DECLINE OF THE MALINDI-WATAMU REEF COMPLEX
Quantitative and qualitative survey of the coral growth

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SYNOPSIS

The coral reef off the Kenya coast has declined strongly over the past two decades.
Aim of this report is to quantify and qualify coral death, and to assess the contribution of certain factors of disturbance to the decline of these reefs.
To attain these objectives, the Watamu Reef Expedition (WRE) developed a special method, that has been called a 'combined line-transect' method. The development and testing of this technique is described in detail in this report.
Application of this method in the first place resulted in a comprehensive description of the reef, which allows an assessment of its present condition.
Because of its broad approach, this method not only gave extensive information on qualitative and quantitative aspects of coral growth, but also on the condition and size of individual coral colonies. In all, more than 10,000 colonies were analysed.
From the composition, cover, condition and colony size, one may assess the degree of reef degeneration, and establish correlations between these four parameters and factors of disturbance affecting the corals.
The results obtained via the combined line-transect method are further discussed in this report. From these discussions it is apparent that the destructive effects of tourism are quite limited, and only felt very locally, and that the primary cause of coral death may be attributed to the sedimentation of silt, originating from the Sabaki river.
GENERAL INTRODUCTION.

Along the Kenyan coast lies a fringing coral reef to beyond the Tanzanian border. During the past few years decay of this reef complex has been noted repeatedly (Bock, 1979; J.M. Wamae, warden of Malindi Marine Park, p.c.; Green et al, 1979). These sources however, are unequivocal about which factors they hold responsible for the reef destruction. According to the Leopard Reef Expedition (Green et al, 1979) the silt load of one of the major rivers has risen to a level that is detrimental to the reef adjacent to its mouth. Ken Bock (1979) holds tourism responsible for reef destruction. On the one hand tourists bring about direct damage by their presence on the reef (mechanical damage, boat anchors, etc.). On the other hand, tourists also demand souvenirs of marine origin, which are gladly supplied by locals seeking a source of income.

Personal communication with game wardens of the Watamu Reserve has made evident the need for information gathered on a scientific basis about coral death, in order to take appropriate management procedures to curb further destruction. This need was further emphasized by the former director of the Kenyan 'Wildlife Conservation & Management Department', Mr. K.M. Kaittani.

Robert Endean (1976, an expert in the field of reef ecosystems), voices his anxiety:

'It is apparent that human activities are affecting coral ecosystems on an unprecedented scale. Moreover, these ecosystems appear to be particularly susceptible to damage caused by a wide variety of human activities. The results of these activities could be catastrophic and may already be irreversible in some areas. Measures should be taken immediately by the appropriate authorities to ensure that exploitation of the renewable resources of coral reefs is compatible with the conservation of these reefs. International action is required to ensure that coral reefs do not suffer the fate that has befallen their terrestrial counterparts, the tropical rain forests which, according to Richards (1973, in Endean, 1976) will probably be destroyed within the next 20 - 30 years, except for a few small conserved relics' (Endean, 1976 p. 250).

East African reefs, in contrast to, for example the Great Barrier Reef and Caribbean reefs, have been hardly investigated up to now. Apart from making an inventory of the coral genera, which has partly been carried out in this area (Green et al, 1979; Hamilton, 1976), the research will have to start from scratch.

Valuable references on coral research are limited for this specific area. Talbot (1965) investigated a more or less comparable reef ecosystem in Tanzania (Tutia Reefs). He gives a description of the coral structure and its related fish fauna. Furthermore he stated a seaward growth of the reef. Brander et al (1971) compared species diversity and ecology of reef-living invertebrates on the Aldabra Atoll and at Watamu, Kenya recording a greater diversity in the latter. They also discussed methods for obtaining quantitative samples, and tested the validity of existing habitat classification. Lewis (1968) describes the morphology of the fringing coral reef along the east coast of Mahé, Seychelles. The general reef structure is comparable to that of Malindi, being a patch reef complex and a sea exposed fringing reef. The main sea currents and trade winds are identical to those in Kenya.
The most important aim of the research was to quantify and qualify 'coral death', and to assess the contribution of certain factors of disturbance to the decline of these reefs.

The research has been carried out by five subgroups, each of which dealt with a part of the whole investigation:

1. Reef investigation of the Watamu National Marine Reserve and coral taxonomy
2. Influence of the Sabaki river on the marine environment
3. Soil erosion and soil conservation in the Athi-river catchment area
4. Tourism and employment

The aim of this part of the research (1) was to quantify (abundance and distribution), and qualify (species composition and condition) the coral growth on the coral reef and to make detailed accounts of the nature and degree of possible damage to the corals. In addition the contribution of certain factors of disturbance to the decline of the reef was assessed.

This coral survey was carried out by nine members of the Watamu Reef Expedition, which (except for the photographer) are all students of the Catholic University of Nijmegen (The Netherlands): Jos Blom, Harrie van der Hagen, Eus van Hove, Marieke van Katwijk, Sjaak Lemmens, Rene van Loon, Rik Meier, Ben Smeets and Ron Eijkman (photographer).

The research has taken place in the Watamu Marine National Reserve and in the Malindi and Watamu Parks, which both lie in this reserve (Figure 1). Both parks are protected areas, which means that the only activities tourists can embark on are diving and swimming, under surveillance of park wardens. The reserve however only has a partial protection, which means that spear-fishing is prohibited and that (shell-)collectors cannot run wild. The reserve and the parks were established in 1968. Research also included the adjacent areas of the reserve, which receive no protection at all. The northern and southern borders of the research area were mainly determined by the boundaries of the reserve, in connection with the occurrence of the corals. (To the North of Malindi the number of corals rapidly diminishes.) Another factor that limited the research area is the accessibility of the various locations by boat. The corals in the area were mainly investigated to a depth of approximately 12 metres. The reseatch was concentrated on the areas in the vicinity of Malindi on the one hand and Watamu on the other.

The underlying report is divided into four parts:

Part one: Informative
Chapter 1 gives general information about coral reefs and their floral and faunal inhabitants as an introduction to the following chapters. In the next chapter the morphology and scenery of the Malindi-Watamu reef complex is discussed, to provide some insight in the development of coral reefs in general and more specifically of the Malindi reef. The method being used for these investigations on the reef is dealt with in chapter 3.

Part two: Analytical
Figure 1: The Watamu Marine National Reserve.
In the next three chapters the data gathered are presented. First of all numerical processing is applied on the data (species composition and abundance) by which 'coral assemblages' can be distinguished (chapter 4). Next, the affections to corals will be quantitatively and qualitatively analysed (chapter 5). Furthermore, this analytical part is concluded by considerations on the size of coral species (chapter 6).

Part three: Integration
In the third part conclusions on the results presented in the previous part an overall characterization of the distinguished topographical units is given. This is followed by a synthesis on the the coral growth within the investigated area.

Part four: Conclusion
General conclusions and recommendations are dealt with in this last part.
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Chapter 1
THE REEF ECOSYSTEM.

1.1 INTRODUCTION.

The supremely beautiful variation in colour and huge number of living organisms on a reef is generally known. Often a coral reef is compared with a tropical rain forest (Connell, 1978). Both have a high species diversity, a high biological productivity within a long timespan (K-selection; Pianka, 1970) and a high complexity (Johannes, 1977). Recovery after severe damage or total destruction takes a long time, in fact several decades if subsequent recovery actually is possible (Benayahu & Loya, 1977). About the stability and predictability in development (succession) of coral reefs little is known. In this respect comparison with tropical rain forests is not always valid (Bak & Luckhurst, 1980).

Charles Darwin (1842) was the first who mapped a great deal of the world’s coral reefs mainly based on his own work but also on previous incidental publications. Before discussing some aspects of the distribution and ecology of coral reefs, a definition of a coral reef is necessary. Vaughan (1919) defined a coral reef as a ridge or mount of limestone, the upper surface of which, lies or lay at the time of formation, near the level of the sea, and is predominantly composed of calcium carbonate secreted by organisms, of which the most important are corals. The last part of this definition is only partly true. Also Lithothamnia (encrusting coralline red algae, e.g. Porolithon) and (macro-)algae (e.g. Halimeda) contribute in considerable amount to the construction of a reef (Cribb, 1973; Randall, 1974). Several decades ago Henson (1950) introduced the term “reef complex”. It does not strictly include the corals but also other carbonate producing organisms and lagoon deposits and off-reef deposits (i.e. carbonate sand). Cloud (1959; pg 387) put the term "reef complex" into words:

Geologically the reef complex is an aggregate of calcium carbonate secreting and frame-building organisms, associated biota and mainly biogenic sediments. Ecologically it is an essentially steady-state oasis of organic productivity featured by high population density, intense calcium metabolism, and complex nutrient chains, and generally surrounded by waters of relatively low mineral and plankton content.

The term "reef complex" in both senses is being used in this study on the one hand as actual habitat of living plants and animals and on the other as in the past and recently formed carbonate formations (Stoddart, 1969). By the latter are meant formations of pleistocene aggregates veneered by a thin semi-fossil holocene layer (Ladd, 1977).

In the next paragraphs the worldwide distribution of reef complexes will be discussed, and which types of reef complexes can be distinguished. Furthermore some major abiotic factors which control the distribution of coral reefs will pass the review and what other life can be found on a coral reef complex apart from the stony corals (Scleractinia).
1.2 TYPES OF REEF COMPLEXES AND THEIR DISTRIBUTION.

Darwin (1842) was the first to study scientifically the distribution of coral reefs over the world. Over the last century several maps have been published on the distribution of coral reefs. Pannekoek (1976) published a good general overview (Figure 3). Hori (1977) published the most recent and most detailed map.

Most of the reef complexes are found in the Pacific and in the eastern part of the Indian Ocean. Also in the western and central Indian Ocean coral reefs are located in the shallow parts: Maldives, Seychelles, Malagasy, along the coast of East Africa and the Red Sea and along the coast of the Persian Gulf. A third concentration of reef complexes is surrounded by North-, Central- and South-America, that is the Gulf of Mexico, the Caribbean Sea and the nearby parts of the Atlantic Ocean (the West-Indian reefs in the wider Caribbean Region).

Generally speaking, coral reefs seem to be most flourishing in the mid-tropics within the 20 degrees C mean winter minimum isotherm and more specifically in waters where a warm water current is prevailing. So, on some places in the mid-tropic, coral reefs only exist fragmentarily or are totally absent, e.g. along the coasts of the East-Pacific and West-Africa. Moreover, earthquakes (Stoddart, 1972), accumulation and mobility of sediments, active vulcanity (New Hebrides), platforms on unsuitable depths (Seychelles) and areas where cold water appears causes absence of coral reefs in those places (Hori, 1977).

On the ground of three criteria, one can recognize three different distribution patterns (Stoddart, 1969; Heys & Brouns, 1976): (A.) form(-ation), (B.) species composition and (C.) exposure to the sea.

(A.) form(-ation).
Barrier reefs. These generally have a linear structure situated several miles offshore, and separated from the land by deep water channels (lagoon).

Atolls. These are annular reefs enclosing a lagoon. They develop near the surface of the sea on the margins of submarine foundations.

Fringing reefs. As for this type see below.

Apart from these one can distinguish table reefs, faro's, micro atolls, knolls and patch reefs (Battistini et al, 1975).

The type of reef along the coast of East-Africa is a fringing reef. It actually is one of the most beautiful examples (Took, 1978) or with regard to the Malindi-Watamu reef complex at least was. Because of sealevel changes in the Pleistocene several platforms have been developed along the coast of East-Africa. This caused submerged terraces or platforms in the subtidal zone. Depending on the steepness of the slope under water the fringing reef is narrow or wide. The most common feature of a fringing reef is development very near to a rocky shore with favourable temperature and oxygen- and foodsupply (Ladd, 1977). The landmass and the actual reef are mostly separated by a shallow lagoon or boat channel. Supply of fresh water and silt from the land and sometimes stagnating food and oxygen supply can cause severe damage to corals, especially in a shallow lagoon. Platforms in the tidal zone clearly show limited coral growth (Hong & Sasekumar, 1979).

(B.) species composition.

A second division can be made based on taxonomic composition. One has to bear in mind however, that taxonomic uncertainties in the Scleractinia and the plasticity of growth form of each species give difficulties in interpreting these (sub-)divisions (Stoddart, 1969). Certain species are found on specific parts on a reef; in unfavourable conditions they become quite different from the typical feature (Yonge, 1969).

Many important genera from the Indo-Pacific are lacking on the Atlantic (West-Indian) reefs. Although the total sum of genera is almost the same in general the number of species is much higher in the Indo-Pacific (Stoddart, 1969; Glynn, 1973). This is best illustrated by the high species diversity on reefs in the Melanesian-Southeast Asian area (50 genera and 700 species). As a result of glacial influences and cold periods in interglacials (Miocene) in the Caribbean area a lot of taxa (species as well as genera) became extinct. These taxa frequently occur in fossil Oligocene reefs. They are still present in Pacific and Indo-Pacific reefs. The isolated position of the West-Indian reefs, because of the uplift of the isthmus of Panama more than a million years ago, is also due to its separate development and speciation (Kuehlmann, 1972; Porter, 1974; Newell, 1971).

(C.) exposure to the sea.

The division of coral reefs in high and low energy reefs is quite obvious as being reefs on the windward and leeward side of islands.
1.3 TAXONOMY AND MORPHOLOGY OF CORALS.

Corals belong to the phylum of Cnidaria. The name Coelenterata is not valid, because it formerly united the Cnidaria and Ctenophora in one phylum. Currently they are promoted to separate phyla.

The Cnidaria are characterized by

- a considerable number of different cell types, each with its own function
- a body wall consisting of two distinct basic layers: epidermis and gastrodermis and in between a structureless mesoglea.
- a gastrovascular cavity for the digestion of the food. It lies along the polar axis of the animal and opens at one end to the outside (the mouth). A circle of tentacles surrounds the mouth capturing food.

The phylum is a large one (approximately 9000 species) and is mostly marine. Apart from the Scleractinia several other taxa from the phylum Cnidaria were found on the Malindi reefs. Briefly these taxa will be dealt with according to the system of Hyman (1940), Hickman (1967), Barnes (1974) and George (1979).

Cnidaria (phylum)

Hydrozoa (Class): most of the hydrozoans are polypoid and colonial. Some are solitary e.g. Hydra. The order Milleporina is a colonial hydrozoan secreting a external calcareous skeleton. The single genus Millepora is very common in tropical waters.

Scyphozoa (Class): these are the coelenterates most frequently referred to as jelly fish (medusoid).

Anthozoa (Class): the anthozoans are strictly polypoid. The gastrovascular cavity is divided by septa into radiating compartments.

subclass Alcyonaria or octocorallia

order Stolonifera, Alcyonacea, Gorgonacea, Coenothecalia.

subclass Zoantharia or hexacorallia

order Scleractinia, Actinaria

Alcyonaria

The Alcyonaria include many common marine organisms such as soft or leather corals, sea pens, sea fans, whip corals and pipe corals. They always possess eight pinnate tentacles corresponding with eight mesenteries and the division of the gastrovascular cavity in eight chambers. They also possess an internally built skeleton. Mostly the separate polyps are connected with each other by a mass of tissue called coenenchyme which is of mesogleal origin. The most familiar Alcyonaria are the gorgonians (order Gorgonacea) or horny corals, which include the sea fans, whip coral and the precious red coral (Corallium). Other members of this subclass frequently seen on coral reefs, are the leather or soft corals (order Alcyonacea). The colonies may reach a considerable size of two metre or more. A third order (Stolonifera) consists of a group with simple polypoid structure. The skeleton of separate specules is fused into flexible tubes. More or less deviating from this general con-
struction is the Indo-Pacific organ pipe coral Tubipora, with its brightly white pinnate tentacles. A fourth group consists of the Coenothecalia of which Heliopora (blue coral) is the sole genus.

**Zoantharia.**

These animals produce an external skeleton and have simple tubular tentacles (multiple of 6), which are arranged in one or more circles around the mouth. The two most important orders of the subclass are the Actiniaria (sea anemones) and the Scleractinia (Madreporaria or stony corals). The morphology of the stony corals will be discussed next as well as its structural organization within a colony.

Unlike the sea anemone, the stony coral produces a calcium carbonate skeleton secreted by the epidermis. One animal, the polyp and one calice is the basis (Figure 4). It consists of a basal plate (tabla) with a surrounding wall (theca). Longitudionally 6 (or a multiple of 6) radiate septae are arranged on the wall. The polyp is draped over the calice, closely following its structure and immovably fixed.

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**Figure 4:** General morphology of a calice and a polyp (Wells, 1956).

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The coral taxonomy is mainly based on the morphology of the skeleton. Some corals are solitary and reach a diameter of 35 cm, but the majority is colonial with small polyps (1 to 5 mm). All the polyps of a colony are interconnected by a horizontal sheet of tissue (Figure 4). The lower epidermal layer secretes calcium carbonate in between the calices, known as the coenosteum (plocoid). If secretion of the coenosteum is lacking, this pattern of polyp...
arrangement is called phaceloid. Another arrangement is cerioid. Cerioid corals do not possess a coenosteum. The polyps do even share thecas. The polyps of brain corals are arranged in rows well separated from another. The polyps in rows are so close together that their calices are confluent and forms a brain-like structure (meandroid). (Figure 5).

Figure 5: Morphogenetic trends in colony formation. A: intratentacular budding, B: extratentacular budding C: transverse division (Wells, 1956).

The increase in size of a coral colony occurs by budding of new corallites. This may take place inside the corallite wall (intra-tentacular budding) or as new corallites in the coenosteum (extra-tentacular budding). Sexual reproduction takes place by fusion of eggs and sperms inside the gastrovascular cavity of a polyp. Also the planulae larvae develop there and are later expelled through the mouth. Probably most species do not exhibit self-fertilization (Endean, 1976).

At the next level of organisation the colony is considered as a whole by its growth form. These are solitary, massive, ramose, foliate, encrusting or tabulate (Rosen, 1971) (Figure 6).
1.4 ECOLOGICAL FACTORS RELATED TO THE DISTRIBUTION OF CORAL REEFS

Many ecologists have made detailed study on the limiting conditions for coral growth and on maintenance and growth of a coral reef. Based on Stoddart (1969), Endean (1976), Bak (1974; 1975) and Odum & Odum (1955) a short outline is given on the factors controlling and affecting the distribution of coral reefs and local coral growth:

- depth / light
- temperature
- salinity
- effects of the tide and water circulation
- solid substrate and sediment.

**Depth / light**

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1 For detailed information on several subjects see Giesen & van der Kerkhof (1984).
Scleractinians can be found in very deep waters, even up to a depth of several thousand metres. Reefbuilding (hermatypic) corals, however, only occur in the shallow parts of the sea. Growth conditions are favourable up to a depth of 30 metres, but they are optimal at about 10 metres. On even shallower places (e.g. shallow reef flats and lagoons) other factors can influence coral growth negatively as there are the effects of the tide, insolation and higher water temperature.

Hermatypic corals live in symbiosis or mutualistic relationship with zooxanthellae. The unicellular algae are photosynthetically active. The coral yields profit from this situation. The speed of calcification raises considerably (upto tenfold; Odum & Odum, 1955).

Clearly light is the limiting factor for reef growth. Directly linked to the quantity of light is the depth. On a depth of 15 metres only 12.5% radiant energy is left from the total quantity at the surface of the water (Figure 7). Connell (1973) did some experiments on the penetration of light. Corals were shadowed with opaque plastic domes, so that they received 10% of ambient illumination, but had the same water circulation as controls under clear plastic domes. The corals in heavy shade died after 2 to 6 months; those under clear plastic domes flourished.

Of course the quantity of light penetrating to the bottom also depends on the length of the day and the number of hours of sunshine during the day. The current and turbidity of the water and the wash of the waves modifies the penetration of the light to the bottom.

Temperature.
Coral reef complexes have a strictly tropical distribution (mid-tropics). Water temperature clearly is the most important explanation for coral reef distribution combined with the equatorial currents. A temperature between 25 and 29 degrees C. seems to be the optimum water temperature for coral growth (Figure 8) and changes in temperature must be very small. Research in Florida (Shinn, 1966) showed a strongly limited coral growth, because of temperature fluctuations of 12 degrees within one year. In the central Caribbean Lewis et al (1968) found no significant difference within one year. The temperature fluctuated only 3 degrees.

But then again every single species has its own temperature tolerance (ecological amplitude). Some species are more sensitive than others. But in general colder water implies impoverishment of coral reefs on diversity as well as in size.

Salinity.
The salinity of the sea is very constant in the mid-tropics (35 permillage S.). Also in the neighbourhood of a coast it is quite stable. Research on the tolerance of corals to lower and higher salinities showed a narrow range viz. 34 to 36 permille (Figure 8). But the range which permits coral growth in its extremes is much wider (27 to 45 permille). At the upper limit only Porites boulders can withstand the extremely high salinity (Kinsman, 1964; Hori, 1977). It also has to be considered that the tolerance of each species can vary in such extent that replacement to another area with another salinity could kill the very coral colony (eco-types).

Unfavourable low salinities seldom occur. Only torrential rain can cause severe damage to corals on very shallow reef flats. Also corals in the neighbourhood of a rivermouth endure stress if an exceptional large amount of fresh water flows on a reef (Squires, 1962; Goodbody, 1961). Hence, it appears that species specifically growing in or near bays are able to stand a more varied temperature and salinity regime. Most of these species are also found on greater depths (Bak, 1975).
Effects of the tide and water circulation.
Exposure over a long period of time to the air as a consequence of extreme low tide can imply a catastrophe. Few species endure this kind of stress. After exposure for a short time most species recover if still some tissue stayed alive. Especially brain-like corals seem to be more resistant from desiccation than the more delicate ramose species (Fishelson, 1973). Fishelson also stated that extreme low water (once or twice in a decade) has its advantages. It guarantees a high diversity by creating open space. But if a reef already is in a bad condition an extreme low tide can mean the 'final blow'.

A combination of factors mentioned above (extreme low water, mid-day sunshine in summer, or torrential rain) can lead to a catastrophe.

Solid substrate and sediment.
Generally in coral reefs four kinds of substrates can be distinguished:

- (coral-) rock
- coral sand
Figure 8: Temperature and salinity tolerances of reef corals (dark: optimum conditions; blank: previously accepted limits; hatched: extreme limits). From Kinsman, 1964.

- silt (often erosion material from the land)
- rubble

A solid substrate is strictly necessary for the settlement (and development) of planula larvae. By suitable is meant that bare (coral-)rock is conditioned by algal communities for larval settlement. So, solid substrate also includes limestone shells, encrusting calcareous algae and foraminifera (Pearson, 1981). If grazing mainly by fish and echinoids is lacking, fleshy algae which are efficient sediment traps smother these encrusting algae. The fleshy algae inhibit larvae to settle. The arrangement of stony corals depends largely on the quantity of solid substrate available and free of fleshy algae.

Rubble consists of pieces of corals of small or medium size broken off, sometimes cemented together by lithothamnia.
Within the coral complex large areas consist of (biogenic) coral sands partly grown over with seagrasses and macro-algae. Settlement of planula larvae is impossible because of the scouring of the coarse sand by oscillating water movement over the bottom. Alteration of the current can cause burial of corals under coral sand. Species most resistant to temperature and salinity stress are also resistant against burial by sand (Stoddart, 1969). Also species with big polyps belong to the "burial-resistant" group e.g. Fungia. (Schumacher, 1977).

Goniopora species are found to be very aggressive towards other corals and do not "tolerate' other corals in their neighbourhood (Sheppard, 1979), and are very resistant against sedimentation (Endean, 1977), because of its long tentacles and their capability to be a primary 'colonizer' by the production of asexually formed 'polyp-balls' (Bull, 1982).

The most important threat to the existence of a reef probably is the occurrence of large quantities of suspended matter due to bad land management and dredging (Johannes, 1977). The fine silt stays in suspension and reduces in some extent the light penetrating to the bottom. If the sediment precipitates, it can cause total destruction of all sessile and mobile inhabitants of the reef (Ditlev, 1978; Rodriguez, 1981). As a result of storm or strong currents the silt can resuspend. Along a reefedge it can reduce the sight to 10 cm (Ditlev, 1978). Quite similar observations have been recorded by Hong & Sasekumar (1979).

In contradiction to ecosystems in the temperate marine waters recovery from a disaster of this character lasts several decades even under favourable conditions.

Summarizing, the above mentioned abiotic factors can be divided in three groups:

Temperature is a fundamental factor which determines the global distribution. All other factors are of more regional or local concern. Salinity, turbidity, sedimentation, water turbulence and tidal effects determine horizontal distribution of corals on coral reefs. Illumination (along with turbidity and water turbulence) limits vertical distribution (Hori, 1977).

1.5 SOME ECOLOGICAL ASPECTS OF CORALS.

This paragraph briefly gives some information on the population ecology (Connell, 1973) and physiology of corals.

Apart from the asexual reproduction by means of colony fragments and budding (Stimson, 1978; Bak, 1975) corals also have sexual reproduction. Mostly fertilization takes place inside the polyp. The planula larvae are released during a specific period (depending on the water temperature) or throughout the year. Several times a synchronous expulsion of planula larvae with a phase of the moon was found (Atoda, 1947; Harrigan, 1972); most research, however, did not find any correlation (Rinkevich & Loya, 1979; Goreau, Goreau & Hayes, 1981).

Recolonization of a dead area or colonization of new areas depends largely on the active and passive dispersal of the larvae. Most investigations report settlement of the larvae within two days (to a maximum of 21 days). Shinn (1966 in Pearson, 1981) suggested that damaged reefs were recolonized by coral larvae coming from undamaged reefs 60 km away caused by longitudinal currents, and transportation also depends on the tidal currents. Consequently the distance covered will be quite small. Larval dispersal is even more
restricted inside a lagoon. Settlement often takes place very near to the "parent". Occupation of space mainly depends on the possibilities for settlement and the actual settlement of the planula larvae and their calcification rate. Most species grow more vigorously in shallow water; some however grow faster in deeper waters (Bak, 1976).

On a coral reef the animal component seems to dominate over the plant component, because of the huge number of Cnidaria. This is not true. The total plant protoplasm exceeds the animal about 3 to 1 (Odum & Odum, 1955: p 298) caused by the enormous quantity of algae, boring as well as symbiotic (Odum & Odum, 1955: fig 6 & 7). The symbiotic algae are situated in the endodermal cells of the Cnidarians, especially in the tentacles and around the mouth (Muscatine, 1974).

A coral reef complex as a result of calcium carbonate accumulation (aragonite) greatly depends on the unicellular algae (Gymnodinium microadriaticum) mostly referred to as zooxanthellae. The mechanism of calcification is still not understood (Chapman, 1974). Only detailed information on a number of subjects considering calcification are available contributing to the total picture (Chapman, 1974; Mann, 1982; Pearse & Muscatine, 1971). A problem that occurs is: why is the concentration of zooxanthellae lowest at the tips of the branches of Acropora where calcification takes place most rapidly? So, calcification must be indirect.

Yonge (1963) formulates the advantages of the symbiosis as follows: The advantage for the algal component is protection and favourable supply of food through and from the polyp e.g. phosphate and nitrogen compounds (Muscatine, 1974). Exposure to sublethal temperatures and low oxygen pressure lead to immediate expulsion of zooxanthellae. This phenomenon also occurs as a result of high insolation (Ditlev, 1978) or after a hurricane has passed (Goreau, 1964).

The advantages of the symbiosis for the polyp are manyfold. The zooxanthellae recycle nutrients and increase calcification (Muscatine, 1973, 1974, 1980). On the other hand the zooxanthellae provide the polyp with organic compounds (vitamins and hormone-like compounds), which also increase the metabolism of the polyp. Hermatypic corals grow up to ten times faster in light conditions than in darkness. The fact that hermatypic corals lacking zooxanthellae are in a bad condition, proves their metabolic dependence. But a certain flexibility in the feeding behaviour and feeding pattern guarantees adaptation to changing or changed circumstances. Survival under temporary extreme conditions is possible.

Zooplankton, being the main food of the polyp, is not really required by corals as a major source of nutrient energy. They can depend on other sources, such as zooxanthellae, detritus, other corals and bacteria. Corals held in the dark for several weeks extruded their zooxanthellae, staying healthy by active food collection but showed strongly reduced calcification (Mann, 1982) (Figure 9).

This elasticity in feeding behaviour could partly explain how so many species are able to coexist in water of such low nutrient and plankton contents (Johannes, 1974).

The increased calcification expresses itself on a variety of growth forms (ramose, tabulate, massive, encrusting and foliate) connected with certain habitats (Yonge, 1963; 1973; Rosen, 1971; Sheppard, 1980). Massive corals point to reduced water movement (sheltered edges). Coarse ramose Acroporas mostly occur on the reef edges with moderate to high water movement (surf zone and windward edges; e.g. Acropora palmata on Caribbean reefs taking the full force of the waves). Foliate taxa often can be found on steep edges.
As a result of growth corals will compete with each other for space. One of the strategies has been discovered by Lang (1970). Certain coral species extend their mesenterial filaments and digest any living coral tissue which they can reach, up to about 2 cm away. More or less based on the former, species can be arranged in an aggressive hierarchy (Sheppard, 1979). Generally speaking slow growing massive colonies are not overgrown by faster growing branching species.

1.6 FLORA AND FAUNA ASSOCIATED TO CORAL REEFS.

As mentioned in the introduction a coral reef complex is a tremendously varied association of plants and animals living in marine tropical waters of low nutrient and plancton content.

Fishes.
Together with the coral the fishes are the eye-catchers of the reef, mainly by their beautiful colours. Striking is the enormous variation and wealth of species (Talbot et al, 1978).

Randall (1974) however expressed it as follows:
Apart from aesthetic aspects and serving as prey for other resident animals, fishes are not beneficial to reefs. They use them for shelter (Holocentridae), reproduction and as a source of food. It is in the former that their impact is the greatest.

Firstly the living tissue is eaten by e.g. parrot fishes and butterfly fishes, the former leaving characteristic double grooves on the corallum. The number of species and fish having this kind of feeding pattern is that small that it can not have a great contribution to coral death. Heys & Brouns (1976) showed that coral recovery (after artificial damage) occurs very frequently if the lesis is small. The coral tissue can overgrow the organisms that colonize first e.g. algae. Secondly algae on dead corallum are a source of food for fish. They scrape off a thin layer of dead calcium carbonate as well while feeding on algae (Scaridae and Acanthuridae), leaving double grooves too on the corallum (Randall, 1974). Research shows a great impact on the coral reef from the latter. Large quantities of coral rock are converted to fine sediment by biogenical processes (Bakus, 1969). Wood-Jones (1919 in Randall, 1974) regarded parrot fishes as “amongst the important agents in making of coral sand”. Fish remove upright (frondose) algae, which can exclude or inhibit indirectly the recruitement of invertebrates as corals (Vine, 1974; Brock, 1979; Hay, 1981). This is in contradiction to Randall’s opinion as fish being not beneficial to coral reefs.

By selective fishing for tropical aquaria (or total removal of all fish) the equilibrium between corals and fish can easily be disturbed.

Alcyonacea (soft corals).
Several dominant and fast growing species can form large monospecific "carpets" on solid substrata. This strategy is helpful in rapidly (re-)colonizing space after a catastrophe e.g. extreme low water (Benayahu & Loya, 1977). At Eilat (Red Sea) and at several places in the Indo-Pacific the latter is occurring periodically but nevertheless in an impredictable fashion.

Comparing the distribution of soft corals on coral reefs from the Red Sea and the Great Barrier Reef it shows that they are an important feature in the Red Sea ecosystem. As stated by others also, Schuhmacher (1975) found hard corals being well adapted to strong currents and swell. But soft corals tolerate extreme low tides better than stony corals do, and they are able to withstand two to three times as much sedimenting material as the stony corals. Consequently, permanent replacement by alcyonarians will take place due to continuing conditions suboptimal to stony corals.

Soft corals also seem to flourish on reefs in later stadia of development. Pichon (1974) called this regressive evolution.

After destruction of a coral reef by Acanthaster planci algal colonization occurs first. Then after a few months a community with soft corals evolves, followed by Scleractinians several years later (Pearson, 1981).

Echinoids (sea urchins).
Diadema antillarum lives mainly on algae and on seagrasses. This sea urchin is also carnivorous. The grazing of echinoids is very systematic, removing the algal layer completely. Echinoids can be very abundant on a coral reef. Two species of echinoids on the reefs of the Sudanese Red Sea were found to a number of 60 to 70 per 100 square metres (Dart, 1972). If the density of echinoids becomes to high (e.g. 200 - 300 per 100 square metres), they also feed on coral tissue because of lack of other food (Bak & Eys, 1975). A too low density threads the existence of the hard corals as well. Algal growth becomes that luxuriant that overgrowing of the coral is obvious (Kristensen, 1978).
Also Benayahu and Loya (1977) find sea urchins being the most important biotic factor regulating and controlling living coverage of algae. High diversity of benthic algae indicates intermittent grazing activity of sea urchins and fishes, preventing them from becoming a monotonous algal cover. Also intense grazing will result in a reduction of the diversity of algae (Paine & Vadas, 1969). Certain species of fish and gastropods (giant triton) feed on echinoids. Disturbance of the equilibrium (e.g. by spearfishing) can cause irreversible situations (Kristensen, 1978). Sea urchins seem to be more susceptible to silt than corals are. During the construction of an air base in Bermuda much dredging was done. For several years the water carried a heavy silt suspension. Lytechinus disappeared completely, although other invertebrates survived including corals (Moore et al, 1963).

A lot of other organisms live on a coral reef directly feeding on the corals (some crabs and polychaetes) as on coral rock (boring molluscs, sponges, polychaetes) generally weakening the skeleton. Other organisms living on a coral reef use the coral skeleton as a substrate sometimes however causing destruction of living tissue by overgrowing it (sponges, tunicates). Or the animal grows along with the coral (bivalves and polychaetes). A very special kind of association is found between Fungia cava eilatensis and corals of the Fungiidae. The bivalve lives inside the gastrovascular cavity of the coral feeding on phytoplancton and zooxanthellae (Goreau et al, 1968, 1972). Another example of a "symbiosis" is from a crustacean living between the branches of Seriatopora, causing deformation of the coral forming a gall. A good review of invertebrates living on corals and coral reefs is given by Patton (1976). A special note is to Acanthaster planci, which is the most notorious in causing a catastrophe when increasing in number as occurred on the Great Barrier Reef (Endean, 1973; Belk & Belk, 1975).

Seagrasses.
In the Indo-Pacific area seagrass beds form a very distinct zone on reef flats. In general the surface of the beds is covered by 2 to 5 m of water at high tide. As already suggested in the introduction marine deposits play an important role in the coral reef complex. The seagrass beds generally occur on biogenic sands. They are of coral, algal (Halimeda) and coralline origin. In addition the remains of echinoids, crustaceans and foraminifera are common but never abundant (Taylor & Lewis, 1970). Due to tidal currents deposition of skeletal sediments takes place continuously. Seagrass plants effectively limit transportation and further stabilize conditions for extension of the beds. Moreover, seagrass beds slow down water circulation in that extent that fine suspended particles can settle. Mainly epiphytes on the grass leaves act as a trap for this fine material (Taylor & Lewis, 1970). Seagrass beds do not occur in areas with strong wave action and where only a thin sediment layer is present.

The relative importance of seagrass beds has been outlined by den Hartog (1977), Kemp (1977), Zieman & Wetzel (1980) and recently by Heys & Brouns (1980). Although one of the most productive systems in the biosphere, only a small part is consumed by direct grazing. Most of the plants disintegrate and are utilised mainly through the detritus food chain. Leaves and rhizomes of seagrasses provide an increased surface for colonisation and growth of faunal and algal epiphytes. The relatively quiet waters also provide conditions for a thin layer of micro algae growing on the bottom.
The seagrass beds, located between the land and many coastal habitats (e.g. coral reefs), have a buffering capacity. It possibly prevents fresh water and dissolved nutrients to penetrate into the sensitive coral communities on the seaward side of the beds. Seagrass beds also provide many habitats for animals as there are crustaceans, molluscs, echinoderms, fish and some coral species (Taylor & Lewis, 1970). These beds are also nursery grounds for many fish species, directly or indirectly of economical importance.

**Algae.**

On a coral reef complex algae are a very important lifeform

- as a fleshy surface on dead corals or coralline rubble
- in symbiosis or mutualistic relationship with corals and anemones
- as boring organisms (algal layer in the skeleton)
- as noncalcareous and calcareous macro-algae
- as free living (planctonic) algae
- as small encrusting calcareous algae (Lithothamnion), mainly responsible for the cementation of loose coralline rubble
- as epiphytic communities on seagrasses and macro-algae.

As a result of a catastrophic event (re-)colonization by algae takes place within one day (Belk & Belk, 1975). Also on artificial substrates benthic algae colonize first and very rapidly. Algal settlement studies done by Vine (1974) show a very quick growth of these algae in shallow zones over large areas of the coral reef. How the available space will be occupied by soft corals, hard corals and algae depends largely on physical and biological factors. So, the total algal cover can greatly vary (3 to 75 %: Benayahu & Loya, 1977). Mostly up to half of the area may be rock, most of which is readily covered by filamentous algae. The size of the living algal crop varies with depth. Dart (1972) found a maximum of 20 grams per square metre at a depth of 3 metres, and 1 gram per square metre at a depth of 10 metres. Naturally the distribution of echinoids and fishes on a reef is closely related to the size of the algal crop. If the grazing activity by echinoids and fish is lacking, soon the algal diversity will decrease to a small number of species. Bak (1976) stated that the total weight increment of crustose coralline algae is highest at greater depths, because the grazing pressure by fish and echinoids is much higher at shallow places. It should be noted though that this statement is not in contradiction with Dart's.

Algae directly related to the corals (symbiotic and boring algae) have a great impact on coral growth and skeletal consistency. The average living coral colony contains three times as much plant as animal tissue of which six percent are zooxanthellae (Odum & Odum, 1955). The rest are filamentous green and blue-green algae living inside the skeleton. Some investigations seem to prove that these inhabitants seem to harden the uppermost surface of the skeleton, though others state the opposite (Cribb, 1973).

Calcareous and non-calcareous macro algae (e.g. Halimeda, Sargassum and Turbinaria) grow on coral rock, or form small or large beds on coral sand together with seagrasses. But the enormous species diversity of macro algae
found in temperate waters is not present on tropical coral reefs (Cribb, 1973).
Chapter 2
THE MORPHOLOGY AND SCENERY OF THE MALINDI-WATAMU REEF COMPLEX.

2.1 INTRODUCTION.

The East African coral reef is an anomalous feature of a fringing reef (Stoddart, 1971). When the tide is extremely low large expanses of the Malindi-Watamu reef complex emerge above sea level. At Mayungu the reef is then left dry over a distance of about three kilometres. It is evident that, as in other places in the world, the simplified model of reef growth as a continuous progression of growing upwards to the sea level, followed by growth on the ocean side (Braithwaite, 1971), does not hold for the Malindi-Watamu reef. The physical and biological processes taking place at this moment can not provide a satisfactory explanation for the surface characteristics of the reef. It is therefore necessary, in order to get some insight in the morphology of the Malindi-Watamu reef, to take into account the geological evolution of the reef.

Since the first scientific investigations of the reefs in the Pacific in the 19th century, reef biologists have been trying to develop a theoretical model for the origin and history of reef formations. In this chapter the three most important theories are briefly discussed: the subsidence theory, the glacial control theory and the antecedent platform theory. In addition a survey will be given of the pleistoceneous formations found by Thompson (1956) during his investigations in 1950-51, by which the geological history of the Malindi-Watamu reef is made clear.

Subsequently an attempt is made to determine whether the present coral reef is in a state of decay or growth. Finally the structure of the investigated area is described.

2.2 THE ORIGIN OF REEFS.

A. Subsidence theory.

In 1842 already Darwin connected the origin of reefs in the Indian Ocean with a downward movement of the earth surface (Stoddart, 1976). Since the growth of coral reefs is fastest at the ocean side, a fringing reef will in due course be changed into a barrier reef when the sea bottom continues to fall (Figure 10). When a reef has formed around a small island, for instance a vulcano, the barrier reef will in the end become an atoll.

B. Glacial control theory.

An alternative for subsidence is Daly's theory of glacial control (Steers, 1976). Daly presumed that, during the glacial periods of the Pleistocene, the tropical sea coasts underwent an intensified surf erosion due to the dying off of the reefs as a result of the low temperatures. According to this theory all reef formations emerging above sea level, and part of the islands consisting of vulcanic material, were then eroded down to the low sea level of the Pleistocene. He supposed that the upper 100 metre of the present atolls were almost entirely formed under the influence of the post-glacial rise of the sea level.

20
It is however improbable that the erosion should have taken place as fast as Daly supposed (Pannekoek, 1976). Daly's most important contribution was that he emphasized the importance of the fluctuations in the sea level during the Pleistocene.

C. Antecedent platform theory.

Hoffmeister and Ladd were not satisfied with the subsidence theory (Steers, 1976). They claimed that any sea bank localized at the right depth within the circumequatorial coral reef zone can be considered as a potential coral reef foundation. Under the right ecological conditions a reef can grow upwards to the sea level without any fluctuations in the relative sea level taking place.

Figure 10: The origin of reefs. The Subsidence theory (left) and the Glacial control theory (right).
Figure 11: Geological map of the Malindi area. From Thompson (1956).
2.3 GEOLOGICAL HISTORY.

The most important coral reefs in the Indian Ocean were formed towards the end of the Tertiary Era, about two and a half million years ago (Newell, 1971). The present characteristics of the coral reef were therefore formed in the period after the Tertiary, the Pleistocene Era. For the Malindi area the Pleistocene was investigated by Thompson (1956).

Thompson claims that in the early Pleistocene the sea level may have been 60 metres lower than today. In the Tertiary rock formations a marine platform was then eroded, on which the coral reef started to develop. During a marine transgression in the middle Pleistocene, the Second Inter-pluvial (the longest of the three Interpluvials), the coral grew upwards to about 30 metres above the present sea level, while the coastline was moved further inland. Along the new coastline dunes were formed, the so-called Magarini Sands, which in the present Arabuko Sokoke forest reach a height of 213 metres. Simultaneous with the dune formation along the coast, sand was deposited in the lagoon between the dunes and the barrier reef, which continued to grow on the ocean side.

This barrier reef, which developed in the middle Pleistocene, now forms the enormous fossil reef extending along the entire coast from Malindi to Watamu (Figure 11). The fossil reef emerges above sea level over a width of 500 metres north of Malindi and a distance of 4.3 kilometres between Msabaha and the coastline. Under the sea level this reef continues to almost 3 kilometres off the coast, where Leopard Reef forms the farthest extremity. Leopard Reef lies on the edge of the continental shelf, so that reef growth on the ocean side could not take place, because of the steep decline of the sea bottom. About three kilometres south of Malindi the fossil reef surface has a height of about 21 metres. Thompson states that the reef has been eroded considerably. He supposes that originally the height of the reef must have been 30 metres above the present sea level. The fossil reef has been completely cemented and consist for only 20% of coral. The rest is calcite, quartz, shell fragments and microfauna, especially foraminifera.

With the approach of the Kanjeran pluvial the sea level began to fall (Figure 12). Simultaneous with the coral growth to the Ocean side banks were formed before the coast, consisting of fine coral grit, shell fragments and foraminifera. When, during the Kanjeran pluvial and later during the Gamblian, this sea bottom rose above sea level, sand was swept over it by the wind. Percolating rain water caused these dunes to cement into so-called coquinas. Thompson defines a coquina as a rough, granular porous, brittle variety of limestone, mainly consisting of coral fragments and shells cemented to rock. The cliff shore at Watamu consists of such coquinas and has a height of nearly 20 metres. The numerous mushroom-like islands in the neighbourhood of Watamu all consist of coquinas and their linear pattern suggests that they form part of the same banks and dunes. Also in the neighbourhood of Malindi coquinas occur. Vasco da Gama Point and Leopard Point are protruding cliffs consisting of coquinas.

Recession of the sea continued during the Kanjeran pluvial and then reached its maximum. During this period parts of the reef became deeply eroded. At a depth of about 30 metres Thompson discovered a marine terrace. In Figure 12 this terrace is shown. In many places far from the shore, e.g. off Turtle Bay, the reef steeply declines to 30 metres, where a submarine sandy beach can be observed on the eroded terrace. During this period the reef was intersected in two places. In the North by the river Sabaki, in the south by the Mida Creek.

After a relatively short interpluvial (Third Interpluvial), which eroded a clearly distinguishable platform only near Mombasa (Talbot, 1964), another regression took place. During this Gamblian Pluvial the sea eroded a marine
Table 1: Main events in the Malindi Area during the Pleistocene.

<table>
<thead>
<tr>
<th>Period</th>
<th>Events</th>
<th>Pluvials</th>
</tr>
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<tbody>
<tr>
<td>Recent</td>
<td>Sea-level as at present day</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Silting up of Mida Creek</td>
<td></td>
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<tr>
<td></td>
<td>Post-pluvial</td>
<td></td>
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<tr>
<td>Upper</td>
<td>Terrace cut</td>
<td>Gamblian</td>
</tr>
<tr>
<td>Pleistocene</td>
<td>Sea-level rises to present-day level</td>
<td>Third</td>
</tr>
<tr>
<td></td>
<td>Coquinas accumulate</td>
<td>Inter-pluvial</td>
</tr>
<tr>
<td>Middle</td>
<td>Wind-blown sands start to accumulate</td>
<td>Kageran</td>
</tr>
<tr>
<td></td>
<td>Sea-level drops; platform cut at about -30 m</td>
<td>Second</td>
</tr>
<tr>
<td></td>
<td>Coquinas accumulate as off-shore bars</td>
<td>Inter-pluvial</td>
</tr>
<tr>
<td></td>
<td>Wind-blown sands accumulate as dunes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lagoonal sands accumulate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corals grow</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marine platform cut on which corals grow</td>
<td>Kamasian</td>
</tr>
<tr>
<td>Lower</td>
<td>Marine recession (to -60 m, ?)</td>
<td>Inter-pluvial</td>
</tr>
<tr>
<td></td>
<td>Margarini sands start accumulating</td>
<td>Kageran</td>
</tr>
<tr>
<td></td>
<td>Marine recession</td>
<td></td>
</tr>
</tbody>
</table>

From Thompson, 1956.

Platform at a depth of 7 metres (Figure 12). An extensive terrace lies at a depth of about 7 metres off the shore of Leopard Point, the so-called Malindi Banks. Off the Malindi reef a similar plateau is also clearly recognizable as a relic from the Gamblian period.

In the final phase the sea rose to the present level (the Holocene transgression), as a result of which another part of the fossil reef was eroded again. Along the coastline, which has been moved westwards, marine erosion is still taking place. The fossil reef rises steeply from the sea. The shape of these cliffs is caused by surf erosion. Because coquinas are less strongly consolidated than the fossil reef, the eroding action is not so intense as in the limestone of the reef. When the tide is extremely low the platform, formed in these last ten thousand years, emerges above sea level over large extents. Thompson concludes that the present day shore line of Kenya in the Malindi district exhibits phenomena resulting from both emergence and submergence (see Table 1).³

³ The pluvials Kageran, Kamasian, Kanjeran and Gamblian probably correspond with the European glacial periods Günz, Mindel, Riss and Würm (Pannekoek, 1976).
In Talbot's discussion of reef structures off the Tanzanian coast (1964) various theories on the vitality of the East African coral reefs found in the literature are investigated. The oldest theory, proposed by Crossland in 1903, is that the reefs are in a state of decay, and that the extensive reef platforms and the lagoons are due to the decay of the fossil reef and not to the seaward growth of the present reef. In his opinion the absence of a strong calciferous algae growth indicates that seaward growth of the reef is impossible. Gardiner (in 1936) also assumed that the existing reef systems in the western part of the Indian Ocean are decaying. His theory is mainly based on the absence of a "steep-to-reef", with the 20 metres depth line within 100 metres from the reef edge. Guilcher (in 1958) found, contrary to Gardiner's statement that steep-to-reefs were present. He found no essential difference in structure between past and present reef building.

Talbot himself detected a growth of the reef over a period of 14 years and measured growth speeds of e.g. Pocillopora verrucosa and Stylopora pistillata of 20 centimetres in 8 months. Also the cementing together of coral grit by algae has been observed by him. After studying the various theories and from his own investigations Talbot assumes that the present fringing reef off the Tanzanian coast is partly the result of the decay of the fossil reef and partly due to the seaward growth of the present coral reef (Talbot, 1964).

Talbot's theory seems to offer a plausible explanation for the formation of the Malindi-Watamu reef complex. As appears from the geological history this fringing reef is the eastern part of a barrier reef which has for the greater part been drained. This fossil reef was formed during the Second Interpluvial. The drainage of the fossil reef was not due to tectonic movements, but to fluctuations of the sea-level, i.e. to eustatic movements. The extent of this fossil reef from the East African coast line to the Maldives, and the general appearance of marine terraces at various levels suggest a narrow relation with the fluctuating sea level during the Pleistocene (Lewis, 1968).

As a result of these fluctuations four clearly distinguishable marine terraces were formed. The highest level, 20 metres above the present sea level, is formed by the emerged and cemented fossil reef. The crumbling coast line is formed by the cliffs of the fossil reef. These cliffs are characteristic of the East African coast line (Jones, 1970). The three other levels are submarine terraces. The first is at sea level, draining at low tide and extending from the foot of the cliffs. The periodical drainage of this terrace is the limiting factor for coral growth. The second terrace, lying at a depth of ca. 7 metres below sea level is overgrown with coral, so that the horizontal surface is difficult to recognize. During the Holocene transgression the reef probably grew upward to such a height that the transition from the first to the second terrace can be hardly recognised. From the reef edge (first terrace) the reef surface gradually declines to a depth of about seven metres. A good example of this terrace, dating from the Gamblian pluvial, is the Malindi Banks, an extensive platform seven metres below sea level. The third terrace can be clearly observed only in Turtle Bay, where it is no more than two or three kilometres from the coast (see geological map). Here the bottom of the sea declines steeply to a depth of 28 metres, where a submarine sandy beach can be observed, dating from the Kanjeran pluvial. The steep slope is luxuriously overgrown with coral. This could be the steep-to-reef which, according to Gardiner, should be present as the growth-front of a growing coral reef. Thompson (1956), however, claims that this slope was eroded during the Kanjeran pluvial, when the sea level was about 30 metres below the present level. The four terraces are thus due to erosion of the fossil reef, which was formed during the Second Interpluvial, when the environmental conditions
were apparently optimal for coral growth. This is corroborated by bore holes showing a thickness of the fossil reef of no less than 90 metres (Hori, 1977).

As pointed out by Stoddart (1971) many modern Indian Ocean reef communities only patchely veneer much older and much more extensive reef structures. The reasons for the destruction and failure to recover these earlier reefs are obscure (Endean, 1976). Rosen (1971) concluded that the present coral reefs around Mahé (Seychelles) considered to be as remnants of earlier structures, which have been subaerially dissected before being submerged again.

It is apparent that for the Malindi-Watamu reef complex the same can be concluded. The periodical drainage of the first terrace is probably the reason why no modern coral growth appears on this fossil substratum. Coral growth of some importance patchely occurs in deeper places, e.g. along the slopes from the first to the second terrace.
Figure 12: Formation of the Malindi-Watamu reef complex. Four Pleistocene phases schematically represented, from which it appears that the main features of the fringing reef are due to eustatic movements.
2.5 PHYSIOGRAPHY OF THE AREA.

The morphological characteristics of the reef are formed by modern conditions of reef growth, such as the influence of gales, tidal currents and other factors. But it appears from the geological history of the reef that the morphology is mainly determined by characteristics formed during the long, complex period of the Pleistocene. Making use of these morphological structures the Malindi-Watamu reef complex can be divided into a number of units. These units differ in topography and consequently in morphology (Figure 11). From north to south the following units can be distinguished:

1. Silversands.
5. Malindi Reef.
6. Turtle Bay and Blue Lagoon.
7. Mida Creek.
8. Whale Island.

Silversands.
This part of the reef lies between Vasco da Gama Point and Casuarina Point, and varies in width between about 500 metres in the south and 1200 metres in the north. This part of the reef is formed by the marine plateau which was eroded into the fossil reef during the holocene transgression. Coral growth only occurs along the slope, because the platform becomes dry at low tide. On the platform the biotope is dominated by sea-grasses, as a result of which sedimentation is taking place. The slope declines slowly to the Gamblian terrace, which lies 7 metres lower. This second marine terrace is covered with sand, and is eroded in some places to a depth of 12 metres.

North Reef, Leopard Reef and Tewa Reef.
Off Casuarina Point, and separated from it by the Barracuda Channel, lies a patch reef complex. Much of the patch reef complex is exposed at low tide which leaves a low and flat rather desolate-looking surface of coralrock covered with a layer of deposit and patches of weed. The three reef banks North reef, Leopard reef and Tewa Reef are relics of the eroded fossil reef, and rise steeply from a depth of 12 metres to the mean low tide level. Tewa reef remains below low tide at all times. The steep slopes of these reefs are overgrown with coral, mainly in the form of monospecific stands. The level of the top surfaces of North Reef and Leopard Reef corresponds with that of the marine platform fringing the shore. It must be assumed that these reefs have been subjected to the same marine erosion process and therefore date from the same period, the late Pleistocene. The extreme level surface of the reef which only varies a few centimetres in height suggest a balance of the forces of decay and growth, and a relation to sea level. The platform consists of fossil coral rock on which a strong sedimentation of sand is taking place. On Leopard Reef a sand bank is being swept into dunes by the wind. On North Reef dune formation can be observed in two places. The platform of North Reef becomes dry at low tide twice a day. The Northern and Eastern Inlets were probably eroded into the platform by the strong tide currents caused by the daily drainage of the platform. In these inlets, which have a maximum depth of 2 metres, corals grow in the form of boulders. These are large coral heads some of which have a circumference of 3 metres. The Malindi Coral Gardens are situated in the Eastern Inlet.

Mushroom Rock.
A reef stretching from Leopard Point in the north to Warakatibu in the south. The platform consists of fossil coral rock extending 500 metres from the beach. On this marine plateau a relic of the fossil reef is left, called "Mushroom Rock". The slope declines steeply to the Gamblian terrace which is 7 metres below sea level, called the Malindi Banks. The coral rocks of the slope and the second terrace are sparsely covered with coral. The first platform is overgrown with sea-grass with along the edges a zone of coral boulders.

**Warakatibu.**

This reef is formed by the fossil reef platform lying between a protruding cliff south of Mushroom Rock and the fishing village of Mayungu. Coral growth only occurs on the slope, where boulders are closely grouped to a depth of 7 metres. Over this entire area the Malindi Banks (2nd terrace), which extend to a point south of Leopard Point, consist of bare, uncovered coral rock.

**Malindi Reef.**

A long and very wide reef, extending from Mayungu to the Blue Lagoon, is the so-called Malindi Reef. The length of this reef unit is about 10 km. The reef is widest near Mayungu, viz. 3 km. This entire marine platform is left dry at low tide. The biotope is dominated by sea grasses. Living coral is absent on most of the surface of the reefflat, being found only where it dips toward its edges, and in the lagoon, the natural harbour of the little fishing village of Mayungu, where coral boulders occur. The slope of this marine platform descends to a depth of 7 metres, where the Gamblian terrace can be easily recognized. This very smooth terrace, which is a continuation of the Malindi Banks is sparsely covered with coral.

**Turtle Bay and Blue Lagoon.** *(Figure 13)*

This unit is bordered in the north by the tombolos, which form the Blue Lagoon, and in the south by the channel of Mida Creek. The three marine terraces formed in the Pleistocene can be clearly distinguished. The first terrace fringes the beach of the Blue Lagoon and Turtle Bay. The plateau of the Blue Lagoon is covered with beds of sea-grass, which accumulate the sand, as a result of which the Blue Lagoon is silting up. Also in Turtle Bay extensive sea grass beds are present on the marine plateau, which is, however, intersected by a lagoon, running parallel with the shore. The water of the tidal currents goes through this lagoon. In the south the lagoon discharges into the channel of Mida Creek and there reaches a depth of 7 metres. To the north the lagoon becomes shallower and shallower, to come to an end in front of the hotels of Watamu. This lagoon, which has been eroded into the fossil reef, has a narrow zone of coral boulders along its edge. This linear pattern suggests that these boulders were formed on rocks which had fallen into the lagoon from the fossil reef. The Watamu Coral Gardens are formed by such boulders. The second terrace lies near Blue Lagoon, just below the steep slope of the coquinas. To the south the second terrace lies farther from the shore. This marine terrace from the Gamblian period is covered with sea-grass meadow alternating with coral zones. Nearly two and a half kilometres from the coast the sea bottom declines steeply from a depth of 12 metres to a depth of 30 metres. Here the third terrace begins. This third terrace was eroded during the Kanjeran pluvial. It is covered with sand, so that this flat marine platform strongly resembles a submarine beach. The slope shows a fine coral growth.
Mida Creek. Mida Creek was formed during the Kanjeran pluvial, when the tidal current cut a channel in the emerged reef. Mida Creek is silting up, and the mangrove marshes were extending up to late the fifties (Thompson, 1956). Coral growth only occurs near the inlet, where the tidal current is strongest.

Whale Island. The most southern reef unit is situated south of Whale Island. The morphology is less clear, because the structure is disturbed by old creek beds. As a result no marine terraces can be distinguished. Along the fossil bank of Mida Creek coral growth appears on closely grouped boulders. The latter occur at a depth between 3 and 12 metres.
Chapter 3

METHODS

3.1 DEVELOPMENT OF THE APPLIED RESEARCH METHOD.

Introduction.

The development of the method is described in great detail because of the fol­lowing reasons.

The researchers participating in this study could not boast of a great experi­ence with this research matter. Unfamiliarity with the research area combined with the paucity in literature available on this kind of study, lead to a rather loose research framework.

This experimental character made it possible to test various methods described in literature. Modification of these methods with regard to the research area, and to the specific demands of the researchers, allowed a convenient handling of the posed problem.

A drawback of this experimental handling is perhaps that part of the gathered data are not as useful as was originally presumed.

Starting-point of the research.

The coral reef

The Malindi-Watamu reef complex, on which this survey is focused, is located in a strip with a width of 2 km, following the coastline for 25 km. Within this coral growth occurs in varying quantaties.

This reef is subjected to various influences that possibly caused the reef decay noted over the last few years. The influences that will be examined are: fishery, tourism, influx of terrestrial sediment, influx of fresh water and pollution of the sea by sewage. At the same time it should be examined if a wholesale increase of Acanthaster planci (a coral predator) could be the cause of decay as it has been on the Great Barrier Reef (Endean, 1973).

Research framework

To find a relationship between the influences as mentioned and the present condition of the coral growth on the reef a comparison has to be made between parts of the reef where a specific influence is expected and areas where it is not expected. At these sites imaginary lines are drawn at right angles to the coast. These lines were termed transverses. Under these infor­mation about species composition, abundance and condition of the coral can be collected by means of the most appropriate method.
The Malindi-Watamu reef complex lies for the greater part in a marine reserve. This reserve, which enjoys a low degree of protection embraces two parks with a higher level of protection. In these parks it is not allowed to fish; in the reserve this is only allowed when traditional methods are used. On the other hand only those two parks are frequently visited by tourists. In both cases most of the attention is paid to the Coral Gardens.

The Sabaki-river that carries the fresh water and the silt to the sea has its outlet north of the reserve. Judging from the longitudinal current it is evident that the influence of the river will be greater in the north than in the south.

Sewer outfalls and waste disposals may be expected near the two coastal villages Malindi and Watamu.

All this leads to the following transverse choice (Figure 14).

Figure 14: Transverse choice as planned in the research proposal.
Development of the research method

Tentative conclusions after a reconnaissance survey.

The model of a fringing reef cross section, as it is known in the literature consisting of three zones (the lagoon, the reef-flat and the outer slope (Battistini et al., 1975)) hardly fits this particular reef. The reef appears to have a complex structure and can be seen as a linked series of seagrass beds, sandflats, current channels, semi-fossil coral platforms and slopes (generally recognizable patterns are described in chapter 2). Concerning coral growth, however, there is no general pattern which is applicable for the whole reef or even the main part of it.

The research area can be subdivided into topographic units (see chapter 2.) A topographic unit enfolds a complex of coral growth. These coral complexes can contain narrow strips with coral boulders, long platforms and slopes overgrown with coral, and several semi-fossil platforms only with coral growth at the edges.

Within this rough framework there appear to be great differences between the coral communities of such a coral complex. The variation in coral growth is great and may consist of a few small colonies in an extensive seagrass bed, to a coral cover of about 100%. The coral growth also may vary from a few very large colonies (size 20 sqm each) to a large field extensively covered (<5 %) with small colonies (size <20 cm each).

Besides these general differences between communities, based on extension, coral coverage and predominant colony size, the community itself may also have a heterogeneous structure and coral growth pattern. Furthermore considerable differences in colony size may also occur.

Coral colonies may be affected in various ways. Not all colonies of a community are affected in the same way or to the same extent. Even if these colonies belong to the same species the extent and nature of the injury may vary considerably. If, in addition, it is considered that colony sizes may vary substantially, information on the colony as an individual is necessary besides data on the community (species composition and coverage).

Given that the above mentioned information is available, judgements may be made about tolerance of species for specific milieu influences and the specific effect of these influences with regard to site and species.

Finally, returning to the original research-framework, no sewer outfalls exist in the Malindi-Watamu area, and few specimen of Acanthaster planci were found. For this reason no further attention will be paid to these subjects.

Considerations on the line of research.

The transverse-concept, which assumes the presence of mutually comparable zones within these transverses, is not suitable for this particular reef. The coral complexes of which the reef is built up, are spread too much and are too irregular and small.

To fathom the character of the coral growth of this reef, the coral complexes have to be described separately by recording the coral communities of which they are composed.

The composition and condition of a community is recorded in a relevée. The relevée-method will be dealt with and described furtheron.

Although a community may extend over a large area within the complex, it is however not uncommon that the coral growth has a rather heterogeneous structure. This growth may be considered an array of communities, often with diffuse transitions in between. By carrying out three relevées in one area, and subsequently comparing the members of this triad mutually, an impression may be gained of the local homogeneity of the coral complex.
Considerations on the relevee method.
In the first place it is necessary to collect information on the composition and coverage of the species occupying the relevee site. Information on the nature and coverage of other bottom structures is also required. Furthermore it is necessary to gather information about the individual colony: species, size and nature and extent of possible injuries.

Seven methods have been described and compared in literature (Weinberg, 1981). However, the qualification and quantification of injuries and condition is not treated in these.

In short:

1. Individual Counting and Cover Estimate (ICCE): the colonies beneath a frame that is subdivided into equal squares, are determined; subsequently coverage per species is estimated and the number of colonies is noted.

2. Line transect (LITR): of all colonies beneath a measuring tape, species and length of the corresponding part of the tape is recorded.

3. Point Intercept Surface Method (PISM).

4. Point Intercept Lineair Method (PILM): this method, and the above mentioned PISM are based on the ICCE and the LITR, but only colonies beneath certain fixed sample-points (resp. intersections and on regular distances) are recorded.

5. Point Centered Quarter Method (PCQM): from a point chosen at random the nearest colony in all four quadrants is described with species name, size and distance from the sample point.

6. Photographic Record (PR): a method by which a transect is recorded by means of a series of photographs; with these photographs species composition and coverages are determined later.

7. In Situ Mapping (ISM): the coral colonies are determined and mapped in the site itself.

Comparison of these methods
On the utilization of these methods for this study the following may be said. The PR method is unsuitable for a number of practical reasons. Determination of corals from photographs is not reliable because some colonies may be hidden from view by others and because the water in the research area can be very turbid at times. Furthermore the method is very expensive and time-consuming, just like the ISM. It is also unlikely whether the gained information has to have such a very detailed character for the purpose of this study or not.

Soils in the terrestrial sense of the word, are often absent, as the seabottom material often consists of an unconsolidated array of sand and coral rubble.

This method is derived from the Braun-Blanquet method (Westhoff & Van der Maarel, 1975), used in phytosociology.
The PCQM provides very little detailed information, and the bottom in particular is not recorded. Also the PISM and the PILM provide too little detailed information, compared with the ICCE and the LITR of which they are derived. Therefore, only two methods, ICCE and LITR remain to be seriously considered. They both give their specific kind of information about species composition and coverage. Weinberg (1981), referring to the Caribbean area, determined that the ICCE provided reliable information whereas the LITR neglected species with smaller coverage (The probability of encountering a colony is proportional to its size.)

Considering the Watamu-Malindi Reef there is no reason to believe it would be different here, however the focus of this study is primarily aimed at dominant and therefore abundant species. These dominant species are considered most characteristic for a coral community. Thus the description and comparison of the examined coral community is mainly based on these species. The most important point of difference between the two methods concerns the description of individual colonies. The ICCE gives information about the number of colonies of each species in a relevé; and it gives also an estimation of the coverage of each species. If moreover each colony has to be characterized by its size and by nature and extent of possible injuries, it is going to be very time-consuming to make a relevé of adequate size. In fact, this would result in a very great resemblance to the ISM. Also of great importance is that the ICCE is hardly usable in undulating areas because of the frame. (The use of this frame will inevitably damage the coral.)

The used relevé-method is based on the LITR as described by Loya (1978). However this method is to be extended considerably. Besides the registering of the line intercept and species name of each crossed colony, an estimate of its size and its condition, by means of nature and extent of found injuries, is also to be recorded. Finally the nature and extent of the bottom types crossed by the line are to be registered as well.

The length of a line transect was considered adequate if after doubling the length no new species were added to the species list of the transect. Experiments on the Watamu-Malindi reef complex determined that a line transect of 10 metres provides a satisfactory description of the species composition. On grounds of these experiments outlined above line transects of 10 metres were used. To achieve a certain reliability on the information about the coverage of species, 5 line transects were placed parallel to each other, together forming one relevé.

The distance between these individual line transects was one metre. This distance is a compromise. On the one hand there is the effort to make a relevé as compact as possible to prevent confusion because of eventual heterogeneity of the coral growth. On the other hand there is the effort to prevent to describe the same colonies by neighbouring lines which would not add useful information to the description of the community.

3.2 DESCRIPTION OF THE CORAL GROWTH OF THE REEF-COMPLEX.

General reef description

Relevés, in which the coral communities are described, formed the building stones of the reef image. These coral communities, in turn, comprise the basis of the coral complexes; the coral complexes together form the total coral growth of the Malindi-Watamu reef complex.

In the first place the coral communities, on the basis of their description in relevés, were compared mutually to obtain an impression about variations and similarities in composition (chapter 4) and condition (chapter 5) occurring on
the reef. Based on similarities in species composition, a clustering of the coral communities was made. In the second place, the coral communities were put in a geographical and morphological context. This was done with the help of a topographical map of the reef, and observations on local characteristics of the coral growth and of bottom structure. The thus obtained reef image was extended with information about various environmental parameters. Connections between those parameters and the composition and condition were elucidated (Part III).

Relevee method
A coral community is described essentially by line transects. Nylon lines, marked every 10 cm, were draped straight over the coral. This line was weighted down with steel nuts, spaced at a distance of 1/2 m from each other to prevent moving of the line. Of all coral colonies crossed by the line, the following parameters were recorded.

- Taxon (genus, and species, where possible).
- Line intercept length.
- Maximal length and width of a vertical projection of the coral colony.
- Nature of found injuries, and an estimation of the part of the colony surface covered by each injury (by means of four injury scores, 1: 0-25%, 2: 26-50%, 3: 51-75%, 4: 76-100%).

The bottom types are described by their type (sand, rubble (coral grit) or massive semi-fossil coral) and by line intercept length.

In short, a coral community is thus described by a relevee consisting of 5 line-transects each with a length of 10 metre, placed parallel to each other at a distance of 1 metre (Figure 16).

Summary
Coral growth is recorded by the relevee method as five sequences of line intercepts. In every line transect the underlying coral growth or bottom type is recorded as a series of 'lengths', each with its own characterization. Every species name in the list of intercepts represents an individual coral colony of which possible injuries are registered by their nature and by an estimation of their coverage of the colony. Furthermore the size of the colony is described by two parameters (e.g. 40 cm Porites lutea, 85 x 45, black cracks 1, algae 1; 30 cm rubble; etc. to a total of 10 m). To obtain a description of the coral community as well as an impression of the homogeneity of the coral growth in the particular area, three relevees were carried out near each other. These three relevees together form a triad. Each triad was further characterized by information on depth, slope angle, exposition and a local description of the reef.

Criteria for the choice of relevee sites

Contribution to the reef description.
A (subjective) criterion for the selection of a relevee site was that the relevees at a particular site must contribute substantially to the reef image. In other words, sites that did not distinguish themselves from already described sites of the investigated coral complex were not sampled by further relevees. These relevees would not contribute to information on diversity within the coral complex, although they certainly might extend the reliability of already gathered information. However, because of the limited time and financial
range of the project, the Malindi-Watamu reef complex had to be characterized with the minimum number of relevee sites.

*Coral abundance.*
Considered as a possible relevee site, an area had to be dominated by corals (determined on subjective grounds). The coral cover per area unit had to exceed a certain level and the size of the area itself was bound to certain minimal dimensions.
(A relevee site was not chosen in areas that were sparsely covered with small colonies, and areas with only a few large boulders were also neglected in the relevee site selection.)

*Practical limitations.*
Various potential relevee sites were excluded on the grounds of three limitations.

1. **Depth.**
   A relevee site had to be described in a single dive, because it was extremely difficult to locate a site during a later dive. Therefore the available air supply was limited. Save a few exceptions no relevees have been made below a depth of 12 metre.

2. **Accessibility.**
Particular sites on the reef complex were inaccessible because of their location and because of financial consequences (petrol costs, boat rents). The available boats were furthermore rather unseaworthy, and risky ventures were avoided.

3. Local circumstances and security. Several sites that were considered for investigation, were excluded because of dangerous currents.

3.3 SIGNIFICANCE OF THE GATHERED INFORMATION.

The description of the coral growth derived from the relevee can be divided in five particular parts. This description is considered to be representative for the coral growth of the relevee and its direct neighbourhood.

1. Coral coverage and coverage of bottom types.
2. Coverage by coral of potential substrate.

3. Species composition, species diversity and coverage of each species.


5. Colony sizes.

ad 1. Coral coverage and coverage of bottom types.

The presence of a coral species in a plot can be expressed in various ways: number of colonies, number of polyps, surface dimensions of living tissue, weight of the calcareous skeleton, volume of occupied space, occupied surface area, occupied surface area where no other colonies can exist (branched species), etc.

All of these expressions are to a greater or lesser extent useful to describe coral growth, although every particular image will be biased in its own particular way.

The starting point of the line transect method is that the proportion of the total length of the transect intercepted by a species is correlated to the cover of that species (Greig-Smith, 1964). This also holds for other bottom types.

However, three notes have to be made.

The used method employed facilitates an enumeration of intercepts of the contours of the coral colonies (N.B. the line is draped over the colonies), not of perpendicular projections of the colonies.

Furthermore a branched colony is recorded by the intercept of the span of the entire colony (as if it is a massive colony); it is not recorded as a total of the intercepts of the branches. Therefore it is not an estimation of the projection of the colony that is provided but an estimation of the projection of the occupied surface.

Because of these and other transformations it is of great importance to consider the gathered data (sum of line intercepts per species per relevée) as a score expressing the presence of a coral species.

In this report it is in this sense that the term coverage is used.

ad 2. Coral coverage on potential substrate.

Coral settlement is not possible on sand or loose rubble. The coverage of potential substrate gives an impression as to how far substrate which is not unsuitable for coral growth is actually covered. This is expressed by the following ratio:

\[
\text{sum of the line intercepts of coral} \quad \frac{\text{-}}{\text{total line length reduced with intercepts of sand and rubble.}}
\]

This coverage of potential substrate gives insight into how far the environmental circumstances during the last decennia have favoured coral settlement and maintenance.

ad 3. Species composition and diversity of the coral are derived from the enumeration of species registered by the relevée. However one must bear in mind that species with a lower abundance have a greater chance to be neglected by the line transect method. Nevertheless, the emphasis within this

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* This term is explained in chapter 9.
research was laid on dominant species, making this shortcoming only a minor problem. Relative coverage of the species is estimated on the base of their corresponding intercepts.

ad 4. The nature and extent of injury of coral communities and of coral populations. The occurrence of each specific form of injury on the corals is described as follows. The extent of injury of a species and of an entire community is expressed by two ratios. They are respectively:

\[
\frac{\text{number of injured colonies of the species}}{\text{total number of colonies of the species}}
\]

and

\[
\frac{\text{number of injured colonies of the relevee}}{\text{total number of colonies of the relevee}}
\]

The stage of injury of a species and of the entire community is illustrated by the following ratios.

\[
\frac{\text{sum of the injury scores of all colonies of the species}}{\text{number of injured colonies of the species}}
\]

and

\[
\frac{\text{sum of injury scores of all colonies of the community}}{\text{number of injured colonies of the community}}
\]

ad 5. Size of colonies. The size of a colony was determined by recording the length and width of a vertical projection of that coral colony. The dimensions of the colony are related to its age. However, the growth rate of coral varies with the species and also depends on various environmental circumstances. Thus, unavoidable, correlations are based on fairly vague information. The subject is further discussed in chapter 6.
ASSIMILATION AND INTERPRETATION OF THE BASIC INFORMATION.

It is assumed that based on mutual similarity of at least three relevees, an adequate impression of the heterogeneity of the coral growth of a particular part of the coral complex may be given. Therefore the coral growth of each location was described by a triad of relevees. The relevees may be arranged according to their species composition and coverage of those species. Clustering of similar relevees provides a picture of the general variations in coral growth all over the reef. As a consequence, the species composition can be related to general differences in environmental circumstances on the reef.

The coral coverage and composition is determined by environmental circumstances, as these exert their influence on the reef during a longer period. The nature and extent of injuries of coral colonies add another kind of information to the reef description.

When the injured part of a colony does not lie below the surface of living tissue, this infliction may be regarded as recent, as the polyps adjacent to the site of injury have hardly grown any further.

One particular remark has to be made. No colonies with large injured invaginations have been found which indicates that an injured colony probably dies relatively quickly. It may be assumed therefore that the ratio between the number of affected colonies and the total number of colonies of a population or of a community, gives an indication about the extent of actual and recent changes in environmental conditions.

If, indeed, the injury is considered a consequence of actual environmental circumstances, the following items are of great importance.

- The ecological amplitude varies between the different species.
- The environmental change may act at different levels: colony, population (community), complex, the entire reef.

Still, it may be assumed that the condition of a population or a community and thus the condition of a complex and even the whole reef may be assessed from the condition of the individual colonies. Although it may be assumed that 'injury' (read: coating) of coral by algae and calcareous algae is a natural phenomenon (Benayahu & Loya, 1977), it may be considered a pathological phenomenon if it occurs frequently on the coral colonies. It is neglected whether the coral tissue is overgrown and thus seriously affected and weakened, or if this overgrowing occurs after the coral tissue has been weakened or died because of other circumstances. It has been proved already (Heys & Brouns, 1976) that such an injury expands at the expense of surrounding healthy tissue. More research on this subject is indeed necessary and valuable.

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7 A specific kind of injury has to be mentioned. Black cracks are slim, deep fissures in the colony surface. Apparently the colony is affected superficially by an injury, that ceased in an early, harmless stage.
Chapter 4

SPECIES COMPOSITION

4.1 INTRODUCTION

An assessment of the species composition and distribution of corals formed the basis for this study, and provided a means to characterize the coral reef complex between Malindi and Watamu. Grouping of similar coral growth stands served to give insight into the relationships underlying coral species composition and distribution. This in turn shed light on the causes of coral mortality, the elucidation of which formed the ultimate objective of this study.

Scleractinians (stony corals) only grow several centimetres per year. Endean (1973) has estimated that colonies of massive species might obtain a substantial size (10 - 40 cm in diameter) in 20 years from the time when the colony was initiated. However, it is unlikely that growth would be uniform from year to year. Indeed, it has been found that the initial rapid growth rate of a coral colony is followed by a slowing down, leading to an almost complete cessation of growth (Endean, 1973). The presence of Scleractinian colonies of a substantial size gives an indication of the environmental conditions over a large period of time, dating from the period of establishment up until the present time. In this period the environmental conditions must have remained favourable enough for the colonies to survive. So, while interpreting coral species composition, one has to bear in mind that the encountered species may not be the result of present environmental conditions, but may reflect a different past history. The absence of coral species, however, may be the direct result of present environmental conditions, as dead specimens are soon overgrown by algae, disappearing from view and decaying rapidly (Belk & Belk, 1975.) A diving observer may in this instance only register a 'potential substrate for coral establishment'. In general, however, the absence of coral species is the result of a long background history.

The total coral cover is also of great significance. The relative amount of potential sites that have been colonized successfully by Scleractinians may give an indication of the environmental conditions over the past decades. An area that only bears a sparse coral growth may thus indicate that the combination of milieu factors represented at that site were not optimal for coral growth in the past. A certain restraint is necessary here, as such a site devoid of a luxurious coral growth may have been the scene of a recent devastation (e.g. a tropical storm), leaving only a few remaining specimens and much 'open substrate'. In the latter case, it may be difficult to judge whether the environmental conditions are optimal or not.

A milieu factor that must not be overlooked is the substrate itself. Apart from a few exceptions, successful coral growth is only possible on a solid substrate (Endean, 1976; Pearson, 1981). It is thus important to relate coral coverage to the area of potential substrate.

In this chapter an attempt is made to arrange the species composition of the different relevées as conveniently as possible. These data have been arranged in five detailed tables, which are subsequently discussed. Furthermore, a generalized pattern of species composition is outlined, making it possible to tentatively draw relationships with a number of milieu factors.
4.2 ANALYSIS

A detailed description of relevee techniques and methods can be found in chapter 3. This part will deal with the taxa that are involved in the research and how they were identified. The study is for the main part confined to the order of the Scleractinians, the stony corals. These are the reef-building corals, which are elsewhere often termed 'hermatypic corals'. In the identification of the coral species the identification key given by Ditlev (1980) was used. Until recently, no useful field guide for identifying Scleractinians of the Indian Ocean was available. Ditlev's determination key allows an identification of all recent reef-building coral genera found in the Indo-Pacific, and a further identification of most of the common and ecologically important species. In most cases the corals were identified up to species level. However, for a number of corals this was not feasible:

The genus Acropora contains about 50 species, and has been subdivided into four growth-form groups in this study.

- Acropora formosa group: bushy, branched colonies, forming a dense shrub.
- A. hyacinthus group: a growth form varying from branching to tabular; finer in form and smaller in size than the aforementioned group.
- A. variabilis group: colonies are formed by numerous anastomosing (cross-connected) branches situated in one plane, often with the tips bent to a vertical position. Corallites are more spherical.
- A. echinata group: colonies are as the A. hyacinthus group, but the corallites are situated at the tip of long, slender thecae, projecting from the stems.

About 150 species of the genus Montipora have been described, but, as Ditlev (1980) states, 'the genus urgently needs revision'. The Montipora species have been lumped into two groups in this study: those with a foliar form, and the rest group, termed Montipora foliosa s.l. and M. spp, respectively. Of the genus Pavona only P. varians was identified up to species level, and the rest have been given the collective heading Pavona spp. The genera Goniopora, Lobophyllia, Pectinia and Fungia were furthermore not identified up to species level.

Two genera that do not belong to the Scleractinian order but are reef builders are Heliopora, of the sub-class Octocorallia, and Millepora of the class Hydrozoa. However, as the two genera are difficult to distinguish from each other, they are treated under one heading, 'Millepora'. The Alcyonacea, the so-called leather or soft corals, are corals that are not reef-builders (the a-hermatypic corals). Because of their abundance these soft corals were also registered in the course of this study. They are referred to as Alcyonacea coral formations in this report.

The primary analysis of all relevees together gave a too diffuse result to be of any use in reef characterization. A preliminary clustering was thus regarded as indispensible. The physiognomy of the coral growth was

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* In the tables that are presented at relevee level, these two groups have been taken together.
* For a list of all species encountered in the study area, see the appendix.
considered a useful criterion for this purpose, as in an analogue way, in the field of phytosociology, structural differences between adjacent vegetation types may be recognized as a basis for distinction, in spite of the occurrence of many species common to both. Thus, the preliminary clustering was carried out on the basis of a similarity in reef structure. The structure of the reef complex is characterized by much variation, as has already been outlined in chapter 2. Reef morphology may vary from very rugged to very flat. Relevees that are similar in these morphological characteristics were grouped into 'coral formations'. A coral formation is defined as a unit of coral growth that displays a certain uniformity in its external physiognomic appearance. Five such coral formations were distinguished:

- **Boulders**: Coral growths belonging to this coral formation display large differences in height. Coral colonies or groups of colonies up to 4 metres high and several metres in circumference, interspersed with sand, rubble or seagrasses, may be found. The boulder formations are primarily situated in lagoons or on the first submarine terrace (see chapter 2).

- **Boulder massive**: As with the previous formation, coral growth belonging to this formation has a rugged appearance, though the differences in height are not as pronounced. The coral 'heads' are furthermore closely grouped, giving the whole a unified appearance, that does not appear to be intersected by gaps of sand, rubble or seagrass. Most boulder masses seem to occur on the undulating slopes between the first and second submarine terrace.

- **Platforms**: This coral growth is situated in areas that are virtually flat. These areas are characterized by rather flat fields of coral growth. Platform formations lie between the first and second submarine terraces, and on the second submarine terrace.

- **Slopes**: Coral growth belonging to this formation is situated in areas characterized by a slope of more than 45 degrees, and are found in waters no deeper than eight metres.

- **Deep slopes**: Six relevees were made on a slope at a depth of 20 - 25 metres, between the second and third submarine terraces near Watamu. The third terrace generally lies at quite a distance from the coast, except in the Turtle Bay area, near Watamu.

**Numerical analysis**

The numerical analysis was carried out with the aid of two computer clustering programmes: Flexclus, used for tables 1 to 4, and Twinspan, used for table 5. Flexclus is an interactive clustering programme, principally based on relocative centroid sorting (Van Tongeren, in prep.). Twinspan is a divisive clustering method, based on the partitioning of the reciprocal averaging ordination space (Hill, 1979; Hill, 1980). The relevees of the abovementioned coral formations were arrayed according to these programmes.
4.3 RESULTS

The map of the Malindi area in the back envelope of this report shows the most conspicuous reef features up to a depth of approximately eight metres (Appendix F). These are:

- seagrass (Thalassodendron ciliatum) dominated areas
- coral dominated areas
- unconsolidated sand
- fossil coral rock.

The coral dominated areas run parallel to the coastline and are very small. Coral growth primarily occurs only in the lagoons, and on the gentle slopes leading down to the second submarine terrace. Coral growth in the study area was registered in a total of 126 releves. These releves are displayed in a clustered form in the tables below. The most striking details of these tables are subsequently described and explained, where possible. In 4.4 and 4.5, general patterns are outlined and the possible inter-relationships are proposed.
Table 2: boulder formations

Table 3: boulder massive formations
Table 4: platform formations

| Species composition | 47 |
Table 5: slope formations

Table 6: deep slope formations
Boulder formations

Striking in Table 2 is the division between relevées taken in the northern part of the study area, near Malindi, and those taken in the southern area, near Watamu. In the Watamu clusters (I and II), the foundation of the boulder formations are formed by Porites lutea colonies. In the northern area this foundation is formed by P. lutea, together with Goniastrea retiformis, whereby the latter usually dominates. In this context it is interesting to note that in triad 36, in Watamu, Goniastrea retiformis colonies are also an important feature of the boulder foundation. It is also not surprising that this area, with its diverse boulder structure, is termed the 'Coral Gardens' of Watamu Marine National Park 10.

The Watamu clusters (I and II) are dominated by Montipora spp. in I, a role that is gradually taken over by Astreopora ocellata in II. The 'constant companions' 11 accompanying these dominant species are Favia favus and Pocillopora damicornis.

The Malindi area is also dominated by two boulder clusters. The first of these, no. III, displays a high species diversity, with an average of 19 species per relevée. The boulder foundations are similar to that of triad 36, consisting of a combination of Porites lutea and Goniastrea retiformis. This cluster III however, distinguishes itself by a presence of Alcyonaceans and Hydnophora exesa. As was the case in the Watamu clusters, Astreopora ocellata and Montipora spp. also occur, though in lesser frequency. The last cluster, no. IV, is dominated by Goniastrea retiformis colonies. Porites eridani, Pocillopora verrucosa and Acanthastrea echinata are species that are characteristic for the Malindi cluster, but also occur in triad 36, in the Watamu cluster. Stylophora pistillata is exclusively encountered in the Malindi area. The most northerly boulder zone relevées of the Watamu area, off the coast near the beach hotels (triad 29), have been deleted from this table. The presence of Montipora spp. and the boulder foundations consisting of Porites lutea agrees with the other relevées of the boulder zone. However, due to the very low species frequency (high sand cover) and the heterogeneity of the three relevées, this triad has been placed outside the 'boulder category'. Relevée 107 (triad 36) falls outside this category due to a low cover of both Montipora spp. and Astreopora ocellata. Triad zero of the 'shallow platforms' table has been added to this table, because it is dominated by Goniastrea retiformis. Triad 0 does not fit comfortably in the Malindi cluster, because of its high Montipora spp. cover, and the absence of Pocillopora verrucosa, Stylophora pistillata and Acanthastrea echinata.

Boulder massives

Acropora hyacinthus-grp and Montipora spp. are species that are abundant in all boulder massives (Table 3) Galaxea fascicularis is furthermore present in all relevées of this table, but is less common than the aforementioned species. Millepora spp. and Porites eridani generally also occur, and members of the Faviidae and Acroporan genera are both reasonably well represented. A large cluster is formed by the triads 11, 39 and 41. The creeping species, Echinopora lamellosa, dominates the relevées of these triads, and is further accompanied by the tabulate Acropora variabilis-grp and the 'brain coral'.

10 The Coral Gardens owe their attraction for tourists not only to the species diversity or the high coral cover encountered there, but also to the 'swimming-pool circumstances' dominating this area. The waters are calm and shallow, making this area ideal for snorkeling and swimming, and for viewing corals from a glass-bottomed boat.

11 'Constant companions' is a phytosociological term used in vegetation science (Westhoff & Van der Maarel, 1973).
Leptoria phrygia, both with a lower coverage. This cluster II displays a large species diversity. The first and third cluster are very similar to the second. However, they are poorer in species (esp. cluster I), and have much larger coverages of Alcyonaceans and Porites lutea (and Pocillopora verrucosa to a lesser extent). The first cluster also differentiates itself by the presence of Stylophora pistillata and a lower abundance of Pocillopora verrucosa, characteristics that are shared with the fourth cluster.

The lower abundance of Platygrya lamellina, Astraeopora ocellata and Porites lutea, and the strong dominance of Goniastrea retiformis in the fourth cluster is striking. Acropora formosa-grp is its constant companion, though with a lower coverage. Cluster IV consists of relevées 61, 62 and 63 and triad 21. This latter area is more strongly subjected to tidal currents than the other triads of this coral formation due to its location near the entrance of the natural harbour of Mayungu village. In the boulder formations Goniastrea retiformis dominance was also encountered in the more turbulent waters, and Porites lutea dominance occurred in sheltered waters. From this angle it is not surprising that triad 20 (of cluster I) strongly differs from triad 21, although they are situated quite close to each other.

The fact that triads 11, 39 and 41 show much similarity in their species composition is rather striking, as the distance between triad 11 on the one hand (Malindi) and 39 and 41 on the other hand (the most southerly part of the Watamu area) is great.

Platforms
Table 4 appears to be rather chaotic, and a prima facie impression is that a much better arrangement could be achieved if further shuffling were carried out. A careful inspection, however, reveals that the relevées of the platforms are very interwoven as far as species composition is concerned. The clusters do not differentiate themselves to any great extent. The dominant species for all platform relevées, except for those of triad 40, are Montipora spp. and Alcyonaceans. In triad 40 the Alcyonaceans are virtually absent, and Physogyra lichtensteini occurred. This latter species is very rare in the study area, and was only encountered in triad 40. Apart from the dominant species, Favites abtida and Galaxea fascicularis are also constantly present, though with a lower coverage. In general one may state that species of the Faviidae family are well represented. The cluster classification reveals the following:

The first cluster is formed by triads 34 and 37. Triad 37 is a shallow water platform (depth 2m) that lies close to the surf zone. Cluster I differentiates itself quite well from the other clusters by a constant presence of Pocillopora damicornis, and the absence of Porites eridani, Porites lutea, Platygrya lamellina, Astraeopora ocellata and Pocillopora verrucosa. Species of the Faviidae family are also poorly represented. Stylophora pistillata is common in clusters I and II, but only occurs once in the other clusters.

When the spatial distribution is regarded, one may observe that relevées of cluster II virtually only occur in the Malindi area. All relevées of this cluster furthermore only occur in very shallow waters of less than 3 metres in depth, and are rich in species (17 species at average). Characteristic of this cluster is further that Goniastrea retiformis and the (less conspicuous) large cover by Millepora spp. Acanthastrea echinata is less common, and Goniopora spp. more common than in the other clusters of this formation.

The third cluster has no clear characteristics. The fourth cluster has a higher cover of Astraeopora ocellata, Acanthastrea echinata, Favia favus and Hydnophora exesa than the other clusters. Lobophyllia spp. only occur in this cluster of this formation. The occurrence (in triad 38) of Tubastreae coccinea, a bright red coral species that is very rare along this coast is also striking. Both clusters III and IV, apart from a single exception, consist of relevées that were taken at depths of more than 3 metres.
A number of relevees have been placed at the end of Table 4, that fit uncomfortably in the 'platform table'. In most cases the incongruity was due to a striking dominance of one or more species, differing from the rest of the table. Triad 3 consists of three totally different relevees, dominated by Lobophyllia spp., Hydnophora exesa and Galaxea fascicularis, respectively. The domination by Lobophyllia spp. and Galaxea fascicularis is most pronounced. The heterogeneity of triad 3 may be ascribed to the exceptionally large colonies, that may exclude each other in our relevee sampling method (see ch. 6). Relevee 50 (triad 17), two relevees of triad 23, and triad zero have dropped out of the table due to a dominance of Galaxea clavus, Porites eridani and Goniastrea retiformis, respectively. Because of these dominances, the first has been placed with the slopes, and the last have been added to the 'boulder table'. Relevee 113 of triad 38 falls outside the table due to the dominance of a Pavona species (probably P. explanulata). Pavona also occurs in lesser amount in relevee 112 of triad 38, but due to the absence of Porites lutea and Echinopora lamellosa relevee 113 could not be placed with the latter.
Slopes

The mass occurrence of branching Acroporan species (especially of the Acropora formosa-grp) (Table 5) is characteristic for these relevées. This abundance of Acropora may explain the enormous amount of 'coral gravel' on the sea bottom in these formations. Between these Acropora branches lie Fungia spp. corals, which are characteristic and common on this substrate.

The picture formed by this table is that of a reciprocal relationship between Acropora formosa-grp and Galaxea clavus, a pattern that seems to coincide with that of water turbidity in the area. The slopes of the inshore side of North Reef (Malindi, triads 9 and 12) are characterized by Acropora formosa grp dominance, and the presence of Pavona species, Psammocora contigua, Favites abtida and Porites lutea. Rosen (1971) found Psammocora contigua and Pavona frondifera together in his Porites assemblages, which he describes as being characteristic for calmer waters. These two species are, however, not found in triads 7 and 10, which never the less show a definite Acropora formosa-grp dominance.

These triads are exposed to the open sea, and are characterized by the presence of Galaxea clavus, G. fascicularis and Echinopora lamellosa. Triads 14 and 16 (at the southern end of North Reef, and Tewa Reef) are exposed to the strong currents in the narrow 'Stork Passage', and show an outspoken dominance of Galaxea clavus. Apart from one exception, the species diversity in these relevées is very low. That many other branching coral species occur in the relevées apart from the branching Acroporans is striking in this table. The branching genus Pocillopora is conspicuously present, being represented by P. verrucosa and P. damicornis. On these slopes the branching corals may be said to dominate, while the Faviidae corals are poorly represented.

Relevées 64, 65 and 66 of triad 22 and relevée 50, on Leopard Reef, have been added to this table. Both areas are platforms, but fit well within the slope formation, and have been added on basis of this affinity. Triad 22 belongs to the Acropora formosa grp. cluster, with the exception of relevée 64, which is not dominated by Acropora formosa grp., and has a high cover of Fungia spp. It is interesting to note the presence of the delicately branching Seriatopora hystrix and members of the Acropora echinata-grp. Relevée 50 has a definite Galaxea clavus dominance and can be thrown in with this formation on this basis. It is also characterized by a relative paucity in species (only 12). Triad 22 lies close to the entrance to the natural harbour of Mayungu, an area which is identical in current conditions to Stork Passage. This could explain the slope characteristics of the coral growth of these platform formations.

Deep slopes

Both triads (Table 6) lie at a depth of about 23 metres, while no other relevées were recorded at depths of more than 11.5 metres. As one would expect on the basis of this difference, these sites differ from all other sites. Both triads lie on the slope between the second and third submarine terraces, in the vicinity of Turtle Bay, near Watamu. In this area the third terrace lies only 2.5 km from the coast.

High species diversity (a total of 40 species!) and the occurrence of a number of species that were not encountered elsewhere in the study area: Echinophyllia aspera, Oxyypora lacera and Pectinia spp. is striking. Pachyseris rugosa and Mycedium elephantotus both occur only sporadically in other relevées, but occur in all relevées of this formation. Pachyseris rugosa is reported by Sheppard (1980) to be a coral species characteristic of deeper waters, as are both Oxyypora lacera and Echinophyllia aspera. Alcyonacea are

\[12\] An additional explanation is also offered by strong water movement occurring on these slopes, that tends to "wash out" finer particles.
abundant in these relevées, but other species are probably involved than were encountered in shallower waters. Montipora spp. (a foliar species) and Fungia spp. are both common, but with a lower cover than in other relevées. One last characteristic that distinguishes this formation from the others is that both the Faviidae family and the genus Acropora are poorly represented.

4.4 SYNTHESIS

Within the field of reef ecology little is known about the sites where corals are found. This makes local and regional comparisons of coral communities a hazardous undertaking. Rosen (1971, p. 166) states on the matter that:

"it is a striking fact that after more than a hundred years of reef study, no really detailed comparative synthesis of coral ecology, based on representative reefs from most regions, has ever been attempted".

One of the major difficulties that has hampered this development has been the lack of a generally comprehensible set of terms. These are essential if areas are to be compared successfully, and generalizations within coral ecology are to be developed. According to Stoddart (1969) the lack of a consequently employed terminology lies at the root of this problem. From the early seventies onwards, however, a number of authors have turned to the field of plant sociology, where similar problems were once encountered (Clements, 1928), but now seem to have been overcome (Miles, 1979). Rosen (1971) has developed a terminology for coral ecology that is analogous to that of plant sociology, recognising the following terms:

- Community: is a term that is used for the whole fauna
- Coral community: is a community that is dominated by corals
- Facies: corals that occur only in local concentrations within a community, which is otherwise made up largely of other organisms
- Elements: corals are only represented within the community as inconspicuous animal elements

An assemblage is a term used by Rosen that embraces the last three levels of order listed above. Assemblages (=collections) are grouped into a number of types. Each type is represented by a 'principal coral community', that consists of a combination of the most representative coral species. Rosen further warns, however, that the recognition of a principal coral community may create a wrong impression about the role of that group of species within its surroundings. He furthermore states that the term 'principal coral community' may not be strictly applied, but that each coral species must consistently be regarded in relation to the other coral species. After his primary surveys in the Seychelles, Rosen concluded that: "Application of the concepts and methods of plant sociology makes it possible to compare coral stands more effectively, and hence to define assemblages and roles within the communities" (Rosen, 1971, p. 181).

An application of Rosen's approach, as was outlined above, leads to the following classification (for an overview see Table 7).
Table 7: General table: all triads united in one table.
Boulder formations in the lagoons and on the sheltered parts of the reef all have a boulder foundation that is primarily built up out of Porites lutea. In Rosen's terminology this formation may be termed a Porites assemblage (Figure 17). Apart from this species, Galaxea fascicularis, Acropora hyacinthus-grp., Echinopora lamellosa and Millepora spp. may be regarded as members of the principal coral community. In the Malindi area, Goniastrea retiformis is co-dominant with Porites lutea in these boulder formations, a phenomenon that was not observed in the Watamu area.

Boulder massive formations display a high degree of similarity with the boulder formations as far as species composition is concerned. Once again, Porites lutea dominates, and one may speak of a Porites assemblage. If the table is generalized, we arrive at the same principal coral community as with the boulder formations, consisting of Porites lutea, Galaxea fascicularis, Acropora hyacinthus grp., Echinopora lamellosa and Millepora spp., with the exception that Montipora spp. must also be included in this group.
The platform formations show the same pattern as both previous coral formations. Next to the encrusting Montipora spp., Porites lutea may be observed to be co-dominant. However, these Porites specimens are not boulder forming, and consist primarily of small and flat colonies. The principal coral community consists of Montipora spp., Acropora hyacinthus-grp, Millepora spp. and Galaxea fascicularis, and furthermore of species of the genus Porites and the Faviidae family, as these prevail in platform formations. The Faviidae are richly represented, including, amongst others, Favia speciosa, Favia favus, Favia maxima, Favia stelligera, Favites abtida, Favites chinensis, and Favites russeli.

Slope formations are subjected to strong water motions, that have a definite influence on the species composition. Here we may speak of an Acropora assemblage (Figure 18). The principal coral community is composed of Acropora formosa grp., Acropora hyacinthus-grp and Fungia spp.. A number of other species may also be included in the principal coral community. In the first place the genus Galaxea must be mentioned. Slope formations are strongly represented by G. fascicularis, and exclusively represented by G.
clavus. Further representative species are branching corals such as Pocillopora verrucosa, P. damicornis, Porites eridani, Stylophora pistillata and Millepora spp.. The low cover of species of the genus Montipora is striking, compared to the other formations, and the genera Favia and Favites are virtually absent.

The deep slopes distinguish themselves by the presence of Pachyseris rugosa. Conforming with Rosen's terminology, one may state that the coral growth of the deep slopes forms a Pachyseris assemblage. Coral species of the principal coral community are Pachyseris rugosa, Mycedium elephantotus and Oxypora lacera. Numerous other foliar species, such as Echinophyllia spp., are exclusive for these areas.

In summary, three assemblages may be recognised in the study area:

1. the branching ACROPORA assemblage, in turbulent waters
2. the foliar PACHYSERIS assemblage, on deeper slopes (> 20m)
3. the massive PORITES assemblage, in shallow, calmer waters

Two coral formations are thus characterized by their own distinct species, namely the deeper and shallower slopes. The differences between boulder, boulder massive and platform formations are not based on differences in species composition. Evidently the physiognomic differences between these three are not displayed in the species composition. Variations in the Porites assemblage will be dealt with later.

Numerous authors have discovered that the most important coral communities are related to the 'prevailing water movements' (Lewis, 1968; Taylor, 1968; Rosen, 1971). The three assemblages found in the Malindi-Watamu reef complex may be partially associated with the water movement factor (see Figure 19).

Especially the difference between the Acroporan assemblage on the slopes and the Porites assemblage in shallower, calmer water, is based on this factor. Porites species thrive under calmer circumstances, and are reknown for their tolerance of variations in the abiotic environment (Taylor, 1968; Kinsman, 1964). They are well able to withstand the fluctuations in temperature and salinity that often occur in shallower, inshore waters. The absence of Porites species, for example on the slopes, can thus only be explained through the mechanism of a less successful competition by Porites for available growing space. Acroporans are fast growing, and are also able to repair damages quickly (Schumacher, 1975). Taylor (1968) suggests that the fast growing Acroporans prevent the successful colonization by Porites species and members of the Faviidae family, in areas with a good water circulation. In calmer waters water circulation is usually insufficient for a strong growth of branching corals, especially the strongly ramified Acropora formosa-grp (Rosen, 1971), and they lose their dominance. However, on the slopes, the dominant position of members of the genus Porites is taken over by the Acroporans, and hence the Acroporan assemblage on the slopes.

The importance of water movement as a determinant of coral species composition is also demonstrated by the differences between shoreward and seaward slopes. The triads on the shoreward side of slopes (e.g. triads 9 and 12) show a different coral growth than that of the seaward slopes (e.g. triads 7, 10 and 14). The former are characterized by the occurrence of species of calmer waters, such as Porites lutea, and facies of Pavona and Psammocora, along with the characteristic Acroporans. This is similar to what Rosen (1971)
found on sheltered slopes. The more exposed, seaward slopes are dominated by Acropora, Galaxea clavus and other branching species, all of which are characteristic for areas with rough water movements. Galaxea clavus is able to manage well on these turbulent slopes, and is also an aggressive competitor in the struggle for living space (Sheppard, 1980). This may explain the high cover of this species that is encountered on slopes with a very low species diversity.13

13 Branching species may also be favoured in turbulent environments because of their relatively low water current resistance compared to other growth
The importance of water movement is also evident from triad 22, that was originally classed with the platform formations on the basis of reef physiognomies. The species composition, however, is similar to that of the slopes. As triad 22 lies near to the entrance of the natural harbour of Mayungu, where strong currents occur, this is not surprising.

On deeper slopes other factors than water movement are decisive for coral growth. At these depths of more than 20 m light becomes limiting for coral growth, and especially foliar growth forms are encountered, growing as overlapping plates. Sheppard (1980) interprets this latter phenomenon as an analogue to plant growth: corals try to trap as much light as possible by increasing their area in these deeper waters.

In Figure 20, triads have been grouped in a two-dimensional plot by means of a so-called DCA ordination. The Pachyseris and Porites assemblage on the left hand of the figure represent calmer waters, and the acroporan assemblages on the right hand represent rougher waters. The horizontal x-axis may be regarded as representing an increase in water movement, from left to right. The greater part of the coral growth in the study area, measured on the basis of cover, falls in the category 'Porites assemblage'. The sub-assemblages that may be recognised within the Porites assemblage will be dealt with below.

The first group (I in Figure 20) that may be recognised within the Porites assemblage embraces triads belonging to the platform formation. Apart from Porites lutea are Acropora hyacinthus-grp and Montipora spp. (see Table 7) dominant. This group will further be referred to as the Montipora - Acropora hyacinthus sub-assemblage (Figure 21). As both platform formations in Malindi and Watamu are represented in this group, one may conclude that the geographical position of sites plays no great role in this area. It is also striking that relevées of the Watamu triads were taken at greater depths than those of the Malindi area. The relative coral cover of potential substrate is also significantly lower in Watamu than in Malindi, and will be discussed in greater detail in chapter 7 and 9.

The second sub-assemblage consists of all triads of the Watamu boulder zone, a Turtle Bay triad, and one taken in the Blue Lagoon. Apart from these, the platform to the south of Whale Island may also be included in this group. Astreopora ocellata plays a dominant role, next to Porites lutea and Montipora spp., and this group may be classed as the Astreopora sub-assemblage. The very low coral cover, and sometimes the total absence of Acroporans is striking. As is evident from the plot (see Figure 20) these areas form the direct antipode to the turbulent slopes. Areas belonging to the Astreopora sub-assemblage are probably the most serene parts of the Malindi-Watamu reef complex, as far as water movement is concerned. Stylophora pistillata is furthermore absent, and Favia favus is strongly represented.

The third group (III in Figure 20) that may be recognised within the Porites assemblage embraces all the boulder triads of Malindi, except triad zero, that exhibits a platform structure. This group is characterized by Goniastrea retiformis, and is thus referred to as the Goniastrea sub-assemblage. Apart from Goniastrea retiformis and of course Porites lutea, Hydnophora exesa and Lep-toria phrygia abound, and play a significant role in the boulder structure of these areas.

Finally triads 11, 39 and 41 may not be regarded as 'platforms' or 'boulders', and are thus found in an intermediate position in the plot. These triads probably have a nucleus function of the Porites assemblage since this assemblage is very well developed in these triads. This optimal development is forms such as foliate or tabulate.

This agrees with what Rosen (1971) found on Mahe, the Seychelles.
Figure 20: DCA ordination diagram of the triads. (DCA = Detrended Correspondence Analysis; The axes are scaled in standard deviation units (Hill, 1980))
recognisable on the wealthy coral growth with a large species diversity, averaging 30 species. The Porites assemblage is thus sub-divided into three sub-assemblages:\(^\text{15}\):

1. The Montipora - Acropora hyacinthus sub-assemblage (I)
2. The Astreopora sub-assemblage (II)
3. The Goniastrea sub-assemblage (III)

\(^\text{15}\) These three sub-assemblages do not agree with the three formations belonging to the Porites assemblage.
These variations within the Porites assemblage have been brought about by water movement, the most conspicuously controlling environmental factor, and especially by the different ecological side-effects brought about by these water movements. This will be discussed in chapter 8.

4.5 **ALCYONACEA**

A very conspicuous phenomenon that has been neglected up to now is that of the occurrence of Alcyonacea, the 'soft corals'. Soft corals are characteristic secondary colonizers, that require a solid calcium carbonate substrate (Schumacher, 1975). Soft corals grow three to five times as fast as stony corals, but under normal circumstances their role on coral reefs is limited (Schumacher, 1975; Benaya and Loya, 1977). On the Malindi-Watamu reef complex, however, these Alcyonacea are very abundant. At average 8% of each sample area is composed of a cover of soft corals, and this figure may even be as high as 48% (triad 1)\(^{16}\) This profusion is contrary to what is observed in most other areas. On the Great Barrier Reef, for example, the cover of soft corals is negligible (Endean, 1973).

The abundance of soft corals found by Schumacher (1975) in the Suez Gulf (Red Sea) were ascribed to their ability to tolerate turbid water conditions. He found that Alcyonacea are able to withstand two to three times as much sedimenting material as the stony corals. This ability may be explained by their high mucus production, and especially by their high flexibility, which results in a shaking-off of gathered sediment. These mechanisms would thus favour soft corals above stony corals in turbid waters (Schumacher, 1975). Hong and Sasekumar (1979) found that soft corals also dominated in turbid waters off the Malayan coast. In these areas, visibility varied between 2 to 7 metres, as was measured with a Secchi-disk. These authors also ascribed this abundance of soft corals to the ability to tolerate sediment. Apart from the numerous Alcyonaceans, the following coral species were also found to be abundant: Porites lutea, Favia speciosa, Favites abtida, Goniastrea retiformis, G. pectinata, G. benhami and Platygryra lamellina. These coral species possibly possess a cleaning mechanism that enables them to remove sediment by mucus secretion or 'ciliary action' (Hong and Sasekumar, 1979).

It would appear that the abundance of soft corals on the Malindi-Watamu reef is caused by the same abiotic factor that is responsible for their abundance in the Suez Gulf and off the Malayan coast\(^{17}\). A similar situation is encountered in the case of the stony corals. The principal coral community of the Porites assemblage is similar to what Hong and Sasekumar (1979) found off the Malayan coast. Endean (1976, p. 229) confirms the assumption that these corals are tolerant of sediment, as he states that:

"species belonging to the genera Favia, Favites, Leptoria, Platygryra, Goniastrea, Symphyllia, Goniopora and Fungia appear to be most resistant to the effects of siltation."

And further (p. 227):

\(^{16}\) Most are of the genus Sarcophyton (Hamilton, 1975).

\(^{17}\) Visibility measured on the Malindi-Watamu reef was found to vary between 0.8 and 24 m during the north-east monsoon, when the most turbid conditions were encountered (Giesen & Van de Kerkhof, 1984).
"Acroporans, particularly the tabular Acroporans, A. hyacinthus and A. corymbosa, are especially susceptible to the accumulation of fine sediment."

Sedimentation of fine silt has probably influenced the species composition of the Malindi-Watamu reef complex. The Porites and Pachyseris assemblages are threatened to be smothered, both in a literal and figurative sense, by Alcyonacea. Corals that possess an effective cleaning mechanism may survive longer under a constant rain of sediment. However, a high percentage of colonies of those corals present may eventually succumb to this constant sedimentation as happened in waters near Magnetic Island, Australia (Endean, 1976).

The absence of soft corals in the Acroporan assemblage may be a further indication that little silt accumulates in these areas. The 'rough water' environmental conditions under which the coral growth of the Acropora assemblage flourishes may thus prevent the rain of suspended matter.

In summary, one may state that coral growth of the Acropora assemblage displays little or no disturbance, whereas that of the Porites and Pachyseris assemblages is disturbed. The latter is indicated by anomalies in the species composition, centering on the Faviidae and the Alcyonacea.
Chapter 5

CONDITION OF THE REEF.

5.1 INTRODUCTION

In the previous chapters, several environmental factors responsible for the establishment and growth of corals were discussed. It was argued that the favourability of these factors in a given area can be established by assessing parameters such as coral quantity, effective use of the available substratum, and the species composition. The time-scale on which one should interpret these environmental data can also be assessed.

Apart from these normal factors governing coral growth, there is the phenomenon of coral mortality and disease.

One can say that, when coral colonies are found to be over-proportionately injured in a certain area, this may be regarded as a more or less direct reaction to recent, unfavourable changes in environmental conditions (see chapter 3).

Before dealing with the results we would first like to elaborate on the terms 'character' and 'amount' of coral injuries. These are dealt with below in the following paragraphs. Finally an attempt is made in this chapter to gain more insight in the different environmental conditions, both in respect to different reef localities and in respect to different coral species.

The injuries are thereby used as an indicator.

5.2 METHODOLOGY

5.2.1 Character of the injuries

During the collecting of the data we regarded a coral as being injured, when part of the colony had died off or was clearly suffering from a certain stress. For example if part of the colony had been devoured, typical white spots (see 'pale tissue'), broken pieces of coral, etc. The injured or dead part of the colony was often overgrown by algae, in some cases either calcareous or with a filamentous thallus. In that case the injury was noted as such.

Because of the general plan of the research project and the working conditions under water, it was impossible to determine the exact character of every injury over and over again. Eventually the types of injuries were classified into 5 main types which will now be briefly discussed.

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18 On every colony in the relevées we looked for possible signs of injuries. In a number of cases it was difficult to distinguish between the different types of injuries. For more detailed information see chapter 3 and the paragraph about quantity of the injuries in this chapter.
Algae
As algae are of course a normal and very common phenomenon on reefs (Benayahu & Loya, 1977), a coral colony was only regarded as being injured by algae if it was very clearly overgrown (Figure 22). Algae were often found growing on scleractinian corals and occurred at least once on practically every species in the area. Some abundant algal species growing on coral were Padina spp. (Phaeophyceae), Ulva reticulata, Ulva fasciata, Ulva lactuca (Chlorophyceae) and Lyngbya spp. (Cyanophyceae). Typical but less frequent occurring algal growth forms on coral were crustose coralline algae and filamentous algae. Crustose coralline algae often appeared in calcareous layers (1-2 mm thickness) on coral colonies, usually on top of them. The filamentary algae often looked like 'cobwebs', draped among often still living coral branches (Figure 23).

Figure 22: Porites lutea with an algal coating.

See also chapter 1.
Coral has a natural defence mechanism against the settling of, for instance, various micro-organisms and fine silt, by means of a slime layer (Yonge, 1963; Loya, 1976). Generally it can be assumed that a weakened condition of a coral colony will weaken its resistance against algal settling and its silt defence mechanism (Loya, 1976). Sedimentation of silt will facilitate algal settling and thus enhance decay. Also nutrient enrichment of the environment stimulates algal growth. Possible sources of eutrophication may be formed by the Sabaki River, Mida Creek and the townships in the area.

Figure 23: Millepora with filamentary algae.
'Black cracks' (Figure 24)
'Black cracks' are literally what the name implies, namely dark sunken spurs, devoid of living tissue. Many of these were probably caused by the dying off of a row of polyps on a colony as a consequence of, for example, predation. The rest of the colony remains undamaged and continues growing, thereby leaving the 'cracks' as slightly sunken spurs often overgrown by algae.

Figure 24: Typical 'black crack' on Goniastrea retiformis.
'Pale tissue' (Figure 25)
As a consequence of unfavourable conditions (light stress, fresh water stress, temperature stress, food stress etcetera) the colony or a number of polyps may undergo a metabolic shock. The Zooxanthellae that live in symbiosis with the coral, can be expelled whereby the polyps lose their colour (Mann, 1982). In that case the colony as a whole can turn white or it shows white spots on its surface. When the environmental conditions improve, the coral may again take up Zooxanthellae. If not, it dies after a period of time and is swiftly colonized by algae on the injured parts of the colony (Belk & Belk, 1975).

Figure 25: 'Pale tissue' on Favia speciosa.
Mechanical damage  (Figure 26)
By this is meant all kinds of breaking or crumbling of coral fragments or colonies as a whole. This may be caused by:

- storms, wave activity, etcera
- boring organisms e.g. several molluscs, sponges or polychaetes
- senescence: older colonies fall apart, possibly aided by boring organisms
- human activity

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Figure 26: Mechanical damage on Galaxea fascicularis.
Predation (Figure 27)
On coral colonies one may often see traces of predation. One of the main predators is the parrot fish (Scarus spp.) (Randall, 1974) which leaves a typical pattern of two scratches. Parrot fishes digest the living tissue of the coral and transform the calcareous skeletons into coral sand. According to estimations a single parrot fish produces more than a thousand kilograms coral sand a year (Bakus, 1964). Another predator is the butterfly fish.

Figure 27: Beak-marks on Hydnophora exesa.
Sporadically we found coral colonies that were partially dead but whereby the cause of death was not evident. Moreover, often there were no signs of colonization of these dead parts by other organisms. In that case the coral species name was reported together with an estimation of the percentage of dead coral. This phenomenon could not be equivocally placed in one of the various 'injury types' and was therefore not specifically involved in the numerical analysis.

The types and the amounts of the injuries on the observed colonies have been reported. However, it is obvious that the above mentioned types of injuries naturally occur on a reef as an ecosystem. Therefore one may say that not the character but mainly the amount of the injuries can give information about the 'quality' of the conditions in the environment.

The living cover of a coral reef can be determined to a great extent by different types of algae (5-70% of the total cover, Benayahu & Loya, 1977). Because of this great variation in cover, it is difficult to speak in general about critical amounts of algae in the ecosystem. In the literature practically no general rules are given about this matter.

The different types of injuries are partly related to each other, for instance in the way they can succeed each other in time. It was discussed that algal growth on coral may be a direct indication of stress in the environment. Indirectly, algae may settle on coral that was previously injured in a different way.

Coral that suffered initially from predation, mechanical damage, or organic stress conditions in the environment ('pale tissue!') is more readily colonized by algae on the spots that were injured. For example, the tops of the coral boulders in the Coral Gardens of the Malindi and Watamu Marine National Parks are subjected to much trampling by tourists, thus unwittingly inflicting much damage. These tops are devoid of living polyps, but have often been recolonized by crustose coralline algae. Another example is the 'black cracks' which are probably caused by predation and are later overgrown by algae.

The different types of injuries are distinguished by their typical appearance and more or less selected on their frequency and significance.
5.2.2 Amount of the Injury

Collecting the data
A modified version of the line-transect method (Loya, 1972) was used while working on the releves (see chapter 3 about methods). In the releves, the cover of a certain coral species was determined from the amount, expressed in centimeters, of that species, that was found beneath the transect lines. Apart from this, every coral colony under the line was examined for possible signs of injuries. In the case of an injury the character and percentage class were reported whereby the following 4 classes were distinguished:

- 0-25% of the colonies' surface was injured: 1
- 26-50% " " " " " : 2
- 51-75% " " " " " : 3
- 76-100% " " " " " : 4

So for every injury one of the classes 1-4 was noted. In the field it was often difficult to distinguish between corals that had died recently and corals that had died off a long time ago. When a colony was totally damaged and no longer recognizable, it was not reported as an individual but as (part of) a 'dead' interval between two living colonies. This means that this colony is considered to belong to the total amount of dead coral rock in the particular area, that can possibly serve as a substratum for new coral settlement (Goreau, Goreau & Hayes, 1981). Although we continuously considered our data from the releves together with general descriptions of the visited areas, in the numerical analysis of injuries, only colonies which were partly injured or not injured at all were involved. We realize we have thus created a keen separation between partly injured and totally damaged coral. However, the partial injuries alone give us relatively most information about the actual environmental circumstances.

Processing the data
In analyzing and interpreting the data there are different levels on which one can work. While collecting the data 'the colony' was used as the basic object in relation to injuries. In this way one can get information about injured colonies as percentages of a whole, being a species, a group of species, a certain growth-form, etcetera. We have the numbers of injured colonies and the injury class of each damaged colony for every relevee, and therefore also for every triad or group of triads. In the discussion of the results the percentages of injured colonies per triad will be mainly used. Roughly one can say that the greater the ratio between the number of injured colonies and the total number of colonies in a given area, the more obvious is the deviation of environmental conditions from the optimum for coral growth. Historical or long term factors responsible for settlement and actual coral cover are only sparsely discussed in this chapter.

Triads that are similar in structure and species composition but geographically spread throughout the research area will be compared (see also the previous chapter about species composition). The most damaged species for every type of injury will be mentioned.
5.3 RESULTS

Totally we observed about 10,000 coral colonies spread over 42 triads. By means of the categories mentioned in appendix C a general view in relation to injuries is presented in Table 8. The table is partly meant as an addition to the literature in which only scanty general data may be found on this topic. The figures recorded in the columns ought to be seen in relative context. These scores are determined from the sum of injury classes of separate colonies divided by the total numbers of colonies belonging to the specific group. Geographical positions of the coral as well as possible species-specific qualities in relation to certain injuries are not discussed here.

Table 8: Growth forms, calice arrangement and calice diameter related to injuries, (for injury scores see text).

<table>
<thead>
<tr>
<th></th>
<th>fleshy calc.</th>
<th>calc. 'black cracks'</th>
<th>'pale tissue'</th>
<th>mech. dam.</th>
<th>predat.</th>
<th>nr. of colon.</th>
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<tbody>
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<td>growth forms:</td>
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<td></td>
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<tr>
<td>encr./foliate</td>
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<td>.04</td>
<td>.04</td>
<td>.01</td>
<td>.01</td>
<td>1920</td>
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<tr>
<td>ramose</td>
<td>.16</td>
<td>.08</td>
<td>-</td>
<td>.02</td>
<td>.05</td>
<td>-</td>
</tr>
<tr>
<td>tabulate</td>
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<td>.20</td>
<td>.03</td>
<td>.03</td>
<td>.02</td>
<td>-</td>
</tr>
<tr>
<td>massive</td>
<td>.20</td>
<td>.11</td>
<td>.12</td>
<td>.09</td>
<td>.05</td>
<td>3240</td>
</tr>
<tr>
<td>calice arrangement:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>solitary</td>
<td>.05</td>
<td>.01</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>292</td>
</tr>
<tr>
<td>phaceloid</td>
<td>.09</td>
<td>-</td>
<td>-</td>
<td>.05</td>
<td>-</td>
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<tr>
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<td>.04</td>
<td>.03</td>
<td>.04</td>
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<td>.20</td>
<td>.22</td>
<td>.30</td>
<td>.01</td>
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<tr>
<td>meandroid</td>
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<td>.05</td>
<td>.09</td>
<td>.04</td>
<td>.02</td>
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</tr>
<tr>
<td>hydnophoroid</td>
<td>.16</td>
<td>.06</td>
<td>.10</td>
<td>.05</td>
<td>-</td>
<td>130</td>
</tr>
<tr>
<td>calice diameter</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1 mm</td>
<td>.18</td>
<td>.09</td>
<td>.03</td>
<td>.03</td>
<td>.01</td>
<td>5075</td>
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<td>1 - 2</td>
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<td>.05</td>
<td>.33</td>
<td>.15</td>
<td>.03</td>
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<tr>
<td>2 - 7</td>
<td>.17</td>
<td>.10</td>
<td>.10</td>
<td>.06</td>
<td>.04</td>
<td>2114</td>
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<tr>
<td>7 - 20</td>
<td>.16</td>
<td>.10</td>
<td>.09</td>
<td>.05</td>
<td>-</td>
<td>360</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>.09</td>
<td>-</td>
<td>-</td>
<td>.05</td>
<td>-</td>
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<td>.05</td>
<td>.09</td>
<td>.04</td>
<td>.02</td>
<td>281</td>
</tr>
</tbody>
</table>

For the locations of the triads, see maps.

Condition of the Reef. 73
Table 9: Predation, relatively most damaged triads. (Predation was certainly not observed in all triads.)

<table>
<thead>
<tr>
<th>triad</th>
<th>number of damaged colon.</th>
<th>tot. number of colonies</th>
<th>percentage of damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
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<td>495</td>
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<td>5</td>
<td>12</td>
<td>276</td>
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</tr>
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<td>6</td>
<td>6</td>
<td>461</td>
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<td>10</td>
<td>11</td>
<td>390</td>
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<td>11</td>
<td>13</td>
<td>250</td>
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</tr>
<tr>
<td>15</td>
<td>19</td>
<td>236</td>
<td>8.0</td>
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</tr>
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<td>31</td>
<td>12</td>
<td>263</td>
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<td>40</td>
<td>11</td>
<td>127</td>
<td>8.6</td>
</tr>
</tbody>
</table>

Table 10: 'Black cracks', relatively most damaged triads.

<table>
<thead>
<tr>
<th>triad</th>
<th>number of damaged colon.</th>
<th>tot. number of colonies</th>
<th>percentage of damage</th>
</tr>
</thead>
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<td>14</td>
<td>281</td>
<td>3.0</td>
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<tr>
<td>11</td>
<td>21</td>
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<td>21</td>
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<td>7.6</td>
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<td>27</td>
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<td>10.6</td>
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<td>39</td>
<td>39</td>
<td>421</td>
<td>9.3</td>
</tr>
<tr>
<td>40</td>
<td>19</td>
<td>127</td>
<td>15.0</td>
</tr>
</tbody>
</table>

Table 11: Mechanical damage, relatively most damaged triads. (Triads 13 and 36 were situated in the coral gardens in Malindi and Watamu respectively.)

<table>
<thead>
<tr>
<th>triad</th>
<th>number of damaged colon.</th>
<th>tot. number of colonies</th>
<th>percentage of damage</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>10</td>
<td>256</td>
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<td>3</td>
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<td>303</td>
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<td>36</td>
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<td>153</td>
<td>9.1</td>
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Table 12: Species that were particularly mechanically damaged in the triads mentioned in table 11

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<th>damaged species</th>
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<tr>
<td>0</td>
<td>10</td>
<td>Galaxea fascicularis, Goniastrea retiformis</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>Galaxea fascicularis, Acropora spp.</td>
</tr>
<tr>
<td>7</td>
<td>12</td>
<td>Galaxea fascicularis, Acropora formosa</td>
</tr>
<tr>
<td>9</td>
<td>21</td>
<td>Acropora formosa, Acropora hyacinthus, Echinopora lamellosa, Acropora variabilis, Porites lutea, Porites eridiani</td>
</tr>
<tr>
<td>12</td>
<td>25</td>
<td>Acropora formosa, Acropora hyacinthus, Porites lutea, Porites eridiani, Galaxea fascicularis</td>
</tr>
<tr>
<td>13</td>
<td>53</td>
<td>Acropora hyacinthus, Porites lutea, Porites eridiani, Stylophora pistillata, Galaxea fascicularis, Porites lutea, Galaxea fascicularis, Porites eridiani, Astreopora ocellata, Acropora hyacinthus</td>
</tr>
<tr>
<td>21</td>
<td>13</td>
<td>Acropora hyacinthus, Porites eridiani, Galaxea fascicularis</td>
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<tr>
<td>36</td>
<td>14</td>
<td>Galaxea fascicularis, Porites eridiani, Astreopora ocellata, Acropora hyacinthus</td>
</tr>
</tbody>
</table>

Condition of the Reef. 75
Table 13: 'Pale tissue', the relatively most injured triads.

(For the triads that are not mentioned in the table the percentages of injuries vary from 0 to 4 %.)

<table>
<thead>
<tr>
<th>triad</th>
<th>number of injured colon.</th>
<th>tot. number of colonies</th>
<th>percentage of injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>12</td>
<td>256</td>
<td>4.7</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>433</td>
<td>5.7</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>154</td>
<td>5.8</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>198</td>
<td>5.5</td>
</tr>
<tr>
<td>13</td>
<td>30</td>
<td>150</td>
<td>20.0</td>
</tr>
<tr>
<td>18</td>
<td>12</td>
<td>174</td>
<td>6.8</td>
</tr>
<tr>
<td>21</td>
<td>17</td>
<td>394</td>
<td>4.3</td>
</tr>
<tr>
<td>23</td>
<td>17</td>
<td>458</td>
<td>3.7</td>
</tr>
<tr>
<td>25</td>
<td>15</td>
<td>200</td>
<td>7.5</td>
</tr>
<tr>
<td>26</td>
<td>11</td>
<td>188</td>
<td>5.8</td>
</tr>
<tr>
<td>27</td>
<td>13</td>
<td>149</td>
<td>8.7</td>
</tr>
<tr>
<td>30</td>
<td>3</td>
<td>68</td>
<td>4.4</td>
</tr>
<tr>
<td>31</td>
<td>8</td>
<td>168</td>
<td>4.8</td>
</tr>
<tr>
<td>34</td>
<td>8</td>
<td>157</td>
<td>5.1</td>
</tr>
<tr>
<td>35</td>
<td>14</td>
<td>221</td>
<td>6.3</td>
</tr>
<tr>
<td>36</td>
<td>11</td>
<td>153</td>
<td>7.2</td>
</tr>
<tr>
<td>37</td>
<td>9</td>
<td>185</td>
<td>4.9</td>
</tr>
<tr>
<td>38</td>
<td>12</td>
<td>172</td>
<td>7.0</td>
</tr>
<tr>
<td>40</td>
<td>16</td>
<td>127</td>
<td>12.6</td>
</tr>
</tbody>
</table>
Table 14: Species that particularly showed 'pale tissue' in the triads mentioned in table 13.

<table>
<thead>
<tr>
<th>triad</th>
<th>most injured species</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Goniastrea retiformis</td>
</tr>
<tr>
<td>6</td>
<td>Goniastrea retiformis</td>
</tr>
<tr>
<td>8</td>
<td>Montipora spp., Astreopora ocelata</td>
</tr>
<tr>
<td>11</td>
<td>several species</td>
</tr>
<tr>
<td>13</td>
<td>Goniastrea retiformis</td>
</tr>
<tr>
<td>18</td>
<td>Goniastrea retiformis</td>
</tr>
<tr>
<td>21</td>
<td>Goniastrea retiformis</td>
</tr>
<tr>
<td>23</td>
<td>Goniastrea retiformis, Montipora spp.</td>
</tr>
<tr>
<td>25</td>
<td>Montipora spp., Porites lutea</td>
</tr>
<tr>
<td>26</td>
<td>Montipora spp.</td>
</tr>
<tr>
<td>27</td>
<td>Porites lutea</td>
</tr>
<tr>
<td>30</td>
<td>Montipora spp., Astreopora ocelata</td>
</tr>
<tr>
<td>31</td>
<td>several species</td>
</tr>
<tr>
<td>34</td>
<td>Montipora spp.</td>
</tr>
<tr>
<td>35</td>
<td>Montipora spp.</td>
</tr>
<tr>
<td>36</td>
<td>Porites lutea</td>
</tr>
<tr>
<td>37</td>
<td>several species</td>
</tr>
<tr>
<td>38</td>
<td>Montipora spp.</td>
</tr>
<tr>
<td>40</td>
<td>Montipora spp., Porites lutea, Astreopora ocelata</td>
</tr>
</tbody>
</table>

Condition of the Reef. 77
Injuries by algae (including calcareous).

The triads are set out according to coral formations as distinguished in chapter 4.

Table 15: boulder areas

<table>
<thead>
<tr>
<th>triad</th>
<th>number of inj. col.</th>
<th>tot. nr. of col.</th>
<th>percentage</th>
<th>av. injury class</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>58</td>
<td>281</td>
<td>20.7</td>
<td>1.6</td>
</tr>
<tr>
<td>13</td>
<td>27</td>
<td>150</td>
<td>18.0</td>
<td>2.8</td>
</tr>
<tr>
<td>15</td>
<td>52</td>
<td>209</td>
<td>24.9</td>
<td>1.9</td>
</tr>
<tr>
<td>18</td>
<td>43</td>
<td>174</td>
<td>24.7</td>
<td>2.7</td>
</tr>
<tr>
<td>19</td>
<td>28</td>
<td>135</td>
<td>20.7</td>
<td>2.0</td>
</tr>
<tr>
<td>33</td>
<td>27</td>
<td>151</td>
<td>17.9</td>
<td>1.2</td>
</tr>
<tr>
<td>36</td>
<td>32</td>
<td>153</td>
<td>20.9</td>
<td>2.4</td>
</tr>
</tbody>
</table>

av. 21.1 %

Table 16: boulder massives

<table>
<thead>
<tr>
<th>triad nr.</th>
<th>number of inj. col.</th>
<th>tot. nr. of col.</th>
<th>percentage</th>
<th>av. injury class</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>31</td>
<td>198</td>
<td>15.7</td>
<td>2.4</td>
</tr>
<tr>
<td>20</td>
<td>30</td>
<td>339</td>
<td>8.8</td>
<td>1.5</td>
</tr>
<tr>
<td>21</td>
<td>47</td>
<td>394</td>
<td>11.9</td>
<td>2.4</td>
</tr>
<tr>
<td>39</td>
<td>61</td>
<td>421</td>
<td>14.5</td>
<td>1.5</td>
</tr>
<tr>
<td>41</td>
<td>21</td>
<td>179</td>
<td>11.7</td>
<td>2.4</td>
</tr>
</tbody>
</table>

av. 12.5 %
Table 17: platforms

<table>
<thead>
<tr>
<th>triad</th>
<th>number of inj. col.</th>
<th>tot. nr. of col.</th>
<th>percentage</th>
<th>av. injury class</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>62</td>
<td>256</td>
<td>24.2</td>
<td>1.5</td>
</tr>
<tr>
<td>1</td>
<td>17</td>
<td>176</td>
<td>9.7</td>
<td>1.4</td>
</tr>
<tr>
<td>2</td>
<td>23</td>
<td>235</td>
<td>9.8</td>
<td>1.8</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>270</td>
<td>13.0</td>
<td>1.3</td>
</tr>
<tr>
<td>4</td>
<td>33</td>
<td>488</td>
<td>6.8</td>
<td>2.8</td>
</tr>
<tr>
<td>8</td>
<td>25</td>
<td>154</td>
<td>16.2</td>
<td>2.1</td>
</tr>
<tr>
<td>22</td>
<td>34</td>
<td>276</td>
<td>12.3</td>
<td>2.4</td>
</tr>
<tr>
<td>23</td>
<td>63</td>
<td>458</td>
<td>13.8</td>
<td>2.4</td>
</tr>
<tr>
<td>24</td>
<td>26</td>
<td>423</td>
<td>6.1</td>
<td>1.5</td>
</tr>
<tr>
<td>25</td>
<td>14</td>
<td>200</td>
<td>7.0</td>
<td>2.4</td>
</tr>
<tr>
<td>26</td>
<td>28</td>
<td>188</td>
<td>14.9</td>
<td>1.7</td>
</tr>
<tr>
<td>27</td>
<td>14</td>
<td>149</td>
<td>9.4</td>
<td>2.0</td>
</tr>
<tr>
<td>30</td>
<td>12</td>
<td>68</td>
<td>17.6</td>
<td>1.6</td>
</tr>
<tr>
<td>31</td>
<td>26</td>
<td>168</td>
<td>15.4</td>
<td>2.2</td>
</tr>
<tr>
<td>34</td>
<td>22</td>
<td>157</td>
<td>14.0</td>
<td>2.2</td>
</tr>
<tr>
<td>35</td>
<td>35</td>
<td>221</td>
<td>16.5</td>
<td>2.0</td>
</tr>
<tr>
<td>37</td>
<td>28</td>
<td>185</td>
<td>15.1</td>
<td>2.1</td>
</tr>
<tr>
<td>38</td>
<td>32</td>
<td>172</td>
<td>18.6</td>
<td>1.8</td>
</tr>
<tr>
<td>40</td>
<td>27</td>
<td>127</td>
<td>21.3</td>
<td>2.1</td>
</tr>
</tbody>
</table>

av. 13.8 %
Table 18: 'shallow' slopes (< 15 m)

<table>
<thead>
<tr>
<th>triad</th>
<th>number of inj. col.</th>
<th>tot. nr. of col.</th>
<th>percentage</th>
<th>av. injury class</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>40</td>
<td>364</td>
<td>11.0</td>
<td>1.8</td>
</tr>
<tr>
<td>9</td>
<td>44</td>
<td>303</td>
<td>14.5</td>
<td>2.4</td>
</tr>
<tr>
<td>10</td>
<td>67</td>
<td>374</td>
<td>17.9</td>
<td>1.6</td>
</tr>
<tr>
<td>12</td>
<td>77</td>
<td>424</td>
<td>18.2</td>
<td>2.0</td>
</tr>
<tr>
<td>14</td>
<td>18</td>
<td>228</td>
<td>7.9</td>
<td>1.8</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>252</td>
<td>6.4</td>
<td>2.1</td>
</tr>
<tr>
<td>17</td>
<td>11</td>
<td>192</td>
<td>5.7</td>
<td>1.0</td>
</tr>
</tbody>
</table>

av. 11.7 %

Table 19: 'deep' slopes (20 - 25 m)

<table>
<thead>
<tr>
<th>triad</th>
<th>number of inj. col.</th>
<th>tot. nr. of col.</th>
<th>percentage</th>
<th>av. injury class</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>3</td>
<td>153</td>
<td>1.9</td>
<td>1.3</td>
</tr>
<tr>
<td>32</td>
<td>2</td>
<td>63</td>
<td>3.1</td>
<td>3.1</td>
</tr>
</tbody>
</table>

av. 2.5 %

Table 20: remaining triads (note the possible difference in structural build up of the triads)

<table>
<thead>
<tr>
<th>triad</th>
<th>number of inj. col.</th>
<th>tot. nr. of col.</th>
<th>percentage</th>
<th>av. injury class</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>90</td>
<td>433</td>
<td>20.8</td>
<td>1.9</td>
</tr>
<tr>
<td>29</td>
<td>3</td>
<td>41</td>
<td>7.3</td>
<td>1.7</td>
</tr>
</tbody>
</table>
5.4 DISCUSSION

Growth-forms and injuries
Table 8 clearly shows that particularly massive and tabulate growth-forms suffer from overgrowth by algae. Massive corals also have high scores with respect to other injuries.

The frequent injury by algae could be linked up with the other high scores because algal settling often succeeds other types of injuries (see paragraph on methodology in this chapter). Notable quantities of massive colonies were particularly found in relatively quiet waters (boulderzones and platforms) whereas ramose colonies frequently appeared in more agitated waters e.g. slopes of the patch reefs (see chapter 4 and Glynn, 1973; Bak, 1975). With respect to silt deposition the influence might be more obvious in the relatively quiet waters thereby facilitating algal growth on coral. Moreover, massive (molar) and tabulate growth-forms in a way might catch and hold silt and organic matter, thus facilitate algal colonisation (see Figure 22). This might also be an explanation for the high occurrence of algae on often massive species of the Faviidae which should be relatively resistant against silt influences (Endean, 1973).

'Black cracks' accompanied by algal growth were only found on unbranched corals. This was also the case for predation marks. These results in a way confirm the possible relation between the two: 'black cracks' may result from earlier predation traces (see the paragraph on methodology in this chapter).

The highest score of different types of mechanical damage are logically found on ramose corals. More noteworthy is the high score for massive corals. Both scores are partly related to conditions in both the Coral Gardens of the marine parks, that are frequently visited by tourists especially during certain

21 Particularly boulders can in a way be considered as 'micro-atolls'. (personal communication dr. Hans Mol, coral ecologist at the Rijksmuseum voor Natuurhistorie in Leiden, the Netherlands).
seasons (Jan., Feb., Apr., Aug., Dec., Waning & Hafkenscheid, 1984). Boat anchors and tourists treading on, or accidently kicking corals, probably account for much of this damage. There were also colonies that had fallen apart under the influence of age, boring organisms and perhaps storms, even massive corals such as Galaxea and Lobophyllia.

In summary, it appears from this survey that in the Malindi area the massive growth-forms suffer most from the different types of injuries.

**Calice arrangement and Injury**

Solitary corals appear to be relatively resistant against all kinds of injuries. In fact, in the relevées most of the injuries except for algae, have never been observed on solitary corals. Because of their small, often foliate growth-form, they are not easily mechanically damaged. Moreover, when they are damaged they probably turn quickly in so-called rubble.

Cereoid corals have the highest score for injuries, except for mechanical damage. This is partly due to the high injury frequency of Goniastrea retiformis, which occurs frequently in the Malindi area. Cereoid corals have no coenosteum. The coenosteum of for example plocoid corals may play a role in removing silt from the coral.

**Calice diameter and Injury**

According to Endean (1973) there is possibly a relation between caliche diameter and resistance against silt. Roughly formulated, caliches with a larger diameter would suffer less from fine silt than caliches with a smaller diameter. To some degree silt stress can be related to (succeeding) injury by algae (see paragraph on methodology). Table 8 shows a rough trend that corals are less injured by algae if the caliche diameter is larger.

**Predation and 'black cracks'**

According to our observations in the Malindi area predation marks are mainly caused by parrot fish (Scarus spp.) and butterfly fish (Pantodon spp.) (see also Ken Bock, 1979). Species that were most often damaged by predation were Goniastrea retiformis, Porites lutea and Montipora spp., and also but less often the species Astreopora ocelata, Platgyra lamellina, Leptoria phrygia and Porites eridani. A number of other genera including Echinopora, Pocillopora, Lobophyllia, Galaxea, Favites, Goniopora and Hydnophora were damaged only once in 126 relevées. The most damaged genera, Goniastrea and Porites often have conspicuous massive growth-forms and a relatively smooth surface, both factors probably enhancing vulnerability.

Predation was certainly not observed in all triads. Table 9 shows the triads where the phenomenon was quite obvious. Triads 5, 6, 10, 11 and 15 are all situated inside the Malindi Marine National Park. Triads 27 and 40 lie in the Watamu Marine National Park (see maps) Both parks have a protection status with respect to fishing. In general we observed larger populations of parrot fishes and butterfly fishes in the marine parks, whereby it should be noted that other environmental factors may also be responsible for the total number of fish.

In triads 20 to 26 we did not observe any predation and in triads 0, 1 and 3 almost none, in spite of the fact that remarkable numbers of observed 'predation vulnerable' corals occurred (Goniastrea, Porites and Montipora)?

---

22 The coenosteum is the space (if present) between polyps of a coral colony, covered with living coral tissue (Barnes, 1974).

23 Many places in the parks were originally flourishing ecosystems with high percentages of coral cover.
The frequency of the phenomenon of 'black cracks' is clearly higher than that of predation and moreover it is more spread throughout the area. 'Black cracks' mainly occurred on Goniastrea retiformis. The genera Porites, Montipora, Astreopora, Platygyra and Favites that were often damaged by predation, regularly appeared to be suffering from 'black cracks' as well. Moreover, it appears that 5 of the 10 triads suffering from predation also show many colonies with 'black cracks'.

The higher frequency of 'black cracks' compared to the frequency of predation could be a logical consequence of the possibility that predation traces transform to 'black cracks' after a period of time (after colonization by algae). Another explanation may be a decrease in the total number of fish in the area, over the past years!

Compared with the other types of injuries, predation and 'black cracks' were not that frequent that they can be held responsible for a degeneration of the Malindi Reef in general. Moreover, in most cases predation and 'black cracks' are not fatal to coral. They may however pave the way for further deterioration.

Mechanical damage: the Coral Gardens

Earlier it was noted that mechanical damage may on the one hand be caused by natural factors such as storm, strong breakers and several boring organisms (and senescence in combination with them), and on the other hand by human activity particularly at sites that are often visited by tourists (e.g. the Coral Gardens) and fishermen.

At the same time we want to say that, except for the Coral Gardens, the phenomenon of mechanical damage plays a very unimportant role in the deterioration of the Malindi Watamu Reef complex.

In Table 11 it is shown that both the Coral Gardens in Malindi and Watamu (triads 13 and 36) are most seriously damaged! Natural mechanical damage easily seems to get a grip on coral skeletons with a relatively small degree of coherence (e.g. larger colonies of Galaxea fascicularis and Lobophyllia spp.). The damage to Galaxea fascicularis (6 out of 8 triads, see Table 12) seems to be mostly due to the activity of boring organisms. The colony then looks like a loose array of polyps, some of which have already been swept away by the currents (see plate 26).

Sometimes tabulate colonies (e.g. Acropora variabilis) but even huge colonies of for example Lobophyllia were observed to be completely turned over by storm, undermining activities of boring organisms, senescence or a combination of those factors.

The mechanical damage to Acropora is also partly due to broken branches of the ramose colonies (see triads 9, 12, 13 and 36). Triads 13 and 36 again are the Coral Gardens, triad 9 is situated in the Barracuda Channel on a place along the supply route to the Coral Garden in Malindi. This place is very shallow at low tide!

The relatively high number of different species that were damaged in the Coral Gardens is remarkable. Even massive colonies as Goniastrea retiformis and Porites lutea, but also solid encrusting species as Echinopora lamellosa and Astreopora ocellata were damaged. In the Coral Gardens mechanical damage is mainly caused by trampling. Both gardens are relatively small areas (each about 2500 m²) that are daily visited by considerable amounts of tourists. A large number of tourists that venture out to the Coral Gardens with a glassbottom boat go goggling on the reef. We, and others before us (Bock, 1979; Green et al., 1979), have observed that most of them stand on top of

24 For the other 5 triads the correlation tends to be the same but is less obvious.
colonies to take a rest from their exploits, accidently kick fragments from colonies or dislodge loose corals. The results are clearly visible: Goniastrea and Porites boulders are often completely dead on the top. Over a longer period they are often covered by crustose coralline algae. In smaller colonies the calice walls or even parts of the colony are often broken. This was observed in species of ramose, tabulate and platy corals (e.g. Acropora, Pocillopora, Montipora).

A different, even more important cause of mechanical damage is the anchoring of the glassbottom boats that are transporting the tourists to the Coral Gardens. To prevent the destructive effects of dragging anchor chains, buoys were placed in the Coral Gardens some years ago (see figure ). The boats are supposed to moor alongside the buoys, but unfortunately some boats still drop their anchors on different places in the gardens.

To reduce destruction even more it is recommended that the buoys are moved twice a year, when the water current changes. Partly as a result of the mechanical stress also algal growth on coral is frequent in the Coral Gardens (see Table 15 and text in the following paragraphs). Algal colonization is facilitated on coral that has been injured earlier in different ways (e.g. Heys & Brouns, 1976). Summarizing, mechanical damage is a serious threat but only very locally, namely in the Coral Gardens. In this point we want to make some recommendations (see the general discussion of this report).

'Pale tissue'

The tops of these boulders do not fall dry at low tide!
Pre-eminently, 'pale tissue' is the phenomenon that points out actual stress (see paragraph on methodology). In the study area it was a common feature although less frequent than several types of algal growth on coral (see tables 7 to 14). This might be explained by the fact that temporary 'pale tissue' might be colonized by algae in a latter stage (see paragraph on methodology). So, in fact 'pale tissue' and algal cover are closely related to each other. 'Pale tissue' refers to on the one side temporary or 'feeble' stress, or on the other actual stress and might therefore, in a way, be seen as less serious than algal cover.

'Pale tissue' was observed on practically all species, but of the most common species particularly on Montipora spp. (5% of all observed colonies), Porites lutea (8%), Astreopora ocelata (12%) and Goniastrea retiformis (19%). Most of the injured colonies were large individuals (diameter > 1 m). Percentages of colonies with 'pale tissue' are shown in Table 13. Again remarkable high the percentages are in both the Coral Gardens, (triads 13 and 36) especially in Malindi (13). Both triads are parts of two zones with quite shallow, relatively quiet water. Triads 6 and 13 are shallow locations on the North Reef platform (see map), triads 8 and 11 (see Table 13) likewise are relatively shallow locations in the Barracuda Channel. In Watamu one finds such a zone near triads 33, 34, 36 and 37 (see table 6 and map). Lowered dynamics in these sheltered places can be related to more serious injuries possibly with respect to fresh water influences and influx of silt and organic matter. More exposed triads e.g. 1, 2, 3, 7, 10, 14, 16, 17, 24, 28 and 32 show far fewer colonies having 'pale tissue'.

Looking at the different structural categories in which the triads are divided (see previous chapter), it appears that 'pale tissue' occurs anywhere in the area, but much less frequently on slopes (more dynamic). Particularly on places were Goniastrea retiformis and Porites lutea are the main reef building corals (boulder areas and boulder massives) both species often show 'pale tissue' or algal cover. As yet, it appears that their specific growth-form (massive) and their large widths are related to the frequency of both the phenomena of 'pale tissue' and algal cover. For more details, read the following paragraph on injuries by algae.

Algae

The whole Malindi Watamu Reef complex is under the influence of the Sabaki River which is about 5 km to the north of Malindi township. The coral in Watamu is moreover under the influence of Mida Creek which lies just south of Watamu township.

Tables 15-20 show a survey of the percentages of injured coral, divided in 5 categories. Triads 28 and 32 (depth > 20 m), about 2 kilometres off the coast of Watamu are clearly least injured. Next are triads 1 to 4 in the north, triads 7, 14, 16, 17 and 20, relatively exposed to more open sea, as well as triads 21 to 24 that moreover are situated further away from the Sabaki River. Triads with high percentages of injuries are situated centrally on North Reef (5, 6, 9, 12 and 13) which are relatively sheltered, often shallow places. Other sites with high injury percentages are located in Barracuda Channel (triads 8 and 11) and places being in a direct line from the channel, dominated by boulder growth-forms (triads 15, 18 and 19). Triads that are under a more direct influence of Mida Creek (triads 30 to 40 except triad 32) are in a

26 Also algal growth on coral is clearly less serious in a number of these triads (see tables 10 to 12)

27 see the report on abiotic conditions in the Malindi area, Giesen & Kerkhof, 1984; and chapter 9 of this report
worse condition. In the previous chapter the triads were classified according to coral formations, namely boulders, boulder massives, platforms and slopes. Triads within one coral formation often lie scattered all over the area. However, they can be best compared on the base of their structural similarities. Tables 9 to 13 present a general view of the degree of injury data arranged according to coral formation.

The percentages of algal cover on coral are relatively high in all boulder triads (18 to 25 %, see Table 15). Triads 5 and 13 (Coral Gardens Malindi) are situated on the North Reef. The other boulder triads 15, 18, 19, 33 and 36 are parts of typical boulder zones we met on the one side in Malindi (15, 18, 19) and on the other side in Watamu (see maps). According to our observations the most frequently injured species were Goniastrea retiformis (dominant in the boulderzone near Malindi) and Porites lutea (dominant in the boulderzone near Watamu, but also abundant near Malindi). In some places more than half of the total number of these corals were injured! Both species were also often injured in the other formations, but their occurrence was less dominant there (see boulder massives 11, 20, 21, 39 and 41) or much less frequent (the other triads).

Particularly in the Watamu Coral Gardens, Astreopora ocellata seems to maintain itself successfully.

The injury percentages of the boulder massives range from 8.6 % in triad 41 to 15.7 % in triad 11 (Barracuda Channel). Besides Porites lutea, in triad 11 Platygyra lamellina, Pocillopora verrucosa and Stylophora pistillata appear to be more injured than the other species.

Of the shallow platforms, triads 1 to 4 (depth < 3 m) in the far north of the study area are relatively less injured. In triads 0, 1, 2 and 4 Montipora spp. occurs very frequently and are only sparsely injured.

On the shallow and deeper platforms in Watamu Montipora is injured more often: up to 25 % or more. Porites eridani seems to thrive better on shallower platforms in the north (triads 0 to 4 and 23) than on the slopes of North Reef (10 to 20% injured).

Galaxea clavus mainly occurred on slopes that were generally least injured (triads 7, 14, 16, 17), but appeared to be the most injured species there.

Several species of Acropora (f.e. Acropora hyacinthus, Acropora formosa) are particularly dominant on the edges of North Reef (partially in the breaker zone), but also centrally on North Reef, near the Coral Gardens, monospecific stands of the Acropora formosa-grp occur. This would imply that originally conditions for settlement and development of this coral were favourable. However, environmental conditions seem to have partly changed as may be observed from the locally large numbers of injured Acroporas (15 to 25 % in triads 5, 6, 10 and 12)! Maybe because of a difference in exposure, Acropora in triads 7, 14, 16 and 17 is less seriously injured (4 to 10%). Triads 4 and 8 in the Barracuda Channel which have also a notable presence of Acropora, show injury percentages of 14 and 18% respectively. To the south, close to the coast in a zone that is relatively sheltered from large breakers (triads 20 to 24), Acropora appears to be much less injured (4 to 9%) except for triad 23. In Watamu Acropora co-dominates in triads 34 to 37 and 39. Here the injury percentages for Acropora are between 10 and 15%.

Acropora can be considered to be sensitive to fine silt (Endean, 1973). Correlating the amount of 'silt stress' to the degree of injury, there might be a correlation with the supply of material from the Sabaki River (in the north)

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28 In the appendices of the report, the condensed data of all triads are presented, including most occurring species and most injured species

29 The injury percentage in triad 0 is again mainly caused by Goniastrea retiformis

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and Mida Creek (in the south). Near Malindi, on places that are relatively protected from the open sea with respect to sinking of fine silt (triads 4, 5, 6, 8, 12) Acropora is more often injured compared with Acropora in the more exposed triads 7, 14, 16, 17, and more southerly triads 20 to 24. Near Watamu the injury percentage is again relatively high in triads 34 to 37 and 39 which are under the direct influence of Mida Creek.

Summarizing for this chapter one can state that the frequency of algal cover on coral and 'pale tissue' point at a certain actual stress in the conditions for coral growth in the Watamu reserve. Both injury types are enhanced by influences of silt and sedimentation, originating from the Sabaki River. The silt or sedimentation stress is largely determined by water movement and geographical position of a specific site. Although the Faviidae are considered relatively resistant against silt influences, they appear to be the most injured coral taxon in the area, especially due to Goniastrea reticularis.

In the general discussion of this report, the results of this chapter have to be evaluated in combination with the other results.
Chapter 6
SIZE OF CORAL COLONIES.

6.1 INTRODUCTION

The recording of individual coral colonies was the basis for the relevee sampling method. When this was carried out, the maximum diameter was measured of all colonies encountered under the relevee-line. Under the maximum length of a colony is understood the maximum diameter of that colony under a vertical projection (see chapter 3).

There are a number of reasons for taking the maximum colony length into account. The most important of these is that the actual coral colony length, and the circumstances under which coral species may attain their maximum length, may reveal important information on local reef conditions. Sites where only small colonies are found may thus differ greatly in local environmental conditions from areas with both large and small colonies. The first may, however, be due to regeneration following destruction.

6.2 FACTORS DETERMINING COLONY SIZE

Colonies are defined as a group of polyps that are inter-connected by living tissue and a calcium carbonate skeleton. The colonies of most species are easily distinguished from each other. Species that may present some difficulties are dealt with below.

Galaxea clavus may form large fields of up to more than 500 square metres in area, consisting of pinnacles of many calices. It was, however, far too time consuming to investigate whether each pinnacle of polyps, group of pinnacles or the whole field, consisted of a single colony. As pinnacles did not vary much in size and fields did, the latter were treated as single colonies, as this may reveal information on local environmental conditions.

The same was also the case with Galaxea fascicularis, another plocoid species, although one can better speak in this case of clumps instead of pinnacles of polyps. These clumps were regarded as single colonies, as fields were only occasionally present, and always under 1 metre in size.

The Acropora formosa-grp also presented some difficulties in the assessing of colony size. The branching arms of this species may entwine to such an extent that the recognition of individual colonies in the resulting entanglement proves a difficult task. However, this only occurred occasionally.

The following factors influence the size of the colonies:

• species-specific characteristics
• environment
• age

These will be dealt with below. It is often difficult to distinguish between these factors, as size is always determined by an interplay of age, species characteristics (such as growth-rate) and environmental factors.
6.2.1  *Species-specific characteristics*

Because of the large number of species involved, and the great variation in specific characteristics, this discussion will be limited to:

- Rate of growth
- Solidity
- Competitive behaviour

**RATE OF GROWTH**

The rate of growth may be observed from two viewpoints: the local rate of growth at a point on a colony, and the rate of growth of the colony as a whole.

The local rate of growth of a colony determines the shape of the whole, and the following forms may be recognised: encrusting, ramose (branching), massive, tabulate, foliate and solitary. Each species is actually bound to one of these forms, but some may show a considerable variation (Vernon & Pichon, 1976; Yonge, 1969).

The growth-rate of whole colonies is variable for the different growth forms. This is logical, as a branching species needs to accumulate less calcium carbonate to achieve the same size as a massive species. Massive boulder forming species may grow 1 cm in diameter a year while the accumulation of diameter of branching species in the same time may be 10 cm (Gladfelter et al, 1978).

However, in spite of the fact that branching forms achieve a larger size relatively faster than massive forms, it must be noted that the rate of calcium carbonate accumulation is greater in the latter (Gladfelter et al, 1978).

The growth-rate may alter by age. Larger colonies increase about the same amount in absolute size as smaller ones. This means that, like all other organisms, they grow proportionately more slowly as they age (Connell, 1973).

Apart from these differences, each species also has its own maximum growth-rate. Some branching species, for instance, may grow faster than others, e.g. Acorpora and Seriatopora. Growth-rates of diameters of some species in the research area found in literature are:

- *Favia* spp. 3.5-7.7 mm a year (Vaughan, 1915).
- A colony of *Porites* grew in 18 years from 5.8 to 6.9 metre (Mayer, 1918).
- *Acropora hyacinthus* 5.1-19.1 cm a year (Mayer, 1924)
- *Pocillopora damicornis* 2.6-8.1 cm a year (Mayer, 1924)

Because of the short duration of our study no growth-rate measurements were carried out, and only actual length was recorded.

**SOLIDITY**

The size of coral colonies may be determined by their solidity. This, in turn, is determined by the arrangement of the polyps and the growth form. The influence of the arrangement of calices is, for instance, found by Lobophyllia spp. This species, with a phaceloid arrangement, may form large, massive colonies that disintegrate at the margins due to their own weight, and decay to rubble.

Solidity and colony growth form are related to each other: e.g. a foliate colony is less sturdy than a massive one.

**COMPETITIVE BEHAVIOUR**

Corals compete with many organisms, but because of the complex nature of this issue only the competition for space within the Scleractinia will be highlighted below.

Size of coral colonies. 89
If little competition for space exists, coral colonies will be large, and if a species is highly competitive, a mono specific coral cover may result. Competition for space between coral species may display itself in aggressive behaviour. At places where two aggressively competing species approach each other, a certain type of large tentacles called mesenterial filaments, is projected. These secrete a toxin, and the final result may be the consumption of the competitor (Lang, 1970). Aggression between coral species has been the subject of several studies (Sheppard, 1979; Land, 1974), and it is possible to construct a rough 'aggression table' from their data:

**strong aggression:** Acropora variabilis, Galaxea clavus, Goneopora spp., Fungia spp., Herpolitha limax

**moderate aggression:** Acropora hyacinthus grp., Favia favus, Favia stelligera, Lobophyllia spp. Echinopora lamellina, Pocillopora verrucosa

**weak aggression:** Porites lutea, Montipora spp., Astreopora ocellata, Seriastopora hystrix, Leptastrea transversa

From this table may be noted that solitary species are strongly aggressive. The slow growing Porites lutea is weakly aggressive so there must be other factors that enable this coral to reach big sizes. Apart from this inter-specific competition there may also be a certain degree of intra-specific competition. There is no aggression between individuals of one species, and the colonies may grow against one another. This does, however, result in a hampering of each others growth, as light, space and substrate may be limiting factors.

6.2.2 Environment

Environmental factors naturally exert a large influence on the sizes of the colonies. The large variety of influences will be dealt with in the discussion of the results.

6.2.3 Age

The size of a colony is also determined by its age. In general, a colony will increase in size with age. Because of the complexity of the influences of the environmental factors it is difficult to determine the exact relationship between size and age. Only under similar environmental conditions one can ascribe the differences in size between specimens of one species to differences in age. In the field, however, one can usually not establish if the environmental conditions are comparable. Coral age may be determined via several methods. For instance, in a cross-section one may distinguish growth rings. These may occur as a coral temporarily decreases its growth-rate, and the bottoms of the thecas (see chapter 1) are deposited closer to each other. This decrease in growth-rate may be caused by a number of factors, such as wet season with fresh-water influence and lower temperatures (Wethey & Porter, 1976). According to Knutson et al (1972), the influence of different cloud covers in different seasons may induce measurable differences in growth-rate, in spite of constant water temperatures. Another method for measuring coral age is the addition of a dye to the medium, which results in a coloured band in a cross-section in later years. From this band the amount
of deposited calcium carbonate may be determined (Dustan, 1975), and a
calculation of the age of the colony can be made. A similar method is based
on the incorporation of radio-active isotopes, such as strontium, wich were
relatively abundant in the earth atmosphere shortly after nuclear experiments
in the fifties. From the location of an isotope-enriched band in a coral cross-
section, the growth-rate, and hence the age of the colony may be calculated

6.3 DATA USED

The sizes of the coral colonies were assessed by means of a vertical projection
of the maximum diameter of each colony. A consequent error that was made
is that large colonies may occur under several relevée-lines (see chapter 3),
and thus be involved in the calculation on several occasions. In this way,
larger colonies may have been 'over-estimated'. However, this does not pres­
ent any serious problems in this discussion, as only the extreme values are
relevant in the results.
The discussion of the results is based on triads (see chapter 3) and coral
formations (see chapter 4).

6.4 RESULTS

The results are presented in 2 tables and one histogram.
In Table 21 average size per species are given.
In Table 22 average size of common species per triad are given. Only the
sizes of common species are given so that differences between triads can be
found. Common means here in more than 28 triads. This number of 28 is cho­
sen because many species occur in 28 or more triads. Occurrance must be in
many triads otherwhise a comparison between triads can not been made.
In order to give an impression of the spread of the sizes in one triad of a
common species (Acropora hyacynthus-grp) size-histograms are given
(Table 23).
In the handling of the data the Alcyonacea (soft corals) and Millepora spp. (a
hydrozoan) have also been dealt with.
Table 21: Average size per species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Nr. of colonies</th>
<th>Av. size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astreopora ocellata</td>
<td>186</td>
<td>53 cm</td>
</tr>
<tr>
<td>Montipora spp</td>
<td>1408</td>
<td>41</td>
</tr>
<tr>
<td>Acropora hyacinthus-grp</td>
<td>1970</td>
<td>27</td>
</tr>
<tr>
<td>Acropora formosa-grp</td>
<td>511</td>
<td>63</td>
</tr>
<tr>
<td>Acropora variabilis-grp</td>
<td>193</td>
<td>47</td>
</tr>
<tr>
<td>Seriatopora hystrix</td>
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<td>17</td>
</tr>
<tr>
<td>Stylophora pistillata</td>
<td>150</td>
<td>14</td>
</tr>
<tr>
<td>Pocillopora damicornis</td>
<td>294</td>
<td>18</td>
</tr>
<tr>
<td>Psammocora contigua</td>
<td>49</td>
<td>10</td>
</tr>
<tr>
<td>Alveopora allingii</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Goniopora spp</td>
<td>24</td>
<td>40</td>
</tr>
<tr>
<td>Porites eridanii</td>
<td>656</td>
<td>27</td>
</tr>
<tr>
<td>Porites lutea</td>
<td>356</td>
<td>69</td>
</tr>
<tr>
<td>Pavona variabilis</td>
<td>22</td>
<td>14</td>
</tr>
<tr>
<td>Pavona spp</td>
<td>79</td>
<td>25</td>
</tr>
<tr>
<td>Gardinoseris planulata</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Pachyseris rugosa</td>
<td>24</td>
<td>83</td>
</tr>
<tr>
<td>Leptoseris pappracea</td>
<td>3</td>
<td>27</td>
</tr>
<tr>
<td>Fungia spp</td>
<td>301</td>
<td>10</td>
</tr>
<tr>
<td>Herpolitha limax</td>
<td>5</td>
<td>26</td>
</tr>
<tr>
<td>Cycloseris patelliformis</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Polyphyllia tajpanima</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>Podobachia spp</td>
<td>2</td>
<td>35</td>
</tr>
<tr>
<td>Coscinarea monile</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>Favia favus</td>
<td>11</td>
<td>21</td>
</tr>
<tr>
<td>Favia speciosa</td>
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<td>18</td>
</tr>
<tr>
<td>Favia stelligera</td>
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</tr>
<tr>
<td>Favia maxima</td>
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<td>35</td>
</tr>
<tr>
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</tr>
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<td>Favites abtida</td>
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<td>23</td>
</tr>
<tr>
<td>Goniastrea retiformis</td>
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<td>55</td>
</tr>
<tr>
<td>Platygryra lamellina</td>
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</tr>
<tr>
<td>Leptastrea phrygia</td>
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<td>59</td>
</tr>
<tr>
<td>Hynophora exesa</td>
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</tr>
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<td>Cyphastrea serailia</td>
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</tr>
<tr>
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</tr>
<tr>
<td>Oulophyllia spp</td>
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<td>60</td>
</tr>
<tr>
<td>Galaxea clavus</td>
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<td>127</td>
</tr>
<tr>
<td>Galaxea fascicularis</td>
<td>813</td>
<td>15</td>
</tr>
<tr>
<td>Acanthastrea echinata</td>
<td>84</td>
<td>33</td>
</tr>
<tr>
<td>Acanthophyllia spp</td>
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</tr>
<tr>
<td>Blastomussa spp</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>Lobophyllia spp</td>
<td>22</td>
<td>246</td>
</tr>
<tr>
<td>Mycedium elephantotus</td>
<td>44</td>
<td>52</td>
</tr>
<tr>
<td>Oxyypora lacera</td>
<td>6</td>
<td>47</td>
</tr>
<tr>
<td>Pectinia spp</td>
<td>4</td>
<td>21</td>
</tr>
<tr>
<td>Echinophyllia aspera</td>
<td>8</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>Gyrosmilia interrupta</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Physogyra lichtensteinii</td>
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<td>70</td>
</tr>
<tr>
<td>Turbinaria peltata</td>
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<td>28</td>
</tr>
<tr>
<td>Tubastrea coccinea</td>
<td>7</td>
<td>21</td>
</tr>
<tr>
<td>Alcyonacea</td>
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<td>28</td>
</tr>
<tr>
<td>Millepora spp</td>
<td>514</td>
<td>36</td>
</tr>
</tbody>
</table>

Size of coral colonies.
| triad nr | Alc Acr for | Acr var | Acr pis | Sty spp | Hyd exe | Ast oce | Por lut | Mon spp | Con ret | Fat abt | Pla lam | Ech lam | Fav fav | Poc dam | Gal fas | Aca ech | Por eri | av. per triad |
|---------|------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------------|
| 0       | 48 19 -26 | 28 15 25 11 35 54 26 29 42 15 9 12 23 30 | 35 49 |
| 1       | 67 31 49 20 15 45 66 74 32 40 30 20 36 30 15 25 15 14 18 49 |
| 2       | 70 34 60 39 28 100 85 58 87 47 50 28 42 69 28 25 16 38 21 52 |
| 3       | 36 43 248 50 30 30 128 107 -- 78 47 50 70 94 10 -- 20 57 29 65 |
| 4       | 20 20 -- -- 49 8 24 28 20 37 26 41 25 23 76 19 12 15 -- 12 22 |
| 5       | 58 32 87 -- 10 54 85 10 25 12 80 42 31 98 10 18 15 30 23 54 |
| 6       | 17 21 20 40 15 31 19 18 26 32 30 13 25 5 18 10 13 -- 18 24 |
| 7       | 20 36 83 -- 18 10 32 44 -- -- 35 10 -- 5 10 14 80 -- 5 10 -- -- 7 27 |
| 8       | 37 28 43 52 8 32 18 57 47 36 35 23 31 -- -- 13 28 13 -- 30 31 |
| 9       | 27 30 74 47 19 18 50 36 45 15 28 -- 15 40 -- 27 17 -- 26 46 |
| 10      | 34 30 155 65 17 94 -- -- 10 20 37 -- 33 83 -- -- 30 13 -- 15 45 |
| 11      | 35 46 -- 85 23 56 77 65 267 40 40 30 62 76 23 33 12 20 23 68 |
| 12      | 20 24 52 -- 10 9 -- 35 10 -- 5 10 14 80 -- 5 10 -- -- 7 27 |
| 13      | 33 42 -- 50 15 -- 131 50 87 47 112 20 38 112 28 28 35 40 45 67 |
| 14      | -- 17 41 -- 15 9 -- -- -- -- -- -- -- -- -- -- -- 20 -- 28 11 -- 60 |
| 15      | 49 43 111 55 21 75 73 30 140 -- 59 51 32 41 33 13 17 38 56 64 |
| 16      | 10 14 81 81 19 34 30 -- -- 25 30 -- 19 65 -- 8 15 -- 22 38 |
| 17      | 18 20 45 -- 11 29 -- -- 20 23 18 19 15 25 25 20 15 18 -- -- 32 59 |
| 18      | 60 45 62 60 18 29 52 56 104 36 67 28 33 23 20 20 14 28 12 42 |
| 19      | 38 36 95 30 13 37 131 25 170 30 170 80 41 50 9 18 13 20 28 53 |
| 20      | 22 22 40 10 10 18 19 57 25 28 35 22 36 20 -- 10 13 25 12 22 |
| 21      | 37 20 101 -- 13 37 52 35 45 29 74 18 32 89 33 35 16 43 16 36 |
| 22      | 10 53 182 13 15 15 60 -- -- 16 30 10 -- 46 30 14 20 29 15 55 |
| 23      | 33 25 50 25 10 43 -- 40 -- 27 67 20 25 27 18 20 11 15 17 36 |
| 24      | 24 19 50 -- 14 18 50 -- -- 18 -- 11 -- -- 15 18 10 9 17 19 |
| 25      | 47 33 63 -- -- 13 65 35 24 38 -- 7 8 81 -- 11 13 12 -- 31 |
| 26      | 26 28 55 79 -- 25 87 90 57 44 80 13 46 87 33 12 15 76 18 48 |
| 27      | 33 9 -- 65 -- 26 38 55 51 37 -- 10 40 100 26 11 14 35 28 29 |
| 28      | 29 10 -- -- 5 -- -- 54 -- -- 18 71 -- -- 21 47 78 14 -- 7 18 21 37 |
| 29      | 18. -- -- -- -- 40 -- 30 128 177 40 15 -- 80 43 -- 20 -- -- 93 |
| 30      | 53 24 -- 60 -- 34 -- 97 80 78 200 15 -- -- 15 14 14 20 -- 42 |
| 31      | 38 18 55 65 -- 32 21 40 49 27 -- -- 10 13 35 10 12 13 25 21 34 |
| 32      | 25 10 -- -- 48 -- 5 20 18 -- -- -- -- -- -- -- -- 22 34 |
| 33      | 33 27 -- 25 65 55 148 94 -- -- -- 45 82 30 15 16 -- -- 57 |
| 34      | 55 24 25 41 11 28 30 -- -- 30 -- 14 -- -- 15 14 10 12 -- 27 |
| 35      | 48 20 76 43 5 44 20 30 24 31 35 11 15 80 13 12 12 18 17 29 |
| 36      | -- 32 40 -- -- 18 42 160 205 51 56 18 20 100 15 28 14 23 19 67 |
| 37      | 34 26 15 24 6 23 25 -- -- 8 22 40 13 20 78 18 12 17 18 14 24 |
| 38      | 16 70 -- -- 7 31 28 29 -- 21 35 100 25 13 18 38 20 61 32 |
| 39      | 34 36 85 36 -- 90 72 75 116 71 50 13 50 118 19 19 13 47 21 52 |
| 40      | 27 -- -- -- -- 55 75 100 77 135 30 24 58 28 61 -- -- 45 45 62 |
| 41      | 25 23 -- 25 12 20 68 38 35 115 8 21 83 -- -- 13 14 28 36 29 |
Table 23: Size-histogram of Acropora hyacinthus-grp

Size of coral colonies.
6.5 DISCUSSION

6.5.1 Average size per species

The largest average size of 246 cm was found in the Lobophyllia species (Figure 28), of which 22 colonies occurred in the relevées (Table 21). Outside the sample areas, colonies of this species of more than 10 metre in length were observed. Next in size is Galaxea clavus, with an average size of 127 cm, out of a total of 268 colonies occurring in the relevées. One ‘colony’ (or field, see 6.2) measuring 30x20 metres was found outside the sample area. The occurrence of such large fields may be the result of competitive strength, which is stronger than most other species (see 6.2.1).

Figure 28: View on a large Lobophyllia 'colony'.
The smallest average colony size was found in Cycloceris patelliformis, with an average size of 4 cm out of five colonies occurring in the relevées. Second smallest is Gyrosmilia interrupta, with 8 cm, and only one colony occurring in the relevées. Both species were found at deeper sites in the research area: i.e. at depths greater than 10 metres.

The differences between the species are very apparent. There are also differences between various species of the same genus, for example, Acropora hyacinthus group and A. formosa group have average colony sizes of 27 and 63 cm, respectively. The various Favia species also show large differences in size, the largest being F. stelligera, with 67 cm, the smallest F. speciosa with 18 cm.

The large average sizes of Porites lutea and Goniastrea retiformis are to be expected, as these species form the basis of boulder and boulder massive triads, with characteristic large colonies. Porites lutea is the largest of these boulders, this in spite of its weak aggression and slow growth.

It proved to be difficult to make a clear distinction between the various families of the Alcyonacea. The general impression was, however, that there was a difference in size between the Alcyoniidae and the Xeniidae. The former occur as encrusting species, forming slabs up to 4 metres in diameter. The latter were fields never larger than about 1 metre in diameter consisting of small individual polyps.

It would be interesting to compare these results with similar data from other areas, but, unfortunately, such data haven't been found by us.

### 6.5.2 Average size of common species per triad

Table 24 illustrates common coral species with an average size per triad above one metre.

From this table is evident that many large colonies occur in the boulder formations. Triads 13, 19 and 36 belonging to the boulder formations often occur in this table.

Large colonies hardly occurs on slopes.

In Table 24 one may further observe that:

- The Alcyoniidae in triads 2 and 3 have a large average size
- In triad 40 there is only one species with an average size of more than 1 metre, although the average size of all species taken together is almost 90 cm. Nearly all species in this area near triad 40 can thus be regarded as fairly large.

Concerning the largest colony per triad the following can be observed.

In the deeper-lying triads, Pachyseris rugosa is the species that forms the largest colonies. This may be due to the fact that deeper waters are less turbulent, which may enable this foliate species to attain a large size. P. rugosa is virtually only found at depths greater than 6 m.

Coral species with a massive growth-form form the largest colony in fifteen triads. These belong often to the boulder formation.

The largest colony was rarely a branched species. The species involved in these situations was usually Acropora formosa-grp. In four out of these five triads, the site was located on a slope, thus one may tentatively suggest that branched growth forms may form the largest colonies in a coral community when this is located on a slope (Bak, 1975).

Little can be stated about the average size per triad, as this is determined by the species composition, to a great extent.
Table 24: Distribution of large size coral species in triads and the coral formations.

<table>
<thead>
<tr>
<th>species</th>
<th>av. size (cm)</th>
<th>triad nr.</th>
<th>formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acropora formosa</td>
<td>248, 142, 155</td>
<td>3, 22, 10</td>
<td>platform, slope, boulder</td>
</tr>
<tr>
<td>Hydnophora</td>
<td>128, 131</td>
<td>3, 13, 19</td>
<td>boulder, boulder-massive, platform</td>
</tr>
<tr>
<td>Astreopora</td>
<td>160</td>
<td>36</td>
<td>boulder, platform, boulder-massive, boulder</td>
</tr>
<tr>
<td>Porites lutea</td>
<td>267, 140, 148</td>
<td>11, 15, 18, 33</td>
<td>boulder</td>
</tr>
<tr>
<td>Montipora spp</td>
<td>177, 118, 135</td>
<td>29, 39, 40</td>
<td>boulder-massive, platform</td>
</tr>
<tr>
<td>Goniastrea retiformis</td>
<td>200, 112, 115</td>
<td>30, 13, 41</td>
<td>platform, boulder</td>
</tr>
<tr>
<td>Favites abtida</td>
<td>128</td>
<td>19</td>
<td>platform, boulder-massive, boulder</td>
</tr>
<tr>
<td>Echinopora lamellosa</td>
<td>112, 100</td>
<td>13, 36</td>
<td>platform, platform, boulder-massive</td>
</tr>
</tbody>
</table>

6.5.3 Size classes

All 1970 colonies of Acropora hyacinthus-grp, that were recorded in the relevées, are distributed over six size classes as follows:

- $< 5, 5 - 15, 15 - 30, 30 - 60, 60 - 100, \text{ and } > 100 \text{ cm.}$

The average size of A. hyacinthus is 27 cm. One must, however, bear in mind that what was recorded as A. hyacinthus is not actually one species, but a group composed of several closely related Acropora species. From the histograms the following is evident:

- Small colonies are nearly always entirely absent in the boulder triads. A peak in the size-histogram is here usually present in the range 30-60 cm. The massive species which form the basis of the boulder formations are thus not the only large species present in the boulder zones.

- In the vicinity of Watamu, the peak of the size-histogram is usually reached in the size-classes 15-30 cm. In Malindi a similar result is only found on the northern side of North Reef.

- In triads where many small colonies are present (more than 20 of less than 5 cm diameter) the peak usually lies in the range 5-15 cm; an exception is formed by triad 20. In this case also many colonies are found...
in size classes above 5-15 cm. Thus there is no case of recent settlement with only small colonies.

- In 21 triads small colonies are either very scarce or absent. Most colonies in these cases fall in the classes 15-30 and 30-60 cm. The total number of colonies per triad is also rather small, and usually less than 20. This may indicate a prolonged period with poor conditions for the establishment of new colonies.

Sheppard (1980) found a double peaked size-histogram in observations on Acropora hyacinthus; one was in the class less than 5 cm, the other in the class 15-30 cm. He gave two possible explanations for this phenomenon:

- In time, there are peaks and dips in the rate of reproduction, which in turn lead to a peak in certain size classes, if the growth-rate remains constant.

- There is no constant growth-rate. Once a colony is somewhat larger than its immediate competitors, it rapidly increases in size.

He found the second explanation likelier; this forms an analogue to a forest, where small trees compete for sunlight, remaining stunted for a long time, and growing rapidly when a certain height above its immediate competitors has been achieved. His findings were, however, based on areas where there is a high density of coral colonies.

Coral colony data from the Malindi-Watamu area show that only one peak is attained in all size histograms, 13 times in the class 5-15 cm, 12 times in the range 15-30 cm and six times in the range 30-60 cm. No peak was found in the range less than 5 cm, which is unlike Sheppards (1980) findings. This may be partially due to our sampling method, which leads to a negative bias of the presence of small colonies. Another explanation is offered by the fact that coral density in our study area is lower than in Sheppards sample areas. His hypothesis about coral colonies remaining small due to inter-specific competition does not seem to hold in our case. The fact that only one peak is found in all triads also makes his hypothesis of 'peaks in reproduction' unlikely in our study area.

The apparent paucity of small colonies may, however, be due to sub-optimal environmental conditions in the area. These conditions may lead to a general lack of vigour of the inhabitants of the reef, corals included, leading to a lowered fertility and a lowered representation of small colonies. Differences between size histograms of a single species of various areas, could reveal the chance of development that particular species may have in a given area.
Chapter 7

CHARACTERISATION OF THE MALINDI WATAMU REEF COMPLEX.

7.1 COMPILED DATA TABLE.

Before the topographical units are discussed, their most important parameters are given in summary below in Table 25. Comprehensive data are given in appendix A.

Table 25: Condensed data (with standard deviation).

<table>
<thead>
<tr>
<th>group</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>% inj</td>
<td>11.9</td>
<td>20.9</td>
<td>16.6</td>
<td>12.8</td>
<td>15.4</td>
<td>2.5</td>
</tr>
<tr>
<td>sd</td>
<td>4.3</td>
<td>3.1</td>
<td>3.2</td>
<td>4.6</td>
<td>5.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Alcy</td>
<td>2.8</td>
<td>5.0</td>
<td>4.3</td>
<td>12.5</td>
<td>2.8</td>
<td>19.7</td>
</tr>
<tr>
<td>sd</td>
<td>2.4</td>
<td>3.2</td>
<td>0.7</td>
<td>9.9</td>
<td>4.3</td>
<td>2.0</td>
</tr>
<tr>
<td>size</td>
<td>44.4</td>
<td>52.5</td>
<td>49.7</td>
<td>31.6</td>
<td>62.5</td>
<td>29.5</td>
</tr>
<tr>
<td>sd</td>
<td>11.0</td>
<td>11.3</td>
<td>16.0</td>
<td>10.3</td>
<td>22.8</td>
<td>7.5</td>
</tr>
<tr>
<td>spp</td>
<td>23.0</td>
<td>25.2</td>
<td>29.7</td>
<td>23.5</td>
<td>19.8</td>
<td>30.0</td>
</tr>
<tr>
<td>sd</td>
<td>3.9</td>
<td>2.0</td>
<td>2.6</td>
<td>3.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>% ps</td>
<td>88.4</td>
<td>69.2</td>
<td>52.3</td>
<td>43.9</td>
<td>40.0</td>
<td>35.0</td>
</tr>
<tr>
<td>sd</td>
<td>7.8</td>
<td>12.4</td>
<td>17.2</td>
<td>16.0</td>
<td>17.2</td>
<td>17.0</td>
</tr>
<tr>
<td>depth</td>
<td>2.6</td>
<td>2.0</td>
<td>4.0</td>
<td>4.0</td>
<td>5.0</td>
<td>23.5</td>
</tr>
<tr>
<td>sd</td>
<td>1.5</td>
<td>0.8</td>
<td>2.3</td>
<td>2.8</td>
<td>2.4</td>
<td>0.0</td>
</tr>
</tbody>
</table>

The groups listed above represent the following:
1: slopes: triads 7, 9, 10, 12, 14, 16, 17, 22, 23.
2: Malindi-boulders: triads 0, 5, 13, 15, 18, 19.
3: boulder massives: triads 11, 39, 41.
4: platforms: triads 1, 2, 4, 6, 8, 20, 24, 25, 26, 31, 34, 35, 37, 38.
5: platforms en Watamu-boulders: triads 27, 29, 30, 33, 36, 40.
6: deep slopes: triads 28 and 32.
7: not classified: triads 3 and 21.

The abbreviated parameters represent:
% inj = percentage injury
Alcy = relative cover of Alcyonacea
size = average size in centimetres
spp = number of species  
% ps = percentage of the potential substratum that is covered  
depth = average depth (in m).

7.2 THREE COMPRISING GRAPHS.

Figure 29 shows the total coral cover of the potential substratum related to the number of species found in every triad. Two lines are drawn in the graph to illustrate the spread in the number of species in the triads. If the coral cover of the potential substratum is between 20 and 80 percent the species diversity (or here species number) lies in the intermediate to high range. At a 50% coral cover, the species number reaches its highest level. Here we find a situation of profitable organisation in space of the corals present. The inter- and intraspecific antagonistic behaviour is absent, and fast growing species do not overshadow weak and slow growing coral specimens. Sheppard (1980) found a similar phenomenon.

Especially interesting are the margins of the graph. If the coral cover of the substratum is low, two possibilities are open.

1) The species diversity is low. The coral growth consists of a relatively uniform, only limited coral cover of the substratum (triad 30), in which the environment is conditioned by one single factor, such as high strength of current or exposure to the sea. Three development strategies are open. Firstly, there may have been a catastrophe, after which regeneration has taken place. Very often, however, species diversity is at its highest immediately after the onset of regeneration (Sheppard, 1980). Another possibility is that one dominating factor, such as current speed or surf, blocks the development to a higher level of diversity. Lastly, a negative development (e.g. silt) may have set in, followed by the survival of a few resistant species.

2) The species diversity is high (triad 32). In this case this triad is situated on a deep slope, and is highly heterogeneous in character. The coral community is very complex, because of its geological formation with a lot of ecological niches.

The right side of the graph shows triad 14. The cover of the potential substratum is extremely high (almost 100%). Practically no algal cover was found and species diversity is low. Galaxea clavus is the dominating species; it forms monospecific "carpets" of more than 500 square metres. Despite the fact that Galaxea clavus is very aggressive compared to other Scleractinians, probably an other, unidentified factor is also likely to be responsible. A terrestrial analogue is formed by arable fields, on which monospecific stands are only maintained taking severe and regular measures.

Figure 30 shows a histogram of all triads (0 - 41) both on the total coral cover and on the coral cover on solid substratum. Two items are outstanding in this histogram. First of all the total coral cover and the coral cover on solid substratum in the Malindi area is much higher than in the Watamu area (70 and 37% respectively). This specifically is valid for the boulder and platform formations. The high coral cover (85 - 90%) in the Malindi area is determined to a great extent by the effective cover of the slopes of the patch reef complex (North Reef, Tewa Reef, and Leopard Reef). These patch reef structures are absent in the southern part of the study area. Patch reef structures may be considered as an internal increase of potential (slope-) substratum. If the water movement on the slopes is high
Figure 29: Number of species related to the coral cover on solid substratum.

enough, deposition of silt is reduced to a minimum. Thus Acropora species, typical for slopes, flourish in spite of their low tolerance of sediment. Boulders, however, are observed to suffer under sedimentation. In the second place the Malindi area positively distinguishes from the Watamu area with regard to the difference in the total coral cover and the coral cover on solid substratum; in the Malindi area the difference is clearly bigger. The biggest part of the substratum is potentially being used by stony corals, in contrast to Watamu, where only a relatively small percentage of the solid
substratum is covered by Scleractinia. A flourishing macro-algae cover blocks coral settlement. Concluding can be said, that the Watamu area is badly developed considering coral growth. Also the stretch in between (21 - 24) shows a decline in the difference of the total coral cover and the actual potential coral cover on solid substratum.

The conception of coral cover on solid substratum (chapter 3) in relation to the proportional injuries, is given in Figure 31. Within the coral formations platforms, boulder massives, and boulders, large variation in cover on solid substratum remains apparent. Slopes in the north of the research area (7, 9, 10, 11, 14, 16, 17, 22, 23), strictly show a high proportional coral cover of the solid substratum (85 - 95 %); On slopes in the south however, the coral cover is low on solid substratum (37 %) (Figure 30).
Figure 31: Coral cover on solid substratum related to injury.

The geographic significant difference in coral cover of the solid substratum seems to have no connection with the differences in proportional injury. Apart from coral formation character and species characteristics, proportional injury seems to be linked with specific locations as described in chapter 4 and 5.
7.3 THE MALINDI WATAMU REEF COMPLEX.

7.3.1 Introduction.

The results of the three previous chapters will be combined in the following chapter, and concluding remarks on the ecology and possible decline of natural value of the Watamu Marine National Reserve will be given. Data of all triads together give a rather jumbled overall impression. Data arrangement on the basis of topographical units enables one to draw general conclusions on local circumstances on the reef. The statements are based on topographical units and general observations, as well as on literature. The division of the reef in the following units is carried out on the basis of geomorphology of the area (chapter 2). The description of all units together gives a detailed picture of the whole reef complex. The topographical units distinguished are:

1. Silversands,
2. North Reef,
3. Tewa Reef,
4. Leopard Reef,
5. Kwafungi,
6. Mushroom Rock,
7. Warakatibu,
8. Malindi Reef,
9. Turtle Bay and Blue Lagoon,
10. Mida Creek,
11. Whale Island.

All basic data are given in appendix A. In the following paragraphs a general picture will be outlined; the following items will be explicitly discussed:

- the specific site,
- the depth or depth range,
- the composition of distinguished structure types,
- the coral assemblage composition,
- the dominant taxa,
- the injury by (calcareous) algae on corals,
- notable data in comparison with other units such as the size of the coral colonies and the proportional cover of the potential substratum by coral colonies.
Unfortunately some of the information gathered is not useful, because comparable investigations of other areas are only sporadically carried out or published. Additional specific data should be gathered to confirm certain ideas derived from these incomplete data.

7.3.2 The topographical units.

Silversands (Figure 32)
(triadnr. 0, 1, 2, 3, 4)

This unit stretches from Vasco da Gama Point to just north of Casuarina Point. Parallel to the beach, about 200 metres off the high tide mark, an algal ridge is present. On the gradually sloping platform on the seaward side of the algal ridge corals may be found, as well as on several shallow parts further on. Inside the shallow lagoon, that is used as a boat channel, corals were found only sporadically.

Figure 32: Overview of Silversands.
Within this topographical unit we found the most northerly distributed coral colonies of the study area (the Watamu Marine National Reserve): Pocillopora damicornis and Alcyonacea on open sides (on semi-fossil rock) in large seagrass beds. North of Vasco da Gama Point the growth consists totally of sea grasses. Further north, in the Malindi Bay, the sea bottom consists of sand of marine and terrestrial origin.

All triads of this unit are classified as platforms. And by means of DCA-ordination (chapter 4) all triads were arranged in the Porites assemblage, of which most are arranged within the Montipora-Acropora hyacinthus subassemblage. This points to low water turbulence on macro-level.

Dominating taxa are the Acropora hyacinthus-grp, Montipora spp., Porites eridani and Echinopora lamellosa. Montipora spp. and Echinopora lamellosa indicate turbid waters and it seems most likely that this is caused by the silt loaded effluent of the Sabaki river. The fact that the nearby Malindi Bay silts up rapidly supports this.

Generally considered, this topographical unit has a high cover of Alcyonacea with a large average size, indicating turbidity, regressive evolution of the reef (Pichon, 1974), and indicating the occurrence of 'suboptimal' conditions for the Scleractinians (Schuhmacher, 1975). It should be noted, however, that Alcyonacea are a quite common feature on the whole reef.

In the coral community on the shallow seaward sites, Millepora spp. and Galaxea fascicularis dominate. Especially the huge amount of coral colonies and their small average size points to poor growth circumstances for corals in these areas, or to the recent colonization by corals.

The injury of corals by (calcareous) algae is quite low, except for the most northern part, where Goniastrea retiformis is dominant. It is likely, that its typical molar-shape contributes to its chances of injury and the high injury rate of this species. Apart from this type of injury, 'black cracks' were very frequently encountered. What is outlined above gives the impression that no particularly favourable conditions for still 'living' coral colonies exist in this area.

Considering the actual coral growth, it can be stated that this unit can in no way be typified as flourishing, and that the Sabaki river must be responsible to some extent for the situation because of the silt brought down to this area by the prevailing currents during the north east monsoon.

North Reef (Figure 33)
(triadnr. 5, 13, 6, 8, 7, 9, 10, 12, 14)

The North Reef complex, off Casuarina Point, is roughly situated at a distance of about one kilometre to the shore. It can be characterized, for the major part, as a patch reef (Battistini et al, 1975). It embraces a reef flat of semi-fossil coral rock encircled by slopes. Especially the east side of this slope is quite steep. Both channels on the east and west side of North Reef, Stork Passage and Barracuda Channel respectively, account for this. In north and south-west directions the platform changes into a gently sloping platform. By far the greater part of the reef flat consists of dead coral rock, and it is regularly exposed at low tide. During low tide two 'bays' are formed. The one south has an eastern inlet; the other lies in the northern part of the platform with a north-eastern inlet (Figure 33). Living coral occurs on the upper edges of the east and south-west slopes of the platform and in the southern bay. Especially at the south side of it (the Coral Gardens of Malindi) many boulders were found. In the north, the reef flat transforms into boulder and platform formations. The northwest and south side of the North Reef are not covered with living coral.

The east and north-east side of North Reef is exposed to heavy surf and belongs to the most exposed coral formations of the whole reserve. As a con-
The DCA-ordination divided the North reef into two assemblages. Clearly different were the slopes (7, 9, 10, 12, and 14), belonging to the Acropora assemblage, characteristic for high water movement. The Porites assemblage is divided into two groups: triad 5 and 13 (boulder formations), belonging to the Goneastrea-subassemblage and the two remaining (6 and 8) which belong to the Montipora-Acropora hyacinthus subassemblage.

Species diversity on the North Reef is of medium range. It varies between 15 to 25 per triad. The platforms are generally poorer in species than the slopes.

The slopes of North Reef are characterized by a very high cover of the solid substratum when compared to other slopes (Tewa Reef). Especially the southeast slopes bear a maximum coral cover despite a limited species diversity (14 species). The high coral cover may be attributed to one species: Galaxea clavus, that is known for its highly aggressive and highly competitive nature, compared to other Scleractinians (Sheppard, 1979). To a lesser extent, this phenomenon was also found on seaward, exposed slopes. Fundamentally, the
Acropora formosa-grp dominates, together with Galaxea clavus, as is typical for surf zones with strong currents. The land orientated slopes are characterized by the presence of Pavona species and Porites lutea; it is obvious that surf plays no significant role in these coral communities. Generally speaking species found in more quiet waters (as Favia and Favites) are lacking on slopes, and species of macro-water turbulance such as ramose species of Acropora are very common.

Both boulder triads on the North Reef (in the northern part and the Coral Gardens) bear the highest coral cover on solid substratum compared to other boulder triads in the reserve (80 - 90% to 35 - 76% respectively). The aforementioned triads are mainly characterized by Goniastrea retiformis, that is heavily injured as in other places in the reserve. The Coral Gardens of Malindi are an exceptional case within the whole topographical unit, due to a high percentage of mechanically damaged colonies (35%). Considering the fact that the Coral Gardens are situated in a sheltered area, the damage found must without doubt have been caused by tourists and the anchors of the glassbottom boats. The same negative impact is valid for the Acropora colonies at the south-west edge of North Reef, which is frequently visited by tourists as well (7% of the colonies is mechanically damaged).

The Acropora hyacinthus-grp is the dominating taxon on the coral abundant platforms. They also have Montipora spp. and Acropora variabilis in common. (Both are relatively common on the whole reef.) The platforms in the western part are protected better from the surf than the platforms on the northern side. The presence of Porites lutea in the one, and Goniastrea retiformis in the other, is explained by the difference in current or, more precisely, the absence of current. Porites lutea is reknown as a species capable of surviving in an extreme situation, such as a deficiency in current (as well as food and oxygen supply) (Ladd, 1977; Kinsman, 1964) and/or a high saltness of the water. Also the much higher cover of Alcyonacea indicate less favourable conditions for stony corals (10 - 25% and 1 - 2.5% respectively). Both platforms are moderately covered with corals; in spite of the fact that on the northern platform much more solid substratum is available for coral settlement than on the western platform. The most plausible explanation is an intervention by 'fleshy algae', which are excellent trappers of silt, making the substratum unsuitable for coral settlement; a cumulative effect develops when silt is present in the water.

Due to numerous causes, corals on the North Reef unit are strongly injured, yet locally the corals flourish and are apparently in good shape. However, if the excessive growth of Galaxea clavus can be regarded as a positive factor may be seriously questioned. Monospecific communities often point to extreme environmental conditions, such as pollution, and nutrient enrichment. Finally, attention should be given to the fact that on the North Reef a strong increase in the seagrass beds on the reefflat during the last 23 years was found. This information is based on the comparison of aerial photographs (see Giesen & v.d. Kerkhof, 1984).

Tewa Reef (triadnr. 16)

Tewa Reef is located just south of the Malindi Marine National Park. Because of its position between Leopard Reef and the coast on the one hand, and the confluence of Stork Passage and Barracuda Channel on the other, strong currents occur. Tewa Reef is part of the larger patch reef complex in this area. Coral coverage is mainly found on the slopes, so that this triad is classified with the slope formations. The DCA-ordination classified the triad to the 'slopes' as well, namely to the Acropora formosa-assemblage.
A striking phenomenon in the whole area is the enormous size of Galaxea clavus beds (some larger than 500 square metres); this species is renowned for its aggressive nature, and its high competitive power with regard to other stony corals (Sheppard, 1979).

Next to Galaxea clavus, the Acropora formosa-grp dominates, and Fungia spp. are quite common, especially on current exposed slopes. A lot of rubble and a high coral cover of the solid substratum is characteristic for slopes. The cover by (calcareous) algae on coral is small, even in comparison to other slopes. Only at Tewa Reef a single specimen of Acanthaster planci (crown-of-thorns starfish) was encountered. Thus, predation on corals by this animal may be considered of minor importance (Endean, 1976).

Leopard Reef (triadnr. 17)

This reef is located about 2 to 3 kilometres off Leopard Point, and east of Tewa Reef. An extensive amount of the semi-fossil plateau is part of the patch reef complex, and is exposed to the relatively high tidal movements of the sea. Because of the patch reef character this unit has a lot in common with North Reef and Tewa Reef. Against all expectations no corals were found on the seaward exposed slopes, most likely due to silt deposition from the Sabaki river. On the east side a sand bank is situated, that falls dry at low tide. Only in the western and most sheltered side coral growth occurred. The cover is very heterogeneous, and species diversity is high.

The coral cover has a strongly dualistic character. On the one hand it consists of species belonging to the slope formation, and on the other it belongs to the platform formations. The former consists mainly of huge Galaxea clavus beds, as on the east slopes of North Reef and on Tewa Reef, and an almost total coral cover of the solid substratum is found. The Alcyonacea cover is low, and Fungia and Acropora formosa-grp occur very frequently. The 'platform' type is represented by Acropora hyacinthus-grp, Montipora spp. and Millepora spp. as well as by Stylophora pistillata and Goniastrea retiformis.

Kwafungi (triadnr. 11)

This topographical unit consists of a strip of about 100 meters length, and located 500 metre off the beach between Casuarina Point and Mushroom Rock. The North Reef complex protects this unit from heavy surf. In spite of this, it certainly is a dynamic environment, because of the tidal movements through Barracuda Channel.

The coral cover consists mainly of boulder massive formations. Locally, however, separate boulders were found, alternating with sand flats. By DCA-ordination the triad is allocated to the Porites assemblage. Together with triads 39 and 41, triad 11 forms a separate Astreopora subassemblage in between the Goniastrea and the Montipora-Acropora hyacinthus subassemblage (all three belonging to the Porites assemblage). The species composition of this unit shows high resemblance to the Whale Island unit. Kwafungi has a relatively high species diversity - more than 30 species - in comparison with Warakatibu, which belongs to the same coral formation. The dominating species are Porites lutea, Echinopora lamellosa and Platygyra lamellina. Acropora variabilis, Acropora hyacinthus-grp, Leptoria phrygia, and Millepora spp. are frequently found as well. Compared to other boulder masses, the corals in this topographical unit are more overgrown by algae. Although the high coral cover on solid substratum
seems to indicate favourable conditions for coral growth, the injury rate by algae points to a recent deterioration of the environment. This decline is possibly due to its position, at the edge of Barracuda Channel. Through this channel lots of silt are transported southward during a specific part of the year. In the less dynamic environment of Kwafungi, the suspended matter may settle on the corals and in the long run damage them. The less injured boulder massive formations of Warakatibu probably enjoy more favourable environmental circumstances. Striking in this unit is the presence of large colonies. This suggests that conditions must have been stable for some time for the relevant species.

**Mushroom Rock**

(triadnr. 15, 18, 19)

This topographical unit stretches from Leopard Point in the north to Warakatibu in the south. The largest concentrations of corals were found in a boulder formation about 500 metres of the mean low tide level, at a depth of 3 metres at low tide. In contrast to the Silversands unit and the surf exposed parts of the North Reef, water movement caused by surf is practically absent; this unit is situated in the ‘surf-shade’ of North Reef. Compared to other boulder formations this unit is very rich in species, viz. 25 to 28. The coral community consists mainly of boulders of Goniastrea retiformis (typical for boulder zones in the neighbourhood of Malindi) and locally of Porites lutea. By DCA-ordination all triads were allocated to the Goniastrea subassemblage, which is a part of the Porites assemblage. Typical taxa are the Acropora formosa-grp, Galaxea fascicularis and the Acropora hyacinthus-grp. Incidental concentrations of Galaxea clavus were found, which are a normal occurrence on slopes and platforms.

Taking the whole reserve and specifically this unit into account, the coral cover on solid substratum declines, going from the north to the south. North Reef has the highest degree of coral cover, and Watamu has the lowest. Mushroom Rock takes an intermediate position between both aforementioned. The injury rate of the corals by algae in this unit, makes the highest proportion contribution for the whole reserve. This high score is mainly due to the luxurious algae cover on Goniastrea retiformis. A plausible explanation for this phenomenon is the geographical position of the unit, in combination with the low water dynamics. The suspended matter (originating from the Sabaki) settles down, improving the micro-environment for algal settlement. Especially fleshy algae (Turbinaria, Ulva spp.) are excellent silt-trappers; as a consequence an itself strengthening process develops (W. Hoppe, p.c.). On the other hand it was found that Goniastrea retiformis, or more generally speaking boulders, of a larger size, often are covered by calcareous algae. A possible explanation for these findings is the specific ‘molar’-shape of the boulder, increased sensitivity due to ageing, or an increased injury risk because of increased size.  

A striking phenomenon encountered in the boulder zone of this unit compared to other units (North Reef and in Watamu) is the abundance of Alcyonacea colonies, which moreover have a remarkably high cover. This could point to suboptimal conditions for stony corals, whilst the species diversity is (still) high. This may indicate that the silting influence of the Sabaki river is a recent phenomenon.

**Warakatibu (Figure 34)**

* A larger coral colony has more polyps than smaller one's of the same species. The possible chance of injuries increases with the number of polyps.
Figure 34: Warakatibu and adjacent reefs.

Warakatibu consists of a long-drawn reef of about 3 kilometres extending from Mushroom Rock up to Mayungu. The algal ridge falls dry at low tide and coral growth occurs in a strip on the sea-ward side of the reef, exposed to surf.

Warakatibu can be typified as a boulder massive formation in which Acropora hyacinthus-grp and Montipora spp. dominate. Frequently Montipora spp. and Galaxea fascicularis are encountered.

In the northern part Alcyonacea dominate as well, and Porites eridani, Hydnophora exesa and Echinopora lammelosa are very often present. The presence of Goniastrea retiformis in the southern part is explained by the more restless waters at the mouth of the Malindi Reef lagoon. The northern part is less exposed to surf and the influence of the sea, which explains the presence of Porites lutea. The division of Acropora hyacinthus-grp into size classes reveals an occurrence of small colonies for this unit, compared to other
boulder massive formations, which are normally characterized by the presence of only a few small sized colonies.

Malindi Reef (Figure 35)
(triadnr. 22, 23, 24)

This unit of about 10 kilometres length, stretches from the fishing-village of Mayungu, 500 metres from the shore, to about 2 km north of Blue Lagoon. At low tide an extensive platform falls dry. Only sporadically corals were found here, and if so, they were only encountered in tidal pools on the reef flat. Coral growth however occurred on the seaward side of the reef flat, from the low tide level to 200 metres from the reef flat. The coral cover is most luxurious in the north and declines going south. South of triad 24, only a meagre coral cover occurs, consisting mainly of Alcyonacea. No triad was placed in this area because the cover does not fulfil the criteria needed for conveying investigations (chapter 3).

Figure 35: Malindi Reef and the natural harbour of Mayungu.
The triads were arranged in the platform formations, on grounds of their species composition. Triads 22 and 23 are part of the Acropora assemblage. During field work high water turbulence was felt. This water turbulence is also expressed in the grooves and spurs, observed in this unit (see also Rosen, 1971; Shinn, 1963). Triad 24 was arranged within the Montipora-Acropora hyacinthus subassemblage. From the north to the south (from triad 22 to 24) a striking development of several factors may be noticed. First of all a development in species composition. In the extreme north, we found that coral communities are dominated by Acropora formosa-grp, Stylophora pistillata and Seriatopora hystrix. Galaxea clavus, Echinopora lammellosa, Fungia spp. and Acropora hyacinthus-grp are locally very abundant. This typifies its 'slope'-quality excellently. To the south Porites eridani and Acropora hyacinthus-grp dominate to an increasing extent. Montipora spp., Goniastrea retiformis and Galaxea fascicularis become more abundant as well, giving it its 'boulder'-quality. Even further south, we encountered species-poor platform formations consisting of Acropora hyacinthus-grp, Montipora spp. and several other encrusting species. Porites eridani and Galaxea fascicularis decreased in numbers. Quite striking is the absence of Porites lutea in all triads. Secondly, a clear decrease in the coral cover of solid substratum is found going south. South of triad 24 the coral cover diminishes rapidly, as was mentioned above. Furthermore, the total amount of Alcyonacea increased south as well as the total amount of colonies. To the contrary, species diversity decreases southward as well as the size of the coral colonies and the injury by algae. Turtle Bay and Blue Lagoon (Figure 36) (triadnr. 29, 33, 36, 25, 26, 27, 30, 34, 37, 31, 35, 28, 32) This unit stretches from the Blue Lagoon area to the entrance of Mida Creek. Parallel to the beach about 1 km off the coast an algal ridge occurs, upon which are sand banks locally superimposed. The shallow lagoon in between consists on the one hand, of fossil rock overgrown with algae and sparsely distributed coral colonies, and on the other hand by seagrass beds on sand. Inside the lagoon, parallel to the coast, lies an extended boulder formation. On the seaward side of this boulder formation runs a channel, that becomes shallower going north. This is probably caused by siltation, primarily of sand of organic origin (coral sand). On the basis of geomorphology (chapter 2) several zones are distinguished within this topographical unit. They correspond with the coral formations that were distinguished: platforms, boulders (parallel to the coast), and off shore, deep slopes. The coral community consists of a Montipora-Acropora hyacinthus subassemblage and an Astreopora subassemblage, both part of the Porites assemblage. The deeper triads belong to a separate Pachyseris assemblage. Each zone in the whole complex will be discussed separately in the following paragraphs. Porites lutea forms the basis of the boulder formation, accompanied to a greater extent by Goniastrea retiformis, going south. These boulders measure to about 5 metres in diameter. Although the partly dead surface is recolonized by other coral taxa, the species diversity is low. The total amount of species and coral colonies, as well as the total cover of living coral, and the coral cover of potential substratum, increases going from north to south. Besides this, the boulder zone changes in character from solitary boulders to a complex of boulders, and becomes wider at the same time. The aforementioned shows a clear gradient, that is most likely connected with currents, due to a poor connection with the sea. Food and oxygen supply may thus stagnate.
Locally the temperature of the water in the lagoon may also reach a high level up to 33 degrees C (Giesen & Van der Kerkhof, 1984). Quite surprising is the absence of Alcyonacea in the boulder zone. This may be due to the low amount of potential substratum for settlement, caused by the abundant growth of fleshy algae (e.g. Ulva spp and Padina spp). Immediately behind the algal ridge lies a gently sloping reef flat, descending to a depth of 10 metres. The coral cover consists mainly of seagrasses and patches or short narrow strips of fossil rock, covered with corals. The whole strip behind the algal ridge may be divided into two parts: the shallow part, that almost falls dry at low tide, and the deeper part. The whole platform reaches the coastline in the most northern part and is directly exposed to the sea. Current-strength and current direction are important environmental factors, for coral growth and the occurrence of specific species. Because of the plateau character, sedimentation and accumulation of coral debris occurs. Increasing depth causes a small shift in the dominant species. The transitional zone is about 5.5 metres deep. Going deeper the abundance of Acropora hyacinthus-grp gradually decreases. Astreopora ocellata, Hydno-
phora exesa and locally Echinopora lamellosa take its place. As almost everywhere on the reef, Montipora and Alcyonacea are present with a high cover.

Only triad 31 (at a depth of 12 m) differs from this pattern, because it is totally identical with the shallow location on the reef flats of this unit.

In the deeper parts, the Faviidae are very common, which indicates calm waters. By the latter is meant a low current-strength, and the absence of surf. On the strip just behind the algal ridge, the Faviidae are almost absent (except for Favites abtida). Also, the dominating encrusting life-form indicates the presence of current, but the absence of surf.

A third zone occurs on the steep slope, down to a depth of about 30 metres. Locally the slope is very steep (it is a nearly vertical wall) and because of its depth, currents are virtually absent. Sometimes overhangs were found. The coral cover is very heterogeneous. A low species number per sample and a high species number per triad is an indication of this heterogeneity. A substantial part of the total coral cover consists of Alcyonacea, and the dominating stony coral species are Echinopora lamellosa, Pachyseris rugosa and Alcyonacea. All these species belong to the encrusting and foliate growth-form, which are very characteristic for deep, steep slopes (Bak, 1975). Also Fungia species are very frequently found. The proportional injuries of coral colonies are particularly low, and the colonies are generally speaking small in size. Because of the depth, the growth rate is limited. Furthermore, the sliding down of coral debris and sand limits coral growth, because coral colonies become buried under the sand. Due to occasional strong currents small parts or whole colonies may break off or be disrupted (e.g. foliate taxa). So, rejuvenation rate on deep slopes is likely to be very high (Bak, 1975).

Mida Creek (Figure 37) (triadnr. 38)

The conditions in the neighbourhood of Mida Creek are mainly characterized by very strong tidal movements. The creek only communicates with the sea by a narrow entrance. Near this entrance, corals were found on platforms. The coral cover belongs to the Montipora-Acropora hyacinthus subassemblage of the Porites assemblage. Sand and rubble are practically absent, because of the strong currents. The substratum is covered to a small extent, as is the case on other platforms in the Watamu area. Coral settlement in this area seems to be limited.

The coral cover is dominated by Montipora and Alcyonacea species, and is furthermore typified by members of the Acroropa hyacinthus-grp, which are very common on the reef. The coral colonies are covered by (calcareaous) algae to a relatively high extent. The injury "pale tissue" is very frequently encountered, especially on Porites lutea and Pavona species. This may indicate recent and probably abrupt poor conditions for coral growth, that may possibly continue over a long period of time. The creek may be a source of eutrophication, e.g., by mangroves, see Giesen & Van der Kerkhof, 1984), and to a limited extent, of fresh water and silt, due to run off and erosion in adjacent agricultural areas. Giesen & Van der Kerkhof (1984) postulate that Sabaki River sediment that is transported along the coast during the north east monsoon, may be reworked by the strong currents of Mida Creek, and than brought into circulation close to the coast. Strong tidal currents however, causing highly dynamic conditions, bring about a good water aeration.

Whale Island (triadnr. 39, 40, 41)
Figure 37: Entrance of Mida Creek.

This topographical unit is situated just south of Whale Island. Fundamentally, the geological and geomorphological zonation corresponds with the Turtle Bay area. At this site a similar boulder formation may be distinguished, in the southern part, near to the coast-line. Off Whale Island lies an algal ridge, which falls dry at low tide. Behind this ridge lies a gently sloping reef flat. In between the boulder zone and the algal ridge, a coral community was found on an irregular, worn out, semi-fossil platform. At present, Mida Creek is connected with the sea by a channel north of Whale Island; in former days possibly this passage may have been south of Whale Island. This may have thus resulted in the unique structure of this reef complex.

The coral composition consists of formations of boulder massives and platforms. All triads belong to the Porites assemblage. Triad 39, and 41, along with 11, belong to a group that may be typified as real boulder massives. This coral formation has an especially high species diversity (= species number). Triad 40 is characterized as a pure Astreopora subassemblage, which is a good indication of weak currents.
Porites lutea forms the basis of triad 39 and 41, which consist of dead corals, for the larger part. Porites is abundantly overgrown with corals of the species Echinopora lamellosa, Acropora variabilis, Leptoria phrygia, Platygyra lamellina, species of Montipora and Acropora hyacinthus-grp. Few Alcyonacea were found.

The injury to coral colonies is so low, that this unit must be considered as the least damaged part of the reserve. Only in this specific area, Plerogyra sinuosa (Fricke & Vareschi, 1982) and Physogyra lichtensteinii (bubble coral), were found. Surprising as well, was the presence of whip coral (Gorgonacea) and Pachyseris rugosa, characteristic for greater depths.

Behind the algal ridge (eastward), directly exposed to the influence of the sea, lies a gently sloping platform (triad 40), consisting of beds of seagrasses, macro-algae and coral colonies on semi-fossil rock. The dominating species are Montipora spp., Porites lutea and Astreopora ocellata. Striking is the low abundance of Alcyonacea, compared to other platforms.

The quite considerable mean size of the coral colonies (especially of Astreopora ocellata and species of Montipora), and the absence of small colonies on the one hand, and the moderate coral cover of the potential substratum on the other hand, indicate stable conditions over a considerable period of time in the past, for the larger colonies. However, it indicates poor conditions for larval settlement over the past years. Recent deterioration of environmental conditions may also be concluded from the high rate of injured coral colonies, possibly caused by an increase in suspended matter. The origin of the suspended matter is a topic of discussion, as both the Sabaki river and Mida Creek are likely candidates. During the field work dives visibility was limited to 8 to 12 metres.
What determines the appearance of the reef?

Many paleontologists have occupied themselves with ecological succession on coral reefs. Walker and Alberstadt (1975) regard community development as an irreversible process, whereby the physical environment is progressively modified by the reef community to produce an orderly and, to some extent, predictable sequence of species. Crame (1980) has termed this phenomenon a 'community controlled' mechanism of fossil reef succession. Walker and Alberstadt (1975) state that in the early stages of succession there is a steady increase in the following community parameters: the number of species, growth habitat diversity, stratification, food-web complexity, and other organism interrelationships. This represents an analogue to the general pattern in terrestrial vegetations (Miles, 1978). Crame (1980) found that in Pleistocene coral reefs of the Kenya coast succession on established reefs is rather random and unstructured. Golley (1977, p. 329) reports that:

"The response of the community to disturbance through succession is more significant than the possible orderly sequence of communities in space or time."

The species composition and condition of a coral community is determined by the local constellation of environmental factors. Each of these factors in turn is influenced by the presence of other factors. One of the factors that may enhance or subdue disturbances and other influences is water turbulence. The influence of 'macro' water turbulences, such as surf and tidal currents, was found to be expressed in the species composition. This is illustrated by the two-dimensional grouping of relevé triads in a plot, using a so-called DCA ordination method (see Figure 19). In this diagram the horizontal axis corresponds with a gradient of increasing macro water turbulence.

The coral dominated communities of the Malindi-Watamu reef complex may be roughly divided into three assemblages (see chapter 4), on the basis of coral species composition: the branching Acropora-assemblage on the slopes, the Porites assemblage in calmer waters and the Pachyseris-assemblage on the deeper slopes (20-25m).

The Porites-assemblage is further sub-divided into three sub-assemblages: a Montipora-Acropora hyacinthus sub-assemblage, a Astreopora sub-assemblage, and a sub-assemblage dominated by Goniastrea retiformis. The first of these sub-assemblages represents platform formations, the second represents boulder and platform formations, and the last one consists of triads of the Malindi boulder formations. These less defined groups of the ordination were found in areas with moderate macro water turbulence, where factors other than turbulence may be decisive for environmental conditions. On the one hand there is the unknown factor of local and regional disturbances and historical circumstances. On the other hand, a micro-dynamic factor probably plays an important role in settlement and maintenance of corals in recent times. This latter factor may play an important role in the vicinity of colonies, where eddies may occur locally. The nature of these water motions is determined by colony form and size.
A good example of this micro water turbulence is formed by the highly irregular relief of the Malindi boulder formations, that causes a large variation in local water movement. It would, however, be rather premature to ascribe the second axis of the ordination plot, and thus the sub-divisions within the Porites-assemblage, to differences in micro dynamic features.

Thus many factors concerning coral growth are related to water movements. The most important of these are nutrient and oxygen supply, and the possible influx of suspended matter and fresh water. The influences of these factors on the reef environment may be indirect. An increased sediment and nutrient supply, for instance, may cause an increase in the number of suspended algae, which may subsequently influence the amount of light reaching the seabottom and the coral growth.

Characteristic for areas with strong micro-dynamics are the occurrence of many niches and the churning up of sediments. Many niches are present because of the inhomogeneity of these areas, and many species may thus find a habitat there. The stirring up of sea bottom material may cause an increase in the nutrient level of the ambient water.

Since both gradients in the plot (one of increasing macro water turbulence, and the other determined to some extent by an increase in micro water turbulence) are ascribed to water movement, it is to be expected that both types of water motion may also affect each other. When macro water turbulence is high (for instance, on the slopes) the relief of an area, and therefore the effects of the micro dynamic features are overshadowed. In the case of areas with an extremely low water turbulence, such as in the Montipora-Acropora hyacinthus sub-assemblage and in the Pachyseris assemblage, the effects of the microdynamic features are also of minor importance.
CONCLUSIONS.

Chapter 9

The Malindi-Watamu reef complex was formed, in geological terms by eustatic movements of the sea. As a result of these fluctuations of the sea level, four distinguishable marine terraces were formed. The highest of these, at 20 metres above the present sea level, is formed by the emerged and cemented fossil reef. The three other levels are (sub)marine terraces. The first of these lies at sea level. The reef flat is exposed at low tide, which leaves a low and flat, rather desolate looking surface of coral rock. The periodic drainage of this terrace is probably the limiting factor for coral growth. In fact, one may speak of a geomorphological cause, in this case. This is especially applicable to the exposed reef flats at Silversands, North Reef, Leopard Reef, and the long, very wide reef flat extending from Mayungu to the Blue Lagoon near Watamu, called the Malindi Reef.

The transition from the first to the second reef can hardly be recognised. From the edge of the reef (first terrace) the reef surface gradually declines to a depth of about seven metres. Far from the coast, the sea bottom declines steeply to a depth of about 30 metres. This is where the third terrace begins. In the lagoons that have worn into the reef flats, and on the slopes down to the second and third terrace, a limited coral growth occurs. It is, however, only a thin veneer superimposed on an older fossil reef structure.

Essentially, the Malindi-Watamu reef complex is a fringing reef type. Within the reef complex, however, two areas clearly distinguish themselves form the rest on the basis of geomorphological properties and the related water motions. These deviations from the fringing reef type are the patch reef complex in the northern part of the study area, and the area near the inlet of Mida Creek, in the south, near Watamu. These influences affect the structure of these reefs in such a way, that no regular structure remains recognisable. Because the morphological structure not only determines the presence of corals, but also the nature of coral growth, the latter may also vary from place to place on the reef. The coral growth may be divided into five coral formations: boulders, boulder massives, platforms, slopes and deep slopes.

This study is focussed on two primary questions:

1. To what extent may one speak of a decline of the Malindi-Watamu reef complex?

2. What are the factors disturbing the reef ecosystem?
The nature of the coral growth is strongly determined by a site-specific combination of factors. Disturbing factors are also site-specific in their influence. Disturbing factors manifest themselves in:

- the **COMPOSITION** of the coral growth
- the **COVERAGE** of the potential substrate
- the **CONDITION** of the colonies
- the **SIZE** of the colonies

A comparison between different coral growth sites throughout the Malindi-Watamu reef complex suggests that three assemblages exist, that are characterized by Porites, Acropora and Pachyseris, respectively. A 'principal coral community' (see Chapter 4) is recognizable for each of these coral assemblages.

The Pachyseris assemblages that dominate deeper waters (20-25 m) are characterized by the presence of Pachyseris rugosa, Mycedium elephantotus and Oxypora lacera. These species have a foliar growth form, which is more advantageous than other growth forms in these deeper waters, due to the limited light penetration.

Acropora assemblages are encountered in areas with rougher water movements. Acropora formosa-grp., Acropora hyacinthus-grp, Fungia spp., Galaxea clavus and Pocillopora dominate here. Porites assemblages are the most important group in terms of total area. They dominate in areas that are unsuitable for the Acropora assemblage, i.e. in areas with calmer waters. On the basis of species composition the Porites assemblage may be subdivided into three sub-assemblages. These are the Montipora-Acropora hyacinthus sub-assemblage, the Astreopora sub-assemblage and the Goniastrea sub-assemblage. This subdivision may be regarded as a product of water movements, the most decisive environmental factor, and especially the different ecological side-effects associated with these motions (see chapter 8).

From the **COMPOSITION** of especially the Porites assemblage, it is evident that environmental circumstances are disturbing the coral reef ecosystem. The primary coral community of this assemblage is represented by species that are relatively tolerant of sediment. Involved are Porites lutea, and species of the Faviid family, all of which probably possess an effective cleaning mechanism.

The species composition indicates turbid waters. The fact that underwater visibility was very limited (at times less than 1 m) during the greater part of the study, confirms the strong suspicion that suspended matter is a strong controlling factor in the area. This disturbance is also evident from the over-abundance of Alcyonacea, the soft corals. At many locations up to 25% of the potential substrate (for corals) was covered with these organisms. Alcyonaceans are at an advantage in turbid waters, when compared to Scleractinians, the stony corals.

The Sabaki river has recently undergone dramatic changes (for an overview, see Giesen and van de Kerkhof, 1984). Due to unbridled agricultural development in the river basin, erosion has increased dramatically, and with it the amount of sediment debouched into the Indian Ocean. Water flow has become more intermittent, and flooding more common a phenomenon. The effect of terrestrial sediments is visible in a number of phenomena. In the sea, there has been an increase in the amount of suspended sediment observed annually as a large, opaque, reddish-brown cloud drifting down the coast. Furthermore, the bays of Malindi and Mambrui have been silted up since the early sixties,
and seagrass beds on North Reef have expanded over the past two decades. The effects are also evident outside the water, as the dunes on North and Leopard Reefs have expanded, and the dune complex between the Sabaki river and Malindi township has widened in a striking way.

The sea current patterns in the area are dominated by the East African Coastal Current, that flows in a northerly direction. This is usually quite strong (about 2 knots), but during the north-east monsoon, in December-February, it meets the southerly flowing Somali Current, and decreases to about 1/4 knot (see Appendix D). These two currents converge in this period at about 3 degrees S latitude, which is approximately in the Malindi area. Inshore currents are more determined by wind directions, however, and although the offshore currents remain (weakly) northerly, the former may be southerly due to southerly blowing winds. The north-east monsoon is also a period of inland rains, thus, in combination with the inshore southerly currents, this is the period of peak Sabaki river influence in the study area. We were able to observe this coastal area from a light aeroplane, with the Sabaki in full flood, and the reddish-brown, silt-loaded waters flowing from the delta

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and moving southward in a gigantic, brown stream to the Malindi-Watamu reef complex.

An increase in Sabaki river influence is suggested by the condition of the corals. The coral species belonging to the Porites assemblage appear to be disturbed in particular. At many sites 25% of the colonies are covered by an algae. Corals of sheltered, shallow triads have been most affected by these algal afflictions. One may expect that the accumulation of fine sediments is highest in these areas. Locally, over 50% of the colonies of the two dominant species, Goniastrea retiformis and Porites lutea, have been overgrown by algae (see Figure 38). Very locally, coral stands of the flourishing Acropora assemblage are also damaged. Of the triads 5, 6, 10 and 12, 15-25% of the colonies of the A. formosa-grp. have been injured. In more exposed areas, the water movement is effective in 'washing out' the accumulated sediment.

The worsening of the environmental conditions may also be detected in the coverage of the potential substrate. The coral communities, that are located in narrow zones running parallel to the coastline, cover the potential substrate only to a limited extent. Only the slopes of the patch reef complex are endowed with an optimal growth (cover 85-90%). This may be a result of the favourable circumstances in which corals occur here, namely in the strong currents of the surf. These ensure a sufficient nutrient and oxygen supply, and allow only a limited sedimentation of suspended matter. A comparison between the triads of the north (0-24) and those of the south (25-41) shows that the average cover of potential substrate in the north is 70%, while the average in the south is only 37%.

Apart from the favourable effects that govern on a patch reef, this difference in cover of potential substrate may be explained by the influence of Mida Creek. This strongly ramified and mangrove lined creek lies in the southern part of the study area. At low tide, large parts of this inlet are exposed, as enormous volumes of water are channeled seawards. Giesen and Van de Kerkhof (1984), in their recording of coastal abiotic parameters, found that both suspended matter and sea bottom silicates had two peak concentrations in the study area. One was in the north, in the vicinity of the Malindi Marine National Park, the other in the south, near Mida Creek. Both the (non-combustible) suspended matter concentration and the silicates indicate a terrestrial influence in these areas. The origin of this southern sediment is not clear, for the catchment of Mida Creek is very restricted, and the inland sands lead to slow percolation drainage rather than surface run-off (Brander et al., 1971). Agricultural activity in the area is heavy (e.g. at Gede Agricultural Centre), and mangroves are exploited for construction poles (boriti) and for making charcoal. However, a comparison between aerial photographs dating from 1965 and 1978 revealed no decrease in the area of these mangroves (Giesen and Van de Kerkhof, 1984). The origin remains a puzzle. Giesen and Van de Kerkhof (1984) postulate that Sabaki sediment may be reworked by strong Mida Creek currents, after longshore transport in a southerly direction. Erosion in the Mida Creek catchment is, however, certainly not to be overlooked and requires further investigation.

Finally, another explanation for the differences in coral coverage of potential substrate between the northern and southern part of the study area is offered by the differences in illumination. Light attenuation in sea water is determined by the product of visibility and depth. Visibility conditions are usually worse in the northern part of the study area during the north-east monsoon, but due to greater depths in the south, light may be limiting for coral growth in these areas as well. In the north, visibility conditions seem to
improve quickly due to the action of the currents, but in the south the poor conditions may last much longer (Giesen and Van de Kerkhof, 1984).

The SIZE of the coral colonies also indicates poorer environmental conditions. In the whole area, and specially in the boulder and boulder massive formations, small (young) colonies are rare, which suggests that the conditions for coral settlement are not optimal. Tourists

The influence of tourists on the reef is very local. Only in the so-called 'Coral Gardens' of Watamu and especially Malindi Marine National Parks, may reef damage be ascribed to tourists. The increasing number of tourists who go to the Coral Gardens, do, however, inflict a substantial amount of damage. Boat anchors are dropped on corals, and tourists standing on or walking over colonies may injure living coral tissues or devastate more fragile specimens. In the Coral Gardens of the Malindi Marine National Park 35% of the coral colonies have been damaged by trampling. Within the study area, there are no indications that other substantial damage to the reef may be directly ascribed to tourism.\textsuperscript{31}

In summary, one may state that many reef characteristics indicate a high degree of disturbance. The coral species composition and the high cover of Alcyonacea indicate silt disturbance. This is supported by the fact that the rest of the ecosystem appears reasonably healthy. Fish populations are large and very varied, and seagrass beds are expanding in some areas. The sedimentation of silt is disastrous for sessile organisms such as corals. The source of the sediment is the Sabaki, and perhaps to a limited extent, Mida Creek. The degree of injury is a strong indication that the disturbance is of a recent nature. One may state that the reef is in a poor condition, and that this may worsen further, as the silt load of the Sabaki has increased dramatically over the past decades, and is still on the rise. Any further increase in silt influx in the area will irrevocably lead to a further decline of the reef, resulting in a higher degree of injured corals and an increase in Alcyonacea. The fact that even relatively silt-tolerant species are also being damaged, is an indication of how serious this problem is. Even if the present silt influx was to remain constant, it remains very likely that a further decline is inevitable.

Remarks

During the preparations for this study, the main focal point was the question which factors could be held responsible for the decline of the corals of the Malindi-Watamu reef complex. It soon became evident during the preliminary work that a comprehensive description of the present condition of the reef would be a necessary prerequisite. In an early stage, we concentrated on finding an adequate method for quantifying and qualifying coral growth in the area. With the available means and time, and embroidering upon existing methods, we found a compromise for sketching an image of the coral composition.

We certainly do not pretend to have given an exact image of all possible constellations of coral present in the area. To achieve a certain degree of typification, the relevées were carried out at the carefully selected locations, that were also reasonably accessible. Making the relevées and the typification of

\textsuperscript{31} Apart from economic reasons (Hafkenscheid and Waning, 1984) it is of utmost importance that the present status of the marine parks is maintained, as in this way the damage caused by tourists will be kept confined to a limited area.

Conclusions. 125
coral communities were both very time consuming without directly contributing to the study of the process of reef decline. To not lose track of this goal, other phenomenae than coral species were also included in the relevées. These included injuries, colony size, conditioning of the substrate and possibilities for coral establishment. It is thus evident that the emphasis was laid on the quantitative research. With the method we established, little information was gathered on the physiology and 'taxonomy' of the injuries, on size and regeneration, and on differences in general, in biotic and abiotic environmental conditions of different parts of the reef.

The gathered information on injuries and colony size contributes to the image formed of the condition of the study area and to information on these topics in general. The method employed may also be viewed at as a contribution to the discussion on how such phenomenae may best be registered in the field. With our broad approach, using the combined reporting of numerous data in a vast area, certain underlying causes important for different local circumstances, may have escaped our attention. A good example of this shortcoming is our failure to find a conclusive reason for the very marginal coral growth on the Malindi Banks.
Chapter 10

RECOMMENDATIONS.

Continuation

This study, which provides a general picture of the present situation on the reef, may serve as a basis for a continuation study. An impression may be gained of the changes in time, especially regarding species composition and coverage of both total and individual coral species. For this purpose, the syntaxonomic and synecological study must be duplicated. The location of the exact relevee sites may present some difficulties. However, if triads are used in the relevee method, a useful comparison of the basic typification is warranted.

At the same time the degree of injury may also be registered using our method. This may facilitate a comparison and a possible assessment of the progression or slowing down of reef decline. It is also recommended that a study should be carried out on the nature and physiology of the injuries, and the growth rate of certain types of injuries where this is applicable. The study of the abiotic factors influencing the reef as was carried out by Giesen and Van de Kerkhof (1984) should be repeated, but then carried out over a longer period and in greater detail. Their results were unfortunately not detailed enough to be directly linked with the relevee sites, and the time pattern of silt distribution was not described in its full cycle. Other abiotic factors in the area should also be investigated, such as (macro and micro) water movements, organic matter, dissolved chemicals.

Tourists

As far as we can assess, little or no coral is collected in the Coral Gardens by tourists. To prevent damage by trampling, etc., we strongly recommend that more information should be given to tourists, for example at the park entrance or in the hotels that are most frequented by tourists. From a complementary study carried out by Hafkenscheid and Waning (1983), members of the Watamu Reef Expedition, it was evident that most tourists were unaware of the life on the reef, and especially of the vulnerability of the corals themselves. A notice board at the park entrance already informs visitors, but such a written message is often not adequate, especially when many visitors are foreigners. A visual representation of the ‘do’ and ‘don’ts’ on visiting the reef is probably far more effective.

Apart from this measure, a better mechanism for controlling the observation of park rules, especially by the boatsmen of the glass bottomed boats, should be established. These boatsmen, and also a number of employees of the parks themselves, are totally unaware of the detrimental consequences of too great human pressure or other damaging influences, on the corals. This is a sad development, as these very persons could fulfill an important task in the regular observation and guarding of reef life in the parks. We strongly support the plans of the Wildlife Conservation and Management Department to establish a centre in Malindi where control and information activities may be coordinated in a more effective way, and where park rangers, wardens and other involved in the parks may be trained.

We are aware that the visitors to the Coral Gardens form an important source of income to both parks and boat owners. The large numbers of tourists, however, damage the corals. Because of this we plea for a limitation of tourist activities to these two coral garden areas for as long as possible. Because of their structure and large fish populations, these will remain worthwhile for tourist viewing for a long time, while the rest of the reef thus remains relatively undamaged.
Silt influx

Van der Kerkhof & Giesen (1983) carried out an extensive study of the main origins of the Sabaki silt. Soil erosion and projects to prevent this phenomenon and the functioning of these projects were investigated by Van Hoof (1983). For recommendations on this subject we refer to the reports of these two complementary studies that were carried out by the Watamu Reef Expedition.

As for this report, the silt influx of the Sabaki river is a major disturbing factor which threatens the whole reef to a great extent.
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A10. boulder massive and deep slope formation
Appendix C
CHECKLIST FROM THE MALINDI-WATAMU REEF COMPLEX.

CLASS HYDROZOA

Order Milliporina

family I. MILLIPORIDAE
(a) genus: Millepora
M. spp.

CLASS ANTHOZOA

SUBCLASS ALCYONARIA

Order Stolonifera

family I. TUBIPORIDAE
(a) genus: Tubipora
T. musica

Order Coenothecalia

family I. HELIOPORIDAE
(a) genus: Heliopora
H. spp.

Order Alcyonaria

SUBCLASS ZOANTHARIA

Order Scleractinia

A. Suborder Astrocoeniina

family I. ACROPORIDAE.
(a) genus: Astreopora
A. ocellata
(b) genus: Montipora
M. spp.
(c) genus: Acropora
A. echinata
A. formosa-grp
A. hyacinthus-grp
A. variabilis-grp

family II. SERIATOPORIDAE
(a) genus: Seriatopora
   S. hystrix
(b) genus: Stylophora
   S. pistillata
(c) genus: Pocillopora
   P. damicornis
   P. verrucosa

B. Suborder Fungiina

family I. THAMNASTERIIDAE
(a) genus: Psammocora
   P. contigua
   P. explanulata

family II. PORITIDAE
(a) genus: Alveopora
   A. allingi
(b) genus: Goniopora
   G. spp.
(c) genus: Porites
   P. eridani
   P. lutea

family III. AGARICIIDAE
(a) genus: Pavona
   P. explanulata
   P. lata
   P. spec.
   P. variabilis
(b) genus: Gardineroseris
   G. planulata
(c) genus: Pachyseris
   P. rugosa
(d) genus: Leptoseris
   L. papyracea

family IV. FUNGIIDAE
(a) genus: Fungia
   F. spp.
(b) genus: Herpolitha
   H. limax
(c) genus: Cycloseris
   C. patelliformis
(d) genus: Polyphyllia
   P. talpina
(e) genus: Podobachia
   P. crustacea

family V. SIDERASTREIDAE
(a) genus: Coscinaraea
   C. monile

C. Suborder Faviina

148
family I. FAVIIDAE
(a) genus: Favia
   F. favus
   F. maxima
   F. spec.
   F. speciosa
   F. stelligera
(b) genus: Favites
   F. abtida
   F. chinensis
   F. russeli
   F. spec.
(c) genus: Goniastrea
   G. retiformis
(d) genus: Platygyra
   P. lamellina
(e) genus: Leptoria
   L. phrygia
(f) genus: Hydnophora
   H. exesa
   H. microconos
(g) genus: Cyphastrea
   C. serailia
(h) genus: Echinopora
   E. lamellosa
(i) genus: Oulophyllia
   O. crispa

family II. OCULINIDAE
(a) genus: Galaxea
   G. clavus
   G. fascicularis

family III. MERULINIDAE
(a) genus: Merulina
   M. ampliata

family IV. MUSSIDAE
(a) genus: Acanthastrea
   A. echinata
(b) genus: Acanthophyllia
   A. spec.
(c) genus: Blastomussa
   B. spec.
(d) genus: Lobophyllia
   L. spp.

family V. PECTINIIDAE
(a) genus: Mycedium
   M. elephantotus
(b) genus: Oxypora
   O. lacera
(c) genus: Pectinia
   P. spec.
(e) genus: Echinophyllia
   E. aspera

D. Suborder Caryophylliina
family I. CARYOPHYLLIIDAE
(a) genus: Gyrosmilia
  G. interrupta
(b) genus: Plerogyra
  P. sinuosa
(c) genus: Physogyra
  P. lichtensteini

E. Suborder Dendrophylliina

family I. DENDROPHYLLIIDAE
(a) genus: Turbinaria
  T. peltata
(b) genus: Tubastrea
  T. coccinea
### Appendix D

**SPECIES, THEIR GROWTH FORM, AND CALICE ARRANGEMENT.**

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<td>Pav exp</td>
<td>Pavona explanulata</td>
<td></td>
</tr>
<tr>
<td>Pav lat</td>
<td>P. lata</td>
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<tr>
<td>Pav spp</td>
<td>P. spp</td>
<td></td>
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<tr>
<td>Pav var</td>
<td>P. variabilis</td>
<td></td>
</tr>
<tr>
<td>Pec spp</td>
<td>Pectinia spp</td>
<td></td>
</tr>
<tr>
<td>Phy lic</td>
<td>Physogyra lichtensteinii</td>
<td>mass</td>
</tr>
<tr>
<td>Pla lal</td>
<td>Platygrya lamellina</td>
<td>mass</td>
</tr>
<tr>
<td>Poc dam</td>
<td>Pocillopora damicornis</td>
<td>ramo</td>
</tr>
<tr>
<td>Poc ver</td>
<td>P. verrucosa</td>
<td>ramo</td>
</tr>
<tr>
<td>Pod spp</td>
<td>Podobachia spp</td>
<td>foli</td>
</tr>
<tr>
<td>Pol tal</td>
<td>Polypyllia talpina</td>
<td>mass</td>
</tr>
<tr>
<td>Por eri</td>
<td>Porites eridani</td>
<td>mass</td>
</tr>
<tr>
<td>Por lut</td>
<td>P. lutea</td>
<td>mass</td>
</tr>
<tr>
<td>Sty pis</td>
<td>Stylophora pistillata</td>
<td>ramo</td>
</tr>
<tr>
<td>Tub coc</td>
<td>Tubastrea coccinea</td>
<td>ramo</td>
</tr>
<tr>
<td>Tub mus</td>
<td>Tubipora musica</td>
<td>encr</td>
</tr>
<tr>
<td>Tur pel</td>
<td>Turbinaria peltata</td>
<td>encr</td>
</tr>
</tbody>
</table>

growth form: soli = solitary; encr = encrusting; ramo = ramose; mass = massive; foli = foliate; tabu = tabulate.

calice arrangement: phac = phaceloid; ploc = plocoid; ceri = ceroid; mean = meandroid; hydn = hydnophoroid.
Figure 39: Sea-currents. The vector mean currents of July (left) and January (right) along the East African coast (from Bliss-Guest, 1983)
Appendix F

ADDITIONAL GRAPHS.

Graph 1. AVERAGE SIZE (cm) - NUMBER OF CORAL COLONIES

The main impression of this graph may be formulated as follows: with an increasing number of colonies, the average size decreases. More conclusions out of this graph are difficult to give, because the average sizes of the colonies in a triad mostly depend on the species composition (see chapter 4). Average sizes of the different species are hardly comparable.
One general conclusion can be made on this graph: it is apparent that, if the coral cover on the solid substratum is high, the cover of Alcyonacea is low. Both stony corals and Alcyonacea need a solid substratum to settle and develop. If the available space is utilized by stony corals, there is no opportunity for settlement by Alcyonacea.
Graph 3. PERCENTAGE CORAL COVER ON SOLID SUBSTRATUM - NUMBER OF CORAL COLONIES

In general, there is no significant correlation found between the total number of colonies and the coral cover on solid substratum. The triads of the boulder formation are easily found in this graph, because of the low number of colonies and the mostly low percentage coral cover on solid substratum.

If the percentage of coral cover on solid substratum is less than 35%, the number of colonies mostly lies between 200 and 300, between 35 and 75% the number of colonies varies in great extent, while above 75% this number lies between 250 and 450.
Appendix G

COMPILATION OF GLOBAL REEF MAPS OF MALINDI AND WATAMU.

INTRODUCTION.

Aerial photography of coastal areas reveals regular patterns in general sea bottom cover, that are often closely related to environmental conditions such as water depth, exposition and water movements. Maps produced from these photos may thus be helpful in gaining insight into the general buildup of community mosaics, and help understand the underlying processes that determine these patterns.

The aims of these mapping procedures were threefold. In the first place, a topographical framework for this present study was considered highly desirable, both to give more significance to the relevées and to provide a visual aid for the description of the many localities. In the second place, a location map was deemed a valuable aid for park and reserve planning purposes, and thirdly, a basis for future studies in the area may be laid in this way.

The area under consideration lies between 3°9' - 3°25' south. It consists, for the greater part, of the Marine National Reserve, and also embraces both the Malindi and Watamu Marine National Parks (see Figure with ID found). The area is geomorphologically characterized by the occurrence of a series of terraces, composed of fossil reefs, that have been worn out by the sea in its eustatic changes in level (see Chapter 2). Of importance for these mapping purposes are the second and third terraces (= first and second submarine terraces). The first submarine terrace is exposed to a great extent at low water, and the second descends down to a depth of 7' - 8' metres. Mapping of features deeper than the upper part of the second submarine terrace proved to be either impossible or highly unreliable, due to resolution problems (see discussion further on).

METHODS.

Mapping was based on the following black and white panchromatic aerial photographs, that were obtained from the Survey of Kenya, Nairobi.

For the Malindi area:
- North Reef, 1:20,000, of March 1960
- Leopard Reef, 1:50,000, of January 1975
- coastline, Silversands, Malindi Reef, and Malindi Banks, 1:12,500, of early 1978

For the Watamu area:
- Mida Creek channel, and areas outside the park, 1:50,000, of January 1975
- rest, 1:12,500, of early 1978.
These photographs were supplemented with a series of overlapping 35 mm colour slides, taken at low altitude from a light plane by Ron Eijkman, of the Watamu Reef Expedition, on the 29th March, 1983.

The primary photo-interpretation was based on land(sea)scape, pattern, texture and tone criteria, plus knowledge of the area after many dives. This primary interpretation was verified, and occasionally corrected, with the aid of the (very detailed) colour slides. Coral dominated communities were later identified as a last step in the interpretation, using a combination of aerial photographs, slides and pin-pointed relevee sites. The legend was established after a preliminary attempt at photo-interpretation, during which the limitations in the recognition of underwater features became evident.

RESULTS AND DISCUSSION.

Final mapping and interpretation was limited to the two marine parks, because of the limited time available. As both the 'coral reef' section of this study, and the planning activities of the Kenya Wildlife Conservation and Management Department are primarily focussed on these two areas, this shortcoming is not insuperable.

Two major difficulties were encountered in the PHOTO-INTERPRETATION procedures. The first of these was caused by the fact that areas seaward of the high water mark are regarded as wasteland by most surveyors, and thus no complete photographic record of both areas was available at a scale larger than 1:50,000. This meant that scales had to be adjusted by means of an optical pantograph, to allow the construction of a mosaic for each area.

The second major difficulty was the limited resolution of reef features, due to water depth, turbidity, surface reflection and photographic scale. Hubbard and Grimes (1974) report that aerial survey of the inter-tidal region is limited to periods when this zone is free from water. Fortunately, however, this is only true of very turbid waters, and in our area resolution was usually possible to depth of about 5-8 metres, depending on local turbidity conditions and reflection. This is close to Swanson's (1968) report of 20-25 ft (6.1-7.6 m) for North American coasts, and Cameron's (1950) report of 4 fathoms (7.3 m) for the Nova Scotia coast of Canada.

The scale of the photographs (the largest is 1:12.500) is too small for an identification that goes into more detail than the broad classes used here (see further discussion on mapping). Hubbard and Grimes (1974) recommend a scale of (at least) 1:5,000 for the identification of communities in a Britain salt-marsh, a scale that is not available for these areas, at present.

All of the photographs were taken early in the year (January - March), during the north-east monsoon, when the cloud cover is lowest and weather conditions are reliable. However, during this period there is usually also an influx of Sabaki river silt, and it is likely that the northernmost photographs are at least slightly affected by these conditions.

The shimmering of sunlight on the water's surface was only a problem on several images, especially of the 1:12,500 images of the Watamu area. However, of all areas, at least one 'reflectance-free' image was available, and at most, this only presented a problem in attempts at stereovision viewing.
This brings us to the problem of stereovision of sea bottom features. For over three-quarters of the two areas, overlapping photographs taken at the same time and scale were available, this would normally allow stereovision viewing, for instance through a mirror stereoscope. Unfortunately, in the submarine circumstances none of the usual terrestrial rules hold. The three-dimensional effect is viturally nihil at scales smaller than 1:25,000, and is minimal for the larger scales. This is due to a combination of two factors. One is that light refraction in water tends to enlarge objects, but mask 'depth' viewing; the other is that most slopes are very gentle and differences in depth are usually only several metres.

The base MAPS were compiled from the British Admiralty map of the 'Port of Malindi', that covers the Malindi area at a scale of 1:37,500, and the topographical maps of Gede (Survey of Kenya, sheet 193/3 of Y731 series) and Sokoke (idem, sheet 192/4), that cover the Watamu area at a scale of 1:50,000. A precautionary note must be made. The boundaries of both parks and reserve that are drawn on the maps are not reliable. The seaward boundary is defined as lying three nautical miles (5545 m) seaward from the mean high water mark. As the scale of these two maps is only an approximation, these boundaries are also bound by this limitation.

All classifications represent impoverishments of the actual situation, and the legend of these maps is a good example. It is highly simplified, as a simple map with a high reliability was regarded more desirable than a complicated, unreliable one. Seagrass communities, dominated by Thalassodendron ciliatum (formerly wrongly called Cymodoce ciliata; see Ruwa, 1981) are by far the most conspicuous feature of the reef, along with sandbars, sandbanks and bare, fossil reef flats. Not surprisingly, the area is in fact characterized by numerous vegetation communities, as different communities may be identified on the reef flats (dominated by Ulva spp.), on sand bars (angiosperms Halodule spp. and Syringodium spp.) and on solid substrate in deeper waters (many Sargassum spp.). The Thalassodendron ciliatum dominated 'fields' themselves are furthermore not as homogenous as they first appear, but are characterized by internal differentiation. Unfortunately, most of these above-mentioned communities may not be identified on the aerial photographs, and only seagrass density classes were distinguished.

In all, four basic classes based on seagrass cover were recognized. In the lowest density class, of less than 2% cover, subdivision of the substrate into sand and sand/rock complex was executed, as this may be of importance in recognizing potential substrate for corals. At higher seagrass densities, the subdivision into different substrate types proved to be unreliable, and it was subsequently omitted. These five basic classes (two substrate and four density, with one overlap) were distinguished by means of colour (please refer to map in black envelope).

Coral dominated communities were indicated with a grid, that was superimposed on the colours of the abovementioned classes, as they could occur in all of these, except in the 'sand' class. No further subdivision was carried out in the registering of these coral dominated communities, as their total area was very small and, more importantly, it was difficult enough to identify coral communities, let alone the different sub-types.
RECOMMENDATIONS FOR FURTHER STUDY.

In order to understand the processes that underly the present reef structures, it must be mapped in greater detail, and parameters such as water movement, visibility, salinity and siltation must be measured at regular intervals and at very specific sites. For mapping the area in greater detail, aerial photographs at a scale of 1:5,000 or more are necessary, as is a more detailed study of the seagrass beds, algal mats and other components of seabed mosaic.

Photography at these scales is usually very expensive, but the costs may be reduced if the area that is photographed is kept limited, or if improvisations are made in the photographing technique. Steffensen and McGregor (1976) have developed a method that is relatively simple, and involves the use of normal black and white 35 mm film, and mirror-reflex cameras.

Regular photography of the area may also be a very effective method to keep track of certain changes in the environment, such as the expansion or contraction of seagrass beds, sandbars of sandbanks.

Aerial photography may also provide useful information on the 'silt cycle' of the area, i.e. how silt spreads from the Sabaki river, at what rate, and when does it disappear from the system. This may, for instance, be based on the regular photography of selected sites, a method that Kelly (1970) reports as giving good results in tracking sewerage pollution.

Finally, if the productivity of the seagrass beds are to be assessed (for instance, in relation to fish populations; see Brakel, 1981), aerial photography may also be a very promising approach (Reimold et al, 1973).