. Adv. Mar. Biol. 22: 1-63.

* COHEN, Y., A. NISSENBAUM, AND R. EISLER. 1977. Effects of Iranian crude oil on the Red Sea Octocoral *Heteroxenia fuscescens*. Environ. Pollut. 12: 173-185.

CONNELL, J. H. 1978. Diversity in Tropical Rainforests and Coral Reefs. Science 199: 1302-10.

ENDEAN, R. 1976. Destruction and recovery of coral reef communities. Pages 215-255 *in* O. A. Jones and R. Endean, eds., Biology and Geology of Coral Reefs,3. Biology 2. Academic Press, New York.

ELGERSHUIZEN, J. H. AND H. A. DE KRUIJF. 1976. Toxicity of crude oils and a dispersant to the stony coral *Madracis mirabilis*. Mar. Poll. Bull. 7: 22-25.

GOODBODY, I. 1961. Mass mortality of a marine fauna following tropical rain. Ecology 42: 150-155.

GRIGG, R. W. AND S. J. DOLLAR. 1993. Natural and anthropogenic disturbance on coral reefs. Pages 439-52 *in* Z. V. Y. Dubinsky, ed., Ecosystems of the world: Coral reefs. Amsterdam, Holland: Elsevier Press.

HAWKINS, J. P. AND C. M. ROBERTS. 1993. Effects of recreational scuba diving on coral reefs: trampling on reef-flat communities. Journal of Applied Ecology 30: 25-30.

HILL, M. O. 1979. TWINSPAN: a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individual attributes. Ecology and Systematics. Cornell University, Ithaca, New York.

* HUBBARD, D. K., J. D. STUMP AND B. CARTER. 1987. Sedimentation and reef development in Hawknest, Fish and Reef Bays, St. John, U.S. Virgin Islands. Biosphere reserve research report 21. Virgin Islands Resource Management Cooperative/National Park Service, p.1-99.

JOHANNES, R. E. AND J. E. MARAGOS AND S. L. COLES. 1972. Oil damaged corals exposed to air. Mar. Poll. Bull. 3: 29-30.

KINSMAN, D. J. J. 1964. Reef coral tolerance of high temperature and salinities. Nature, Lond. 202: 1280-1282.

KENT, M. AND P. COKER. 1992. Vegetation description and analysis. CRC Press and Belhaven Press, pp. 363.

LEWIS, J. B. 1971. The effect of crude oil and oil dispersant on reef corals. Mar. Poll. Bull. 2: 59-62.

LOYA, Y. 1972. Community structure and species diversity of hermatypic corals at Eilat, Red Sea. Mar. Biol. 13(2): 100-123.

LOYA, Y. 1975. Possible effects of water pollution on the community structure of Red Sea corals. Marine Biology 29: 177-85.

LOYA, Y. 1976a. Recolonization of Red Sea corals affected by natural catastrophes and man-made perturbations. Ecology 57: 278-89.

LOYA, Y. 1976b. Effect of water turbidity and sedimentation on the community structure of Puerto Rican corals. Bull. mar. Sci. 26: 450-466.

LOYA, Y. 1978. Plotless and transect methods. Pages 197-217 *in* D. R. Stoddart and R. E. Johannes, eds., Coral reefs: research methods. UNESCO, Paris.

LOYA, Y. AND B. RINKEVICH. 1979. Abortion effect in corals induced by oil pollution. Mar. Ecol. Prog. Ser. 1: 77-80.

LOYA, Y. AND B. RINKEVICH. 1980. Effects of oil pollution on coral reef communities. Mar. Ecol. Prog. Ser. 3: 167-80.

LOYA, Y. AND B. RINKEVICH. 1987. Effects of petroleum hydrocarbons on corals. Pages 91-102 *in* B. Salvat, ed., Human impacts on coral reefs: facts and recommendations. Antenne Museum E.P.H.E., French Polynesia.

MAGURRAN, A. E. 1988. Ecological diversity and its measurement. Croom Helm, London, Sydney. pp.1-179.

*MITCHELL, R. AND I. CHET. 1975. Bacterial attack of corals on polluted sea water. Micr. Ecol. 2: 227-233.

*MORELOCK, J., N. SCHNEIDERMANN AND W. R. BRYANT. 1977. Shelf reefs, southwestern Puerto Rico. Pages 17-25 *in* S. H. Frost, M.P. Weiss and J.B. Saunders eds., Reefs and related carbonates - ecology and sedimentology. Am. Ass. Petr. Geol., Tulsa, Oklahoma.

NAIK, R. M., M. S. MURTHY, A. P. MANSURI, Y. N. RAO, R. PRAVEZ ET AL. 1985. WWF-India sponsored research projects on studies on coastal marine ecosystems and the effects of anthropogenic pressure in the Gulf of Kutch and the ecology of the Hingolgarh (Motisari) educational sanctuary, First Progress Report, Department of Biosciences, Saurashtra University, Rajkot, Gujarat.

NAIK, R. M., T. MUNDKUR AND P. PALMES. 1988. The directory of Indian wetlands WWF India and AWB, Kuala Lumpur pp. 94-98.

ÖHMAN, M. C., A. RAJASURIYA, AND O. LINDÉN. 1993. Human disturbance on coral reefs in Sri Lanka: A case study. Ambio 22(7): 474-80.

PALMER, M. W. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. Ecology 74(8): 2215-2230.

PATEL, M. I. 1985. Calcareous sand mining from beaches and littoral areas in the Gulf of Kutch, Gujarat and their possible deleterious effects on Marine life, Proc. Symp. Endangered Marine Animals and Marine Parks, Vol. 3, Paper no.41.

PETERS, E. C., P. A. MEYERS, P. P. YEVICH AND N. J. BLAKE. 1981. Bioaccumulation and histopathological effects of oil on a stony coral. Mar. Pollut. Bull. 12: 333-339.

PETRAITIS, P. S., LATHAM, R. E. AND NIESENBAUM, R. A. 1989. The maintenance of species diversity by disturbance. *Quart. Rev. Biol.*, **64(4): 393-418.**

RASHID, M. A. 1985. Gujarat's Gulf of Kutch - A marine paradise, Proc. Symp. Endangered marine animals and marine parks, Vol.3, Paper no.40.

RASHID, M. A. 1988. Gujarat's Gulf of Kutch - A marine paradise. Pages 467-74 *in* E. G. Silas, ed., Proceedings of the Symposium of Endangered Marine Animals and Marine Parks 12-16 Jan, Cochin. Cochin: The Marine Biological Association of India.

REIMER, A. A. 1975. Effects of crude oil on corals. Mar. Pollut. Bull. 6: 39-43.

RINKEVICH, B. AND Y. LOYA. 1977. Harmful effects of chronic oil pollution on a Red Sea coral population. Pages 585-591 *in* D. L. Taylor, ed., Proceedings third international coral reef syposium. II Geology. University of Miami, Miami.

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. 1990. Responses of coral reefs and reef organisms to sedimentation. Mar. Ecol. Prog. Ser. 62: 185-202.

SALM, R. V. 1983. Coral reefs of the western Indian Ocean: a threatened heritage. Ambio 12: 349-353.

SCOTT, D. A., EDITOR. 1989. A directory of Asian wetlands. Gland, Switzerland and Cambridge, U.K.: IUCN. xiv + 1181 pp, 33 maps pp.

SHEPPARD, C. R. C. 1980. Coral fauna of Diego Garcia lagoon following harbor construction. Mar. Pollut. Bull. 11: 227-230.

SHEPPARD, C. R. C. 1981. Illumination and the coral community beneath *Acropora* tables. Mar. Biol. 64: 53-58.

SHEPPARD, C. R. C. 1982. Coral populations on reef slopes and their major controls. Mar. Ecol. Prog. Ser. 7: 83-115.

SHINN, E. 1976. Coral reef recovery in Florida and the Persian Gulf. Env. Geol. 1: 241-254.

SINGH, H. S. 1995. Management plan for the Marine National Park. Misc. Reports. Govt. of Gujarat.

SOUSA, W. P. 1979. Disturbance in marine intertidal boulder fields: The non-equilibrium maintenance of species diversity. Ecology 60(6): 1225-39.

SPOONER, M. F. 1970. Oil spill in Tarut Bay, Saudi Arabia. Mar. Pollut. Bull. 1: 166-167.

STODDART, D. R. 1963. Effects of Hurricane Hattie on the British Honduras reefs and cay, Oct.30-31, 1961. Atoll Res. Bull. 95: 1-142.

TER BRAAK, C. J. F. 1987. Ordination. Pages 91-173 *in* R. H. G. Jongman, C. J. F. Ter Braak and O. F. R. Van Tongeren, eds., Data analysis in community and landscape ecology. Pudoc, Washington.

VAN KATWIJK, M. M., N. F. MEIER, R. VAN LOON, E. M. VAN HOVE, W. B. J. T. GIESEN, G. VAN DER VELDE AND C. DEN HARTOG. 1993. Sabaki river sediment load and coral stress: correlation between sediments and condition of the Malindi-Watamu reefs in Kenya (Indian Ocean). Marine Biology 117: 675-83.

WAFAR, M. V. M. 1986. Corals and coral reefs of India. Proc. Indian Acad Sci. (Anim. Sci/Plant Sci.) Suppl. :19-43.

WALLACE, C. C. AND B. L. WILLIS. 1994. Systematics of the coral genus *Acropora*: Implications of New Biological findings for species concepts. Ann. Rev. Ecol. Syst. 25: 237-62.

WOOD, E. M. 1983. Coral reefs of the World - biology and field guide. T.F.H. Publications Ltd., Inc.

* Not seen in the original

**Appendix I. A list of coral species enumerated by quadrat sampling in Pirotan and Narrara, Marine National Park, Gujarat**

**Coral Species**

1. *Porites compressa*
2. *Mycedium* sp.?
3. *Cyphastrea serallia*
4. *Porite lichen*
5. *Favia favus*
6. *Platygyra sinensis*
7. *Favites melicerum*
08. *Porites lutea*
9. *Favia speciosa*
10. *Sideastrea savigynyana*
11. *Montipora explanata*
12. *Favites complanata*
13. *Goniopora nigra*
14. *Goniopora minor*
15. *Goniopora planulata*
16. *Turbinaria peltata*