AN ECOLOGICAL ASSESSMENT OF LITTORAL SEAGRASS COMMUNITIES IN DIANI AND GALU COASTAL BEACHES, KENYA

BY

JACQUELINE NDUKU UKU

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signature.......................................

J.N. UKU

This thesis has been submitted for examination with our approval as Supervisors

Signature.......................................
Dr. E. Martens
Supervisor and former Senior Lecturer,
Department of Zoology,
University of Nairobi.

Signature.......................................
Prof. K. M. Mavuti,
University Supervisor,
Department of Zoology,
University of Nairobi.

DEDICATION

I dedicate this thesis to my father Gideon Wambua Uku and to my mother Beatrice Mbinya Uku.

"It might have appeared to go unnoticed,
But I've got it all here in my heart.....
I would be nothing without you......
Did you ever know that you're my hero(s)...,
And everything I would like to be,
I can fly higher than an eagle,
Coz you are the wind beneath my wings."

(Betty Midler)

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ABSTRACT

Most studies along the Kenyan coast have concentrated on coral reefs and mangrove swamps. Limited studies have been carried out on seagrasses though they provide an important link between the mangroves and the coral reefs. Seagrass beds are located in intertidal lagoons which lie directly in front of coastal hotels, hence they are thought to be affected by hotel sewage through underground seepage particularly where the sewage disposal systems are located close to the shore.

The aim of this study was to ascertain the effects of this on the marine life sustained by the seagrass community. The flora, fauna and physico-chemical parameters of the littoral seagrass community in Diani Beach, a tourist resort located in the south coast of Kenya, was compared to the one in Galu Beach, a relatively unexploited area in terms of beach hotel development.

The mean biomass of seagrass was significantly higher in Diani Beach ($H = 6.96$, $p \leq 0.05$). Though the algal biomass was higher in Diani Beach, a comparison between the two areas revealed that the difference was not statistically significant. The epiphytic load on the stems of the seagrass *Thalassodendron ciliatum* (Forssk.) den Hartog was significantly different ($H = 18.13$, $p \leq 0.05$). However, the abundance of the epiphytes was governed by the availability of *T. ciliatum* stems in both Diani and Galu Beaches. The mean number of epibenthic fauna and infauna were higher in Diani Beach though

it was not statistically significant when the two areas were compared. The fauna, unlike the flora, experienced significant seasonal fluctuations attributed to the seasonal environmental changes particularly in the sediment characteristics.

Detectable nutrient levels in the water column in both Diani and Galu Beaches indicated the presence of nutrient seepage into the seagrass ecosystem. The overall levels of nitrates were significantly different ($H = 4.57$, $p \leq 0.05$) when the two areas were compared with higher levels recorded in Diani Beach. However the levels of ammonium and phosphate were similar in the two areas. Nutrient levels in the two areas appeared to be related to the maximum spring tidal heights and the tidal pumping of groundwaters as well as rainfall levels.

The levels of biochemical oxygen demand were less than the critical level of 10 mg O_2/l in both Diani and Galu Beaches. Inspite of the high concentration of beach hotels in Diani, tidal out-flushing and strong circulation patterns prevent the eutrophic accumulation of nutrients in this lagoon.

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Seagrasses (marine angiosperms) are the only group of higher plants that have adapted to live submerged under sea water and have a complete life cycle under water. They form extensive intertidal meadows in shallow coastal waters from the Arctic to the southern tips of Africa and New Zealand (Zieman, 1975). Seagrasses occupy a wide range of habitats from coarse sand and coral rubble to soft muddy bottoms. They extend from the intertidal zone down to 20 m water depths or more (Nienhuis *et al.*, 1989). Some seagrass species are exposed during periods of low spring tides. Others grow in pools and depressions which are left filled with water during the receding tides (Isaac, 1969).

Worldwide there are about 50 species of seagrasses. Seagrasses are grouped into 12 genera, 9 of which belong to the family Potamogetonaceae and the other 3 to the family Hydrocharitaceae. The two families belong to the monocotyledonous order of Helobiae. The family Potamogetonaceae contains the following genera: *Zostera, Phyllospadix, Heterozostera, Posidonia, Halodule, Cymodocea, Syringodium, Amphibolis* and *Thalassodendron*. The genera *Enhalus, Thalassia* and *Halophila* are grouped into the family Hydrocharitaceae (den Hartog, 1977).

Seagrass beds are areas of diverse ecological functions. Primary productivity in seagrass ecosystems is high and ranges between 500 - 1000 g C/m^2/yr (Zieman & Wetzel, 1980), thus they constitute an important food source for marine organisms. A few invertebrates such as sea urchins graze directly on seagrass leaves. Vertebrate grazers are restricted to fish species, turtles and Sirenia. Birds such as geese and ducks graze on seagrass species when the beds become exposed during the low tide (den Hartog, 1977). Seagrass leaves fall off, decompose and then enter the detritus food chain where the microorganism decomposers are cropped off by protozoan grazers. These are then consumed by carnivorous microzoa that become the prey of larger fauna (McRoy & Helfferich, 1980; Zieman & Adams, 1982). The largest part of the primary production of seagrasses hence goes into the detritus food chain.

The stems and leaves of seagrass species provide a substrate for the attachment of epiphytic organisms and in particular algae. Majority of the algae are sessile and need a surface for attachment. Virnstein (1987) indicates that epiphytic algae add a degree of habitat complexity to the seagrass beds. They are preferentially grazed by most species of small invertebrates associated with the seagrasses and contribute to the primary production of seagrass ecosystems. The roots and rhizomes of seagrasses form a complex interlocking matrix which binds sediment and hinders erosion of the surface sediment. The presence of extensive seagrass beds contributes to coastal protection and stability (den Hartog, 1977; Zieman & Adams, 1982; Lakshamanan, 1983).

Additionally, seagrass beds serve as a nursery ground for fry and juveniles of a variety of finfish and shellfish. The mature stages of epiphytic organisms (that live on the plant surface e.g. amphipods), epibenthic organisms (which live on the sediment surface e.g. large gastropods and sea urchins), infaunal organisms (which are buried in the sediment e.g. sedentary polychaetes) and mobile nektonic species (which swim among the seagrasses e.g. fish and turtles) also inhabit seagrass areas. The seagrass leaves provide cover and camouflage from predators as well as food for these organisms (Zieman & Adams, 1982; Lakshamanan, 1983).

Nutrient cycling occurs in seagrass meadows. Species such as *Zostera* sp. have been shown to be capable of absorbing nutrients either via the leaves or roots. Ammonia and phosphate are taken up from the sediments through the roots, translocated and pumped out of the leaves and into the surrounding water (McRoy & Barsdate, 1970). Seagrasses provide organic matter for the sediments and maintain an active environment for nutrient recycling. They are efficient at capturing and utilizing nutrients and maintain a high productivity in a low nutrient environment.

Seagrass beds are areas of commercial fishery activities in several parts of the world. In Florida, the pink shrimp and the spiny lobster, which contribute to the fishery in this area, rely on seagrass areas as nursery grounds (Zieman & Adams, 1982). In the ASEAN region exploitation of fish, crustaceans and shellfish is widespread in the seagrass zones. Rabbitfish (Siganids) are the most important commercial fish in this area (Fortes, 1990).

Historically, temperate seagrass species like *Zostera* sp. and *Phyllospadix* sp. were used by coastal Indians of western North America for weaving baskets (Zieman & Wetzel, 1980). In Europe, seagrasses have been used as animal fodder and manure. The associated macroalgae have been utilized for agar, iodine and salt production (Chapman, 1950). Seagrass utilization ranges from food items, fertilizers and fodder to uses in aquaculture and industry in the Philippines (Fortes, 1990). In Mozambique, seagrasses are used in witchcraft (Bandeira, 1995) while in East Africa direct usage of seagrass species is limited to the utilization of the leaves of *Enhalus acoroides* (L. f.) Royle to weave mats (UNEP, 1982). The rhizomes of this species are consumed as *mtimbi* by the inhabitants of Lamu, Kenya (Isaac & Isaac, 1968). Modern uses have developed over the years. In nature, seagrass ecosystems serve as traps for sediment and organic material so efforts are underway to develop their use as natural sewage filtration systems (McRoy & Helfferich, 1980). Other uses in paper manufacture, chemical, fodder, food and medicine production are anticipated (McRoy & Helfferich, *op. cit.*; Fortes, 1990).

Environmental degradation is often severe in coastal areas where population pressure, tourism and industrialization converge (Johannes & Betzer, 1975). Due to their shallow sublittoral and intertidal existence, seagrasses are subjected to stress imposed by man's use of the coastal zone (Wakibia, 1995). The impacts are from oil pollution, thermal pollution, sedimentation, boats, toxic substances and eutrophication.

In the East African region, the main seagrass beds are located in between the coral reef and the mangrove ecosystems. They also occur on reef flats and reach far into the mangrove creeks. Though they form one of the most conspicuous communities of the intertidal area, their importance has only recently been recognized. Seagrass beds are prone to the effects of human activities as they lie close to beach areas. Along the Kenyan coast, hotel development has been seen as one of the threats to this ecosystem due to the seepage of liquid sewage wastes into the lagoons that support seagrass meadows.

Thus the two study areas of Diani and Galu, located in the south coast of Kenya, were chosen for the ecological assessment of the effects of hotel effluents on the seagrass community. Diani Beach is a tourist resort and it is an area of high hotel concentration compared to Galu Beach, which has fewer hotels along the beach. Information from hotels is often not forthcoming hence the analysis of the receiving ecosystem would indicate the extent and intensity of the sewage effects. The ecological role played by the seagrass meadows is immense and this study was also carried out in order to broaden the information base on the seagrass ecosystem in Kenya and to highlight its importance in the maintenance of marine biodiversity.

1.2 LITERATURE REVIEW

1.2.1 The seagrass community in Eastern Africa

1.2.1.1 Taxonomy and distribution of seagrasses

The taxonomy and distribution of marine angiosperms along the Kenyan coast was first documented by Isaac and Isaac (1968). A species list is given in Table 1 with the common names of the species from Fortes (1990). *Cymodocea ciliata* Ehrenb. ex Aschers (now known as *Thalassodendron ciliatum* (Forsk.) den Hartog) and *Thalassia hemprichii* (Ehrenb.) Aschers have been found to be the most prominent species along the Kenyan coast (Isaac & Isaac, 1968; Njuguna, 1985).

Isaac and Isaac (1968) also described the distribution of each species. *T. ciliatum* grows in most places along the coast and it forms dense under-water meadows. *Cymodocea serrulata* (R. Br.) Aschers & Magnus and *Cymodocea rotundata* Ehrenb. & Hempr. ex Aschers are both found in quiet waters of sheltered bays or tidal pools high on the shore. *Halodule wrightii* Aschers is found higher on the shore than any of the other seagrass species and it is capable of withstanding several hours of exposure. *H. wrightii* plants that grow submerged in pools during low tides are larger

Table 1. List of common seagrass species in Kenya. (Source: Isaac & Isaac, 1968; Fortes, 1990; Phillips & Meñez, 1988)

FAMILY	SPECIES	COMMON NAME
Potamogetonaceae	*Thalassodendron ciliatum* (Forsk.) den Hartog	Woody seagrass
	Cymodocea serrulata (R. Br.) Aschers. & Magnus	Toothed seagrass
	Cymodocea rotundata Ehrenb. & Hempr. ex Aschers	Round tipped grass
	Halodule uninervis (Forsk.) Aschers	Fiber strand grass
	Halodule wrightii Aschers	-
	Syringodium isoetifolium (Aschers.) Dandy	Syringe grass
	Zostera capensis Setchell	-
Hydrocharitaceae	*Halophila ovalis* (R.Br.) Hook. f.	Spoon grass
	Halophila minor (Zoll) den Hartog	Small Spoon grass
	Halophila stipulacea (Forsk.) Aschers	-
	Thalassia hemprichii (Ehrenb.) Aschers	Dugong grass
	Enhalus acoroides (L. f.) Royle	Tropical eelgrass

and more luxuriant than those that grow in exposed areas. *H. wrightii* may be found in association with *Halophila ovalis* (R. Br.) Hook. f. and *Halophila minor* (Zoll) den Hartog. *Halodule uninervis* (Forsk.) Aschers is located in shallow water where it is rarely exposed. *Syringodium isoetifolium* (Aschers) Dandy is common in fringing pools with denser growth occurring in deeper water. *H. ovalis* colonizes muddy areas exposed at low tides and shallow pools where it is partially exposed. *H. minor* occurs in association with *H. wrightii* at the highest level on the shore, though the long periods of exposure causes it to disappear. It regenerates from rhizomes when the conditions become favorable. *Halophila stipulacea* (Forsk.) Aschers is less common than *H. ovalis* and is often found at 0.61 - 0.92 m under water during the low spring tides. *T. hemprichii* forms extensive beds along the Kenyan coast and extends from the high areas on the shore to deeper waters reefwards. *Enhalus acoroides* (L. f.) Royle is found in muddy areas under deep water and it is not fully exposed at low water. *Zostera capensis* Setchell is a temperate genus which has a patchy occurrence in the East African waters. It is thought to have been brought here by ships (Isaac, 1969).

A general seagrass zonation pattern has been described recently by Coppejans *et al.* (1992) for Gazi Bay. A similar pattern is thought to occur along the Kenyan coastline wherever seagrasses are found. *H. ovalis* and *H. wrightii* constitute the pioneer vegetation in the muddy intertidal zone at the upper seagrass limit in Gazi Bay. *T.*

hemprichii forms the climax vegetation in this zone and it may be associated with *C. rotundata* and *C. serrulata*. From the mean low water down to 1 m mixed meadows of *T. hemprichii, C. serrulata, C. rotundata, H. uninervis, S. isoetifolium* and *H. stipulacea* exist. Monospecific *T. ciliatum* meadows exist from 1 m downwards and are locally replaced by *E. acoroides*.

Semesi (1990) found a high degree of patchiness in the distribution of seagrasses along the Tanzanian coast. The most commonly encountered species were *T. ciliatum, S. isoetifolium, T. hemprichii, Cymodocea* spp. and *Halodule uninervis*. *E. acoroides* had a discontinuous distribution along muddy habitats in mangrove creeks or near sewage outfalls. *Halophila* spp. were the rarest species. During work carried out in various parts of the East African coast, Aleem (1984) attributed the seagrass distribution to the substratum type and depth of water in pools and depressions.

1.2.1.2 Macroalgae and macrofauna found in seagrass areas

The algae that are associated with the seagrass species in East Africa include: *Ulva reticulata* Forskaal, *Chaetomorpha crassa* (Ag.) Kütz, *Nereodictyon* sp., *Ceramium* sp., *Galaxaura* sp., *Haliptylon subulata* (Ell. et Sol.) Johansen, *Jania* sp. and *Lyngbya majuscula* (Dillw.) Harv. ex Kuetz (Coppejans *et al.*, 1992; Moorjani & Simpson, 1988). Aleem (1984) found several epiphytic macroalgae attached to the rhizomes and leaves of *T. ciliatum*. These included *Ulva lactuca* L., *Gracillaria* sp., *Codium* sp. and *Padina* sp.

There was a rich fauna associated with the East African seagrass beds. The animals seen included sponges, ascidians, isopods, amphipods, ostracods, echinoids, ophuroids and molluscs. Studies by Kikuchi & Peres (1977) revealed the presence of various fauna among the *T. ciliatum* beds in East Africa. These were pelecypods of the genus *Atrina* and echinoderm species such as *Diadema* sp., *Holothuria* sp., *Synaptidae* sp. and *Protoreaster* sp.. A variety of gastropods and ophiuroids were also observed. Epiphytic fauna included *Zoanthus* sp., hydroids, bryozoans and the ascidian *Polyandrocarpa* sp. Crustaceans found here were *Etisus* sp., *Etisodes* sp. and *Typhlocarcinodes* sp.

Along the Tanzanian coast, Semesi (1990) collected detritivores such as polychaetes, bivalves, echinoderms and annelids. In Kenya, nektonic species such as turtles and dugongs are much lower in number than they used to be hence seagrass utilization is now merely restricted to fish and invertebrates (Martens, 1992). *Lethrinus* sp., Carangids, *Siganus* spp. and *Acanthopagurus* spp., octopuses and holothurians (beche-de-mer) form the edible harvest from seagrass areas (UNEP, 1982) while gastropod shells such as *Cyprea* spp. and starfish such as *Protoreaster lincki* (de Blainville, 1834) are collected from seagrass and coral reef areas and sold to tourists as souvenirs (Kwale District Environment Assessment Report, 1985; Kendall, 1985).

1.2.2 Sewage and eutrophication

Sewage effluents contain excess quantities of phosphates and nitrogen based compounds which lead to eutrophication. Upwelling, land run-off and nitrogen fixation are the natural sources of nitrogen in the East African coastal waters. Nitrates in nearshore waters off Tanzania are reported to reflect the breakdown of nitrogenous compounds from nitrogen fixing algae however terrestrial run-off may be more important in estuaries and littoral areas (McClanahan, 1988). Smith and Codisporti (1980) showed that nitrate values of open Western Indian Ocean waters rarely exceed 5 µg-at N/l. Upwelling areas off the coast of Somalia had values of 13.1 µg-at N/l and 19.9 µg-at N/l. Kazungu *et al.* (1989) recorded the highest nitrate concentration during the rainy season in Tudor Creek. This was 22.6 µg-at N/l at the river mouth and 2.75 µg-at N/l at the open ocean station. At the end of the rainy season the nitrate concentration fell to 1.0 µg-at N/l throughout the estuary.

In the East African coastal waters phosphorus comes from water column mixing, upwelling, river discharge and land run-off during the rainy season. Phosphorus concentrations in oceanic waters peak in June after the start of the SE monsoon and this is due to mixing in the water column. River discharge contributes to the peaks during the rainy season of both the NE and SE monsoon (McClanahan, 1988). Ryther *et al.* (1966) reported that phosphate concentrations rarely exceed 0.5 µg-at P/l in the open north Indian Ocean surface waters. Recent work by Kazungu *et al.* (1989)

indicates that the phosphate concentration in Tudor Creek, Mombasa, was below 1 µg-at P/l. The highest value was 2µg-at P/l which was recorded during the peak rainfall period.

The waters of the Kenyan coast are poor in nutrients especially nitrates and phosphates (Martens, 1994). Nitrates and ammonium are utilized more rapidly than phosphates thus making phosphates the surplus nutrient in the water (Ryther & Dunsten, 1971). Nitrates and ammonium are the principal sources of fixed nitrogen for aquatic plants and of the two ammonium is the preferred nitrogen source (Furnas, 1992).

In the East African coastal towns, sewage treatment (when present) is limited to the removal of coarse suspended solids. The dissolved substances such as nitrogenous compounds, phosphates and other organic salts are mainly released into the creeks and the sea (Ngoile, 1988; Martens 1992). The increasing populations of coastal towns like Mombasa and Malindi has caused an increase in the volume of domestic solid and liquid wastes in the sea. Hotels with septic tanks close to the shore constitute a threat due to sewage seepage by underground percolation through porus limestone rocks and this is bound to affect the flora and fauna (Ruwa, 1991). Increased nutrients may be favorable in the initial stages but may later have adverse effects associated with eutrophication (Bock, pers. comm.; Martens, 1992).

1.2.2.1 Response of flora to eutrophication

Zieman (1975) noted that as seagrasses take up nutrients through the leaves and roots, moderate amounts of extra nutrients could enhance growth. Dissolved nutrients are lower in tropical surface waters than in temperate waters thus the impact of an increase in nutrient levels would be more evident in the tropical areas (Johannes & Betzer, 1975).

McComb and Lukatelich (1986) have documented several consequences of nutrient enrichment. The most direct response is an increase in the phytoplankton population as well as enhanced growth of submerged angiosperms. Prolific growth of epiphytic macroalgae occurs next and this leads to the shading of seagrass leaves which hinders photosynthesis. Macroalgae accumulations are not desirable as they hinder fishing and swimming. Offshore accumulations of macroalgae rot more offensively than seagrasses. Lastly, blooms of cyanobacteria occur causing anaerobic conditions and fish kills due to toxic effects. These blooms have an offensive odour and inhibit recreational activities in the area. Seagrass growth is curtailed by the low light penetration levels and low oxygen levels caused by blooms of cyanobacteria. According to den Hartog (1977), organic pollution leads to the degradation of the original seagrass vegetation as it is replaced by species that are normally not involved in the succession series or species that are rare companion species.

In Rhode Island, USA, Harlin and Thorne-Miller (1981) documented the response of flora to different levels of nutrient enrichment. Low concentrations of nutrients tend to favor marine vascular plants which have an additional source of nutrients in the environment. Intermediate nutrient concentrations favor macroscopic algae while a high concentration of nutrients favors the proliferation of phytoplankton. The seagrass *Thalassia testudinum* Banks ex König has been found to typify an oligotrophic environment while *Halodule wrightii* is found in eutrophic areas (Lapointe *et al.*, 1994). In areas that experienced the effects of eutrophication in Florida Keys and Western Carribean *Giffordia mitchellae* (Harv.) Hammel, *Dictyota divericata* Lamouroux and *Enteromorpha flexuosa* (Wulf. ex Roth) J. Ag. were reported to be the dominant epiphytes (Tomasko & Lapointe, 1991).

In East Africa, the sewage input has direct effects on the marine biota. In areas close to the points of discharge it has been observed that prolific growth of seaweeds and intertidal animals occur (Bryceson, 1982). However, in some areas there has been no evidence of a direct relationship between algal productivity and nutrient enrichment (Ngoile, 1988). In 1975, the Norconsult report indicated that the presence of nutrients and biostimulants in waters of the Kenyan coast did not result in any overall undesirable biological productivity. More recently, Wakibia (1995) noticed excessive growth of *Enteromorpha* sp. and *Ulva* sp. at the Municipal sewage discharge point in Mombasa.

In a survey conducted in Florida Keys, Lapointe and Clarke (1992) noted that coastal sewage disposal into septic tanks and cess pits increase the nutrient concentrations of limestone ground waters. Tides and rainfall enhance the submarine discharge of these enriched ground waters thus increasing coastal eutrophication. This process can have far reaching consequences as the effects of enrichment may extend to the coral reef community.

1.2.2.2 Response of fauna to eutrophication

Tropical waters have a lower oxygen concentration and the rate of oxygen removal is increased by high levels of microbial respiration (Johannes & Betzer, 1975; Zieman & Adams, 1982). This in association with other physical, chemical and biological changes in the seagrass ecosystem have direct and indirect effects on the fauna. Benthic fauna have been used in various parts of the world as biological indicators of water quality (Pearson & Rosenberg, 1978; Raman & Ganapati, 1987). According to Reish (1972) the use of benthic organisms for water quality assessment is based on the belief that natural unpolluted environments are characterized by balanced biological conditions and a diversity of plant and animal life without a dominant species. Pollutants affect the sensitive species and the tolerant ones that remain dominate. Many of the marine benthic organisms are attached forms (sessile) or substrate burrowers thus they are immobile and subjected to pollution which is reflected by a less diverse community.

Pearson and Rosenberg (1978) reviewed literature on macrobenthic (macroinfauna) succession in relation to organic enrichment in the marine environment. They discovered that similar genera of species occur all over the world. In western Mediterranean areas, characteristic species were. found in concentric zones from the point of pollution outward. The first zone adjacent to the source was found to be devoid of macrofauna. A second zone of impoverished fauna dominated by *Capitella capitata* (Fabricius, 1780) followed. The third zone exhibited an absence of species that normally occur prior to pollution. The species present such as *Nematoneris unicornis* (Grube, 1840), *Lumbriconeris latereilli* (Fauvel, 1923), *Heteromastus filiformis* (Claparède, 1864), *Corbula* sp. and *Thyasira* sp. were higher than normal in number. The zone beyond this had the normal communities. However, Eagle and Rees (1973) call for caution in the study of benthic communities. The polychaete *Capitella capitata* which is considered to be the best indicator of organic pollution has been found to show similar responses in areas of physical environmental disturbance.

Species that are associated with the early stages of succession in organically enriched areas are "enrichment opportunists" and their reproductive characteristics are of great importance for rapid colonization. In general, there is a decline of suspension feeders and an increase in deposit feeders as the organic input into the sediment increases. Thus the shift is from larger long lived benthos to smaller rapidly growing but shorter lived species. The detritus food chain persists as long as the enrichment prevails (Pearson & Rosenberg, 1978, Nixon, 1993).

Information on the effect of enrichment on epibenthic fauna is sparse. It is thought by Pearson and Rosenberg (1978) that migration away from or into a polluted area may occur depending on the species tolerance. Therefore the distribution pattern of epifauna may not follow that of the infauna.

Changes in the macrobenthic community structure have been used to detect the effects of marine pollution on the biological benthic community. The level of taxonomic classification has been discussed by Warwick (1988) and Ferraro and Cole (1990, 1992). Taxonomic expertise is required for a detailed identification to species level. In addition, the reliance on the identification of a particular indicator species which may not have a world wide distribution presents a problem. Analysis at different classification levels (Phylum, Order, Family, Genus, Species) indicates that classification to higher levels may clearly reflect the gradients of stress and be less affected by natural confounding factors such as sediment granulometry and water depth which affect individual species.

Studies by Samoilys (1988) revealed a high biomass of coral fish in the Diani area and the input of nutrients from hotel sewage has been cited as one of the main causes of this. Increases in numbers of the common sea urchin *Echinometra mathaei* (de Blainville, 1825) in several parts of the Kenyan coast, including Diani reef, has been attributed to the effects of overfishing (Muthiga & McClanahan, 1987), though nutrients may play a role by the increase of macroalgal food plants.

CHAPTER TWO

AIMS, OBJECTIVES AND STUDY AREA

2.1 OBJECTIVES OF THE STUDY

Studies on seagrass ecosystems in East Africa have been few as research has been directed mainly to other resources with higher economic returns and which are more easily measured in terms of monetary value (Fortes, 1990). Seagrasses are usually not regarded as something to protect and are usually considered to be a nuisance to swimmers and motor boats. As a result, it is the ecosystem that has been least studied in the East African region and information concerning it is extremely limited (Semesi, 1991).

Owing to the importance of seagrasses in the maintenance of inshore marine biodiversity and the sustainability of fishery activity it is important to document the effects of man-induced threats such as sewage disposal. Hotel development along the Kenyan coast has been intensive due to the abundance of attractive beaches and lagoons. The seagrass community lies directly in front of the beach hotels and therefore it would be the first ecosystem to exhibit the effects of land based nutrient enrichment. However, there has been a lack of research data on which to base protective measures that could control the human effects on the lagoon and aid in the long term preservation of both the quality and productivity of the marine environment.

The main aims of this study were to describe the biodiversity and establish the nature, intensity and extent of sewage impacts on the seagrass ecosystems of Diani and Galu Beaches. To do so the following objectives were set:

1. To determine and compare the floral composition of littoral seagrass communities in Diani and Galu Beaches.

2. To compare the abundance and diversity of fauna in Diani and Galu Beaches.

3. To study the nutrient levels and associated physico-chemical parameters in Diani and Galu Beaches and the effects on the flora and fauna.

2.2 STUDY AREA

2.2.1 Location

This study was conducted in Diani and Galu Beaches, Kwale District. Diani Beach is located 35 km from Mombasa town, on the Kenyan south coast, at a latitude of 4^0 18'S (Fig. 1). Galu Beach lies 2 km south of Diani. The coastline in these two areas is separated from the main body of the Indian Ocean by a fringing reef platform. The lagoon between the reef and the shore varies from 500 to 800 m in width and it is drained at low tides through gaps in the fringing reef. Seagrass beds cover upto 75% of the lagoon and they are exposed during the periods of low spring tides. Diani Beach is an

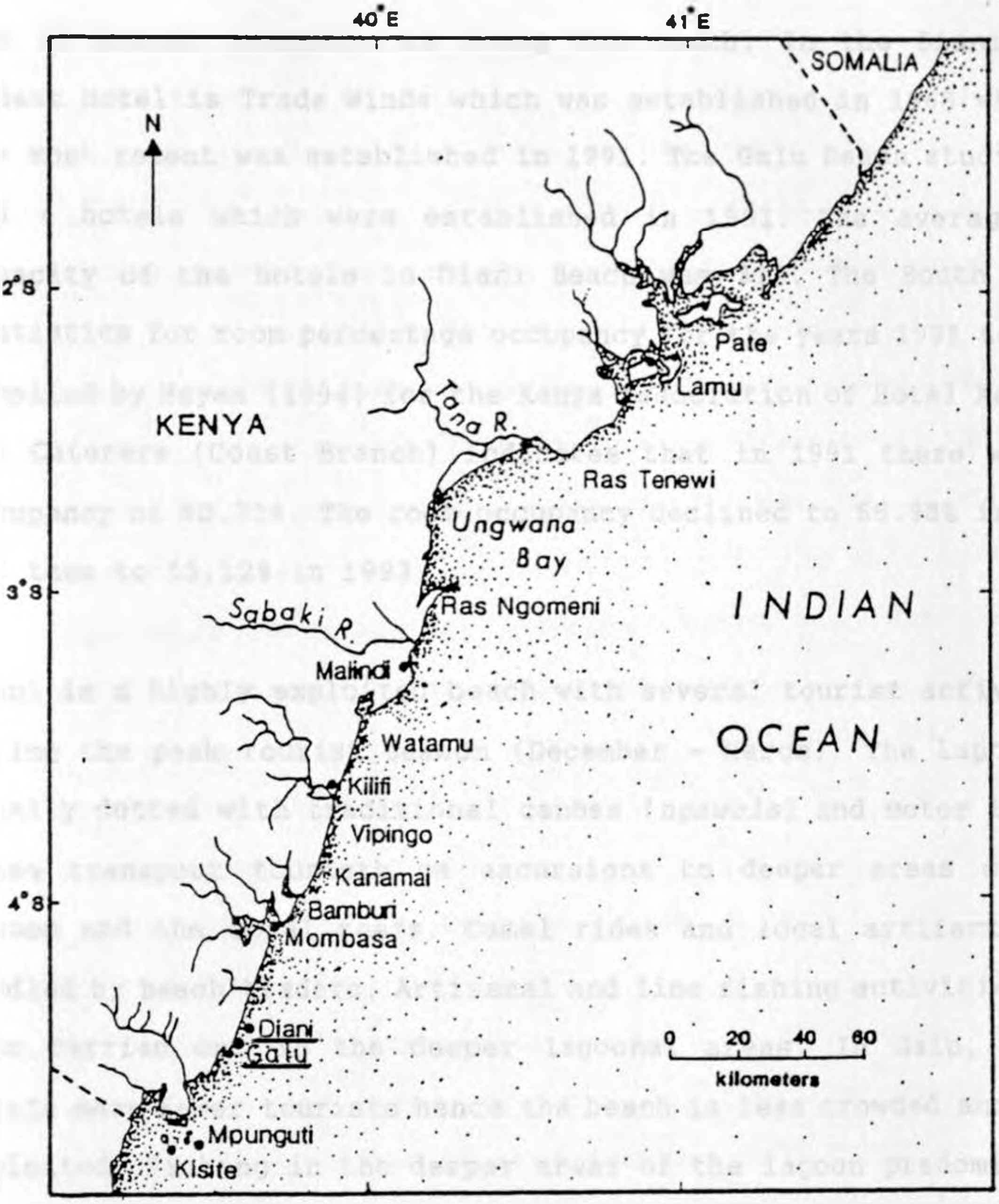


Fig. 1. Map of the Kenyan coast showing the location of Diani and Galu Beaches (Source: McClanahan, in review).

important tourist center with a high hotel density whereas the hotel density is low in Galu Beach. The study area in Diani Beach had 13 hotels concentrated along the beach. In the Diani, the oldest hotel is Trade Winds which was established in 1968 whereas the most recent was established in 1991. The Galu Beach study area had 4 hotels which were established in 1991. The average bed capacity of the hotels in Diani Beach was 311. The South Coast statistics for room percentage occupancy for the years 1991 to 1993 compiled by Hayes (1994) for the Kenya Association of Hotel Keepers and Caterers (Coast Branch) indicates that in 1991 there was an occupancy of 80.71%. The room occupancy declined to 66.98% in 1992 and then to 55.12% in 1993.

Diani is a highly exploited beach with several tourist activities during the peak tourist season (December - March). The lagoon is usually dotted with traditional canoes (*ngawala*) and motor boats. These transport tourists on excursions to deeper areas of the lagoon and the coral reefs. Camel rides and local artifacts are peddled by beach traders. Artisanal and line fishing activities are also carried out in the deeper lagoonal areas. In Galu, fewer hotels mean fewer tourists hence the beach is less crowded and less exploited. Fishing in the deeper areas of the lagoon predominates as the other beach activities are minimum.

In most hotels liquid wastes are disposed of in septic tanks and soakage pits. These tanks are located about 50 - 300 m inland from the beach thus increasing the possibility of nutrient percolation, through the porous limestone rocks, into the lagoon area.

2.2.2 Climate

The climate along the Kenyan coast is influenced by the Inter-Tropical Convergence Zone (ITCZ). This creates two monsoonal periods. The North East monsoon (*Kaskazi*), which occurs from October to March, and the South East monsoon (*Kusi*) which occurs from March to October. During the NE monsoon air masses pass over the Somali land mass and therefore only a small amount of rainfall is received between November and December. In contrast, winds pass over the Indian Ocean during the SE monsoon and this results in the long rains that are experienced between March and June. The SE monsoon is characterized by high cloud cover, rain, high wind energy, decreased temperatures and light. During the NE monsoon these variables are reversed (McClanahan, 1988). The East African Coastal current flows along the coast in a south to north direction and it is influenced by the monsoons (Isaac & Isaac, 1968).

There is a north-south transition in the rainfall regime. In the south coast, the long rains end later and the short rains start earlier. Thus the south coast area receives more rainfall and it has more rainy days. This changes northwards from Mombasa where the rainfall is less (Moorjani, 1977; Munga, 1993).

Figure 2 shows the total rainfall in 1993 recorded at the Ukunda

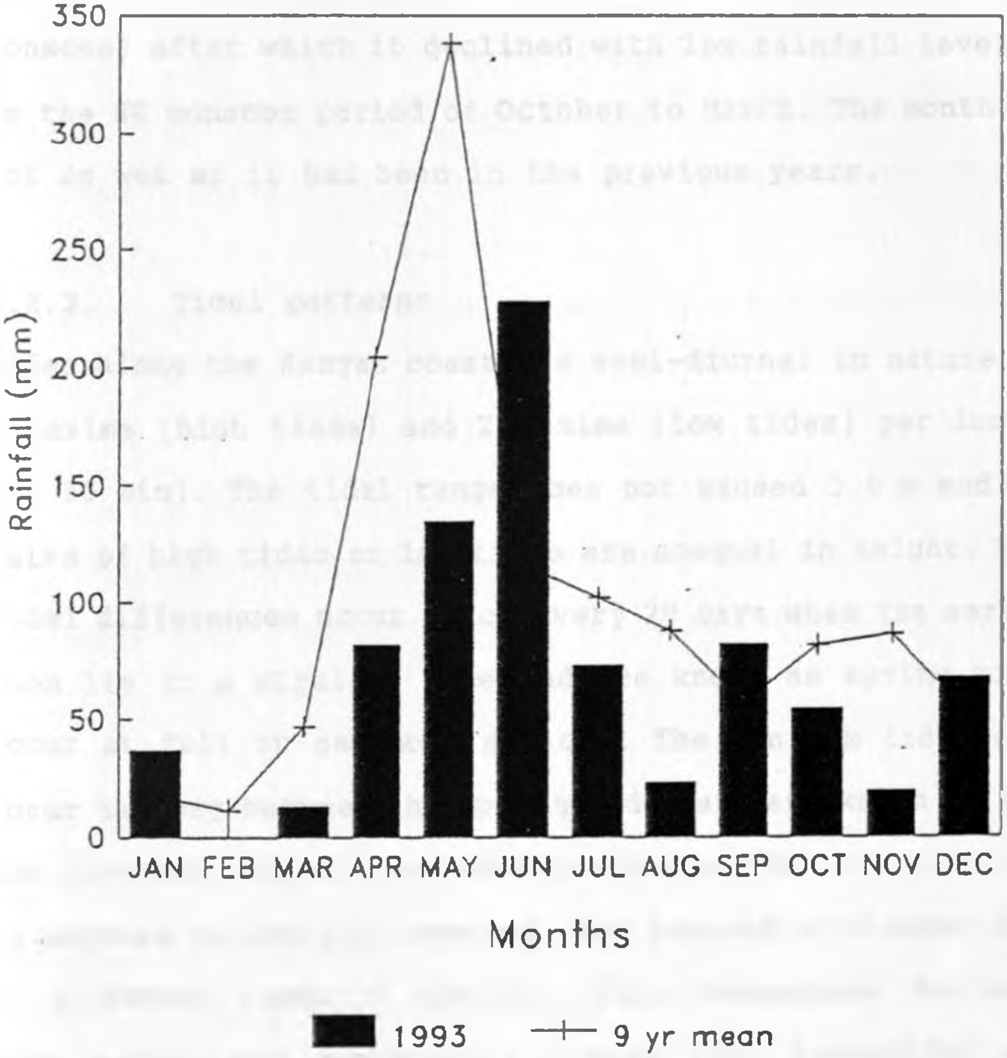


Fig. 2. Total rainfall in 1993 and the 9 year mean rainfall recorded at the Ukunda Veterinary Research Station (No. 9439066) (Source: Kenya Metrological Department, Nairobi).

Veterinary Research Station (No. 9439066) (Source: Kenya Meteorological Department, Nairobi). The mean rainfall over a 9 year period since the station was established is also indicated on the graph. In 1993, the rainfall increased to a peak in June (SE monsoon) after which it declined with low rainfall levels recorded in the NE monsoon period of October to March. The month of May was not as wet as it had been in the previous years.

2.2.3. Tidal patterns

Tides along the Kenyan coast are semi-diurnal in nature. There are 2 maxima (high tides) and 2 minima (low tides) per lunar day (24 hrs 50 min). The tidal range does not exceed 3.9 m and successive pairs of high tides or low tides are unequal in height. The maximum tidal differences occur twice every 29 days when the earth, sun and moon lie in a straight line and are known as spring tides. These occur at full or new moon periods. The minimum tidal differences occur halfway between the spring tides and are known as neap tides. The rise and fall of the tides creates a wide intertidal zone which is exposed to the air (emersed) and covered with water (submersed) at different times of the day. This determines the desiccation, wave action and temperature stress that intertidal plants and animals are exposed to (Brakel, 1982). During the NE monsoon, the lowest tides occur during the day whereas during the SE monsoon they occur at night. This has a biological significance on the flora of the intertidal coastal areas. The lowest density and diversity of species is recorded at the end of the NE monsoon. The vegetation density and diversity is high during the SE monsoon. (Isaac & Isaac, 1968; Brakel, 1982).

2.2.4 Sampling stations

Permanent line transects were established in Diani and Galu Beaches. There were four transects in Diani and four transects in Galu. The transects were perpendicular to the shore and extended seawards from the upper seagrass zone, at the beach, to 100 m (Fig. 3). The transects were established at the following points:

I. DIANI BEACH

Transect D_1

This was the furthest transect to the north of the sampling area in Diani. It was located close to Kaskazi Hotel opposite an outlet in the coral reef through which the water from the lagoon drains during the tidal cycles.

Transect D_2

This transect was located about 1 km south of transect D_1. It extended seawards from the landing point of the Solacher Diving School and was situated close to the Ali Barbour cave restaurant.

Transect D_3

This transect was located approximately 1 km south of transect D_2. Barbour transect. It was in an area bordered by Two Fishes Hotel and Diani Sea Resort.

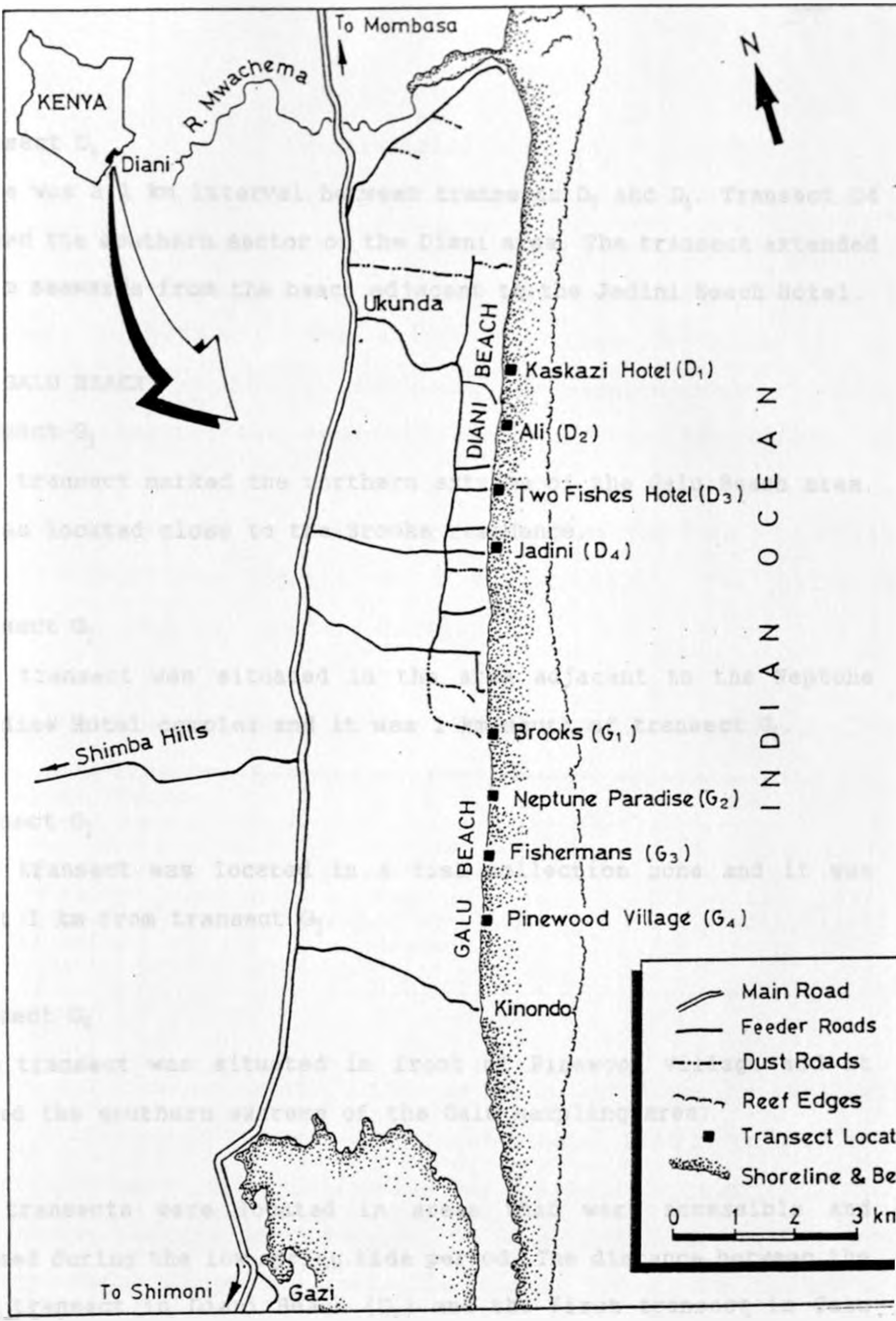


Fig. 3. Map of Diani and Galu Beaches showing the sites of the transects (Modified from Mollison, 1971).

Transect D_4

There was a 1 km interval between transects D_3 and D_4. Transect D4 marked the southern sector of the Diani area. The transect extended 100 m seawards from the beach adjacent to the Jadini Beach Hotel.

II. GALU BEACH

Transect G_1

This transect marked the northern extreme of the Galu Beach area. It was located close to the Brooks residence.

Transect G_2

This transect was situated in the area adjacent to the Neptune Paradise Hotel complex and it was 1 km south of transect G_1.

Transect G_3

This transect was located in a fish collection zone and it was about 1 km from transect G_2.

Transect G_4

This transect was situated in front of Pinewood village and it marked the southern extreme of the Galu sampling area.

The transects were located in areas that were accessible and exposed during the low spring tide period. The distance between the last transect in Diani Beach (D_4) and the first transect in Galu Beach (G_1) was about 2 km.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Sampling program

Sampling was undertaken during the dry and rainy NE and SE monsoon periods respectively. The Kenyan coastline is influenced by seasonal changes brought about by the monsoon periods. Hence seasonal sampling was necessary to account for the effects of seasonality on the seagrass ecosystem. In each case, sampling was carried out during the low spring tides as during this period the seagrass beds were exposed and easily accessible. The following table indicates the sampling dates.

Table 2. Monsoon periods during which sampling was undertaken.

Monsoon Period	Month	Dates
NE dry	February	6th - 13th, 1993
SE rainy	May	4th - 11th, 1993
SE dry	August	18th - 25th, 1993
NE rainy	November	12th - 19th, 1993

The composition and distribution of flora and fauna in seagrass beds is influenced by various physico-chemical factors such as the substratum type, salinity levels, pH, temperature, nutrients and the oxygen content of the water. In this study, the biotic and physico-chemical factors were determined using the following methods.

3.2 Biotic Factors

3.2.1 Seagrass and algal species composition and density

One meter-square quadrats were laid at regular intervals. The intervals chosen were 10, 30, 50, 70 and 90 m from the upper seagrass limit at the beach towards the sea. A floral survey was made within each quadrat to identify the seagrass and algae species. Voucher specimen were obtained and preserved using standard herbarium techniques. Identification was undertaken with the help of botanical keys by Isaac and Isaac (1968), Jaasund (1976) and Moorjani and Simpson (1988).

Samples of seagrass and algae were cropped in a smaller area of 0.0625 m^2 and preserved in 5% neutral formaldehyde. The formalin was neutralized to prevent acidity during storage as acidic formalin damages specimen. In the laboratory, the samples were washed with fresh water and sorted into the different species. Epiphytic encrustations were removed after soaking in dilute HCl for 2 hours. Bulky samples of seagrass were cut down to a manageable size based on the number of shoots present in the samples and the wet weight determined after blotting the plants with absorbent paper to remove excess water. Thereafter, the plants were oven dried at a temperature of 80 ^{0}C to constant weight. The dry weight was obtained after the plants were cooled in a desiccator. The dry weight was an estimate of the leaf standing crop biomass.

3.2.2 Faunal composition and abundance

The species composition and number of epibenthic fauna found within each quadrat was recorded during the transect surveys. Voucher specimen were collected and preserved in 10% neutral formaldehyde for later identification. This was undertaken using keys by Clark and Rowe (1971) and Day (1974).

Infauna (macroinfauna) were sampled using a Polyvinyl Chloride (PVC) pipe core with a stopper at the top. The core had a diameter of 6.8 cm and went down to a depth of 13 cm. The core samples were placed in plastic bags and preserved in 10% neutral formaldehyde. The formaldehyde was mixed with Rose Bengal stain at a concentration of 1 g/l to ease the sorting of infauna.

In the laboratory, the infauna were separated from the sediment by floatation during repeated washing. Sieves of 0.5 mm mesh size were used to collect the infauna as recommended by Holme and McIntyre (1971). The animals were preserved in 10% neutral formaldehyde and the individuals belonging to different taxa were enumerated under a binocular microscope. Petri dishes with an imprinted grid pattern were used to aid in sorting and counting of the animals. Identification was carried out to family level using keys by Day (1974). The lack of adequate keys hindered further identification to species level.

As a measure of diversity the Shannon Weiner index (H') was calculated for both the epibenthic fauna and infauna as described by Magurran (1988). The calculation was based on the number of individuals in the different phyla. H' was calculated as:

$$H' = -\sum pi \log pi$$

where pi = the proportion of the i^{th} species.

Evenness of the distribution, which is a measure of how the individuals are distributed within the phyla, was calculated as:

$$J' = H'/H\ max$$

where H max = log S

S = number of species; H' = diversity index

3.3 Physico-chemical Factors

3.3.1 Transect survey

Transect surveys were conducted to establish the elevation of the transects above the mean low water spring (MLWS) level. The heights above the MLWS were computed using the 1993 tide tables for Kilindini Harbour, Mombasa.

3.3.2 Temperature

During each field visit, the air and water temperatures were recorded at the various sampling points. This was done using a mercury in glass thermometer with 0.5 $^{\circ}$C graduations.

3.3.3 Salinity

Water samples were collected, at every sampling point, in plastic bottles and transported to the laboratory. An Aanderaa Instruments Salinometer was used to determine the salinity of the water in parts per thousand (‰).

3.3.4 pH

Water samples were collected at every sampling point. In the laboratory, the samples were analyzed using a CG 840 (Schott) pH meter. Samples for pH can be assessed *in situ* or by titration techniques in the laboratory (Giere *et al*, 1988).

3.3.5 Sediment particle size determination

Sediment samples were obtained using a core of 3.5 cm diameter and down to a depth of 13 cm. These samples were collected at each sampling site adjacent to the infauna collection sites. The core samples were oven dried at 40 ^{0}C in the laboratory. The different sediment particle sizes were analyzed using a series of sieves and a mechanical shaker. They were graded into the following Wentworth grades: 2000 - 1000 µm, 1000 - 500 µm, 500 - 250 µm, 250 - 125 µm, 125 - 62 µm, 62 - 4 µm and <4 µm. The residues in each sieve were weighed and the sediment particle statistics of each sample were determined using methods described by Griffiths (1967) and Buchanan & Kain (1971) (See Appendix II).

3.3.6 Sediment organic matter content

The organic matter content of each sediment sample was determined using the ignition method documented by Byers *et al.* (1978). 3 g of each sample was weighed and placed in a porcelain crucible. This was then ignited to 500 ^{0}C fpr 6 hours. The samples were composed of sediments that are rich in calcium carbonate ($CaCO_3$) hence the break down of carbonates during the ignition process contributes to errors in the organic matter estimate. By keeping the ignition temperature at or below 500 ^{0}C there was a very insignificant change in the $CaCO_3$ content of the sample. The samples were reweighed and the percentage loss in weight calculated. This represented the organic matter content of the sample.

3.3.7 Nutrient analysis

Nutrient surveys focus on the concentration of readily measured dissolved inorganic macronutients which are taken up directly by macrophytes and phytoplankton (Furnas, 1992). In this survey, seawater samples were collected in 100 ml capacity acid washed bottles. The samples were preserved with 2 drops of chloroform and frozen to avoid metabolism by micro-organisms. Inorganic macronutrients analyzed were nitrates, ammonium and phosphates using a Technicon Auto-Analyzer.

3.3.7.1 Nitrate (NO_3^-)

The sample was passed through a cadmium-copper column and reduced to nitrite. The nitrite was then diazotized by reacting it with an aromatic amine sulfanilamide in acid to form a diazo compound. This was reacted with N-(1- naphthyl)-ethylenediamine dihydrogen chloride to form an azo dye. The absorbance (optical density) of the dye was measured using a spectrophotometer at a wavelength of 543 nm. Standard nitrate solutions of 0.1, 1.0, 2.0, 3.0, 4.0 and 5.0 µg at N/l (µM) were prepared from a stock solution of potassium nitrate. Concentrations of nitrite have been reported to be low and undetectable in the surface waters of the East African region (Kazungu, pers. comm.) thus the concentration of nitrate estimated in this study was a combination of nitrite and nitrate.

3.3.7.2 **Ammonium (NH_4^+)**

The water samples were treated in an alkaline citrate medium with sodium hypochlorite and phenol in the presence of the catalyst sodium nitroprusside. A blue indophenol color was formed and this was measured using a spectrophotometer at 640 nm wavelength. Standard solutions of 0.2, 2.0, 4.0, 6.0, 8.0, and 10.0 µg at N/l (µM) were prepared from a stock solution of ammonium sulphate.

3.3.7.3 **Phosphate (PO_4^{3-})**

The water samples were reacted with a composite reagent containing molybdic acid, ascorbic acid and trivalent antimonyl. The resulting complex was reduced to give a blue solution. The optical density of this solution was measured using a spectrophotometer at a wavelength of 882 nm. Standard solutions of 0.2, 1.0, 2.0, 3.0, 4.0 and 5.0 μg at P/l (μM) were prepared from a stock solution of potassium dihydrogen phosphate for calibration.

3.3.8 Biochemical oxygen demand ($BOD_{5/20}$)

The BOD test is used to assess the organic matter content of water due to sewage and industrial effluents. Two water samples were obtained from the beach end, mid-section and the seaward end of each transect using BOD bottles. The Winkler method described by Parsons *et al.* (1984) was used to analyze the oxygen content of the samples. One of the samples was fixed in the field using manganous chloride and sodium hydroxide. In the lab, the sample was acidified in the presence of iodide and subsequently titrated with 0.01 N sodium thiosulfate to indicate the dissolved oxygen content. The second sample was incubated at a temperature of 20 ^{0}C for a period of 5 days after which the oxygen content was determined. The difference between the oxygen content of the first and second sample was taken to be the $BOD_{5/20}$ estimate. This gave a measure of the biodegradable material in the sample.

3.3.9 Hotel Survey

This was undertaken in order to investigate the sewage disposal practices of the hotels found in the study area. A mail questionnaire was formulated as described by Moser (1958) (Appendix 1) and distributed with the assistance of the Mombasa and Coast

Tourist Association. The response rate was low, consequently personal interviews were undertaken to obtain the relevant information.

3.3.10 Statistical Analysis

A non-parametric statistics method was used because it does not require assumptions about the type of population distributions especially in cases like this study where a small number of samples were obtained from populations with unknown distributions. Therefore, the data collected were analyzed using the non-parametric Kruskal Wallis equivalent of ANOVA with replication for the effect of area, season (months) and their interaction as described by Sokal and Rohlf (1969) and Zar (1984). The significance level used was $\alpha = 0.05$.

The diversity indices were analyzed statistically using the t test proposed by Hutchenson and described by Zar (1984). Relationships between the biotic and physico-chemical factors were tested using the Pearson regression analysis on the SPSS program.

CHAPTER FOUR

RESULTS

4.1 Biotic Factors

4.1.1 Taxonomic composition and distribution of seagrasses in Diani and Galu Beaches

Table 3 shows the seagrass species and their overall abundance in the transects during the study period. In Diani Beach, *C. serrulata* was notably absent from transect D_1 while *H. ovalis* did not occur in transects D_2 and D_3. In Diani Beach, transect D4 had the highest number of seagrass species. The most abundant species were *T. ciliatum* and *T. hemprichii.*

In Galu Beach, transect G_1 had seven seagrass species compared to the other transects in this area which had a total of eight species. *T. ciliatum* was absent in transects G_1 and G_2 while *H. ovalis* was absent in transects G_3 and G_4. *C. rotundata* was not found in transect G1 during the sampling periods. In Galu Beach, the most abundant species were *H. wrightii* and *T. hemprichii.*

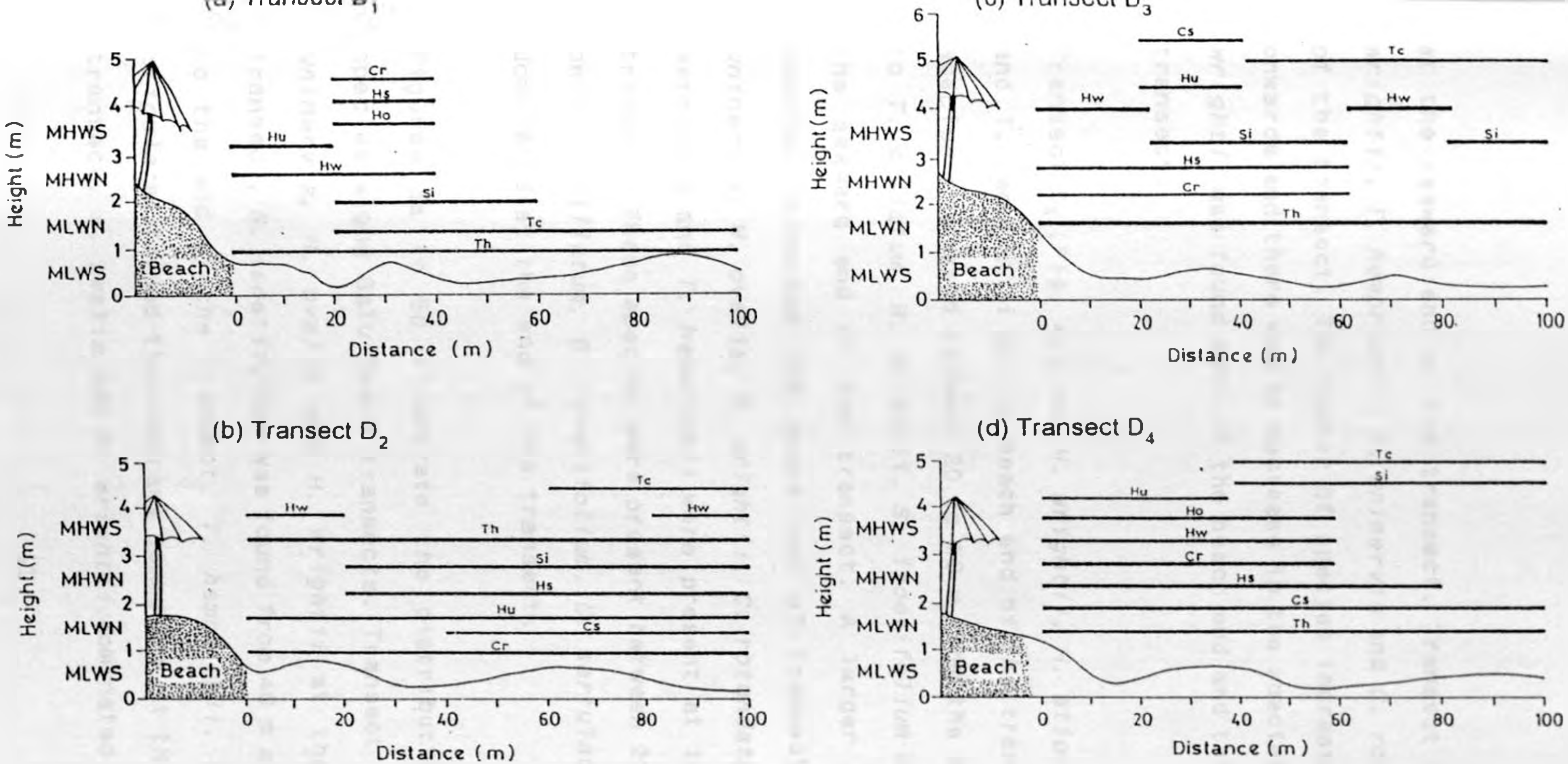
The distribution of these seagrasses along the transects in Diani Beach is shown in Figs. 4a to 4d. Transect D_1 (Fig. 4a) had eight species of seagrasses excluding *C. serrulata. H. uninervis, H. wrightii* and *T. hemprichii* dominated at the beach end of the transect upto 20 m. After this, the number of species increased in the mid sections of the transect (between 20 - 60 m) then decreased seawards to *T. ciliatum* and *T. hemprichii* dominating

Table 3. Species composition and abundance of seagrasses in Diani and Galu Beaches.

SPECIES	DIANI BEACH TRANSECTS				GALU BEACH TRANSECTS			
	D1	D2	D3	D4	G1	G2	G3	G4
Thalassodendron ciliatum (Forsk.) den Hartog	6+	1+	5+	4+	-	-	1+	1+
Cymodocea serrulata (R. Br.) Aschers & Magnus	-	4+	2+	3+	1+	4+	3+	1+
Cymodocea rotundata Ehrenb.& Hempr. ex Aschers	1+	6+	1+	2+	-	2+	3+	2+
Syringodium isoetifolium (Aschers.) Dandy	2+	4+	3+	3+	4+	3+	6+	1+
Halodule uninervis (Forsk.) Aschers	1+	6+	2+	2+	2+	2+	1+	1+
Halodule wrightii Aschers	3+	1+	3+	3+	6+	6+	3+	2+
Halophila stipulacea (Forsk.) Aschers	2+	5+	3+	2+	1+	4+	3+	1+
Halophila ovalis (R. Br.) Hook. f.	2+	-	-	1+	3+	3+	-	-
Thalassia hemprichii (Ehrenb.) Aschers	3+	3+	6+	5+	1+	2+	6+	6+
TOTAL NO. OF SPECIES	8	8	8	9	7	8	8	8

Legend:

- \- absent in all the quadrats sampled during the year
- 1+ found in 1 - 9% of all the quadrats sampled during the year
- 2+ found in 10 - 19% of all the quadrats sampled during the year
- 3+ found in 20 - 29% of all the quadrats sampled during the year
- 4+ found in 30 - 39% of all the quadrats sampled during the year
- 5+ found in 40 - 49% of all the quadrats sampled during the year
- 6+ found in over 50% of all the quadrats sampled during the year



Seagrass species		Tide levels
Hw: *Halodule wrightii* Hu: *Halodule uninervis* Ho: *Halophila ovalis* Hs: *Halophila stipulacea* Cr: *Cymodocea rotundata*	Cs: *Cymodocea serrulata* Th: *Thalassia hemprichii* Si: *Syringodium isoetifolium* Tc: *Thalassodendron ciliatum*	MHWS: Mean high water springs MHWN: Mean high water neap MLWN: Mean low water neap MLWS: Mean low water springs

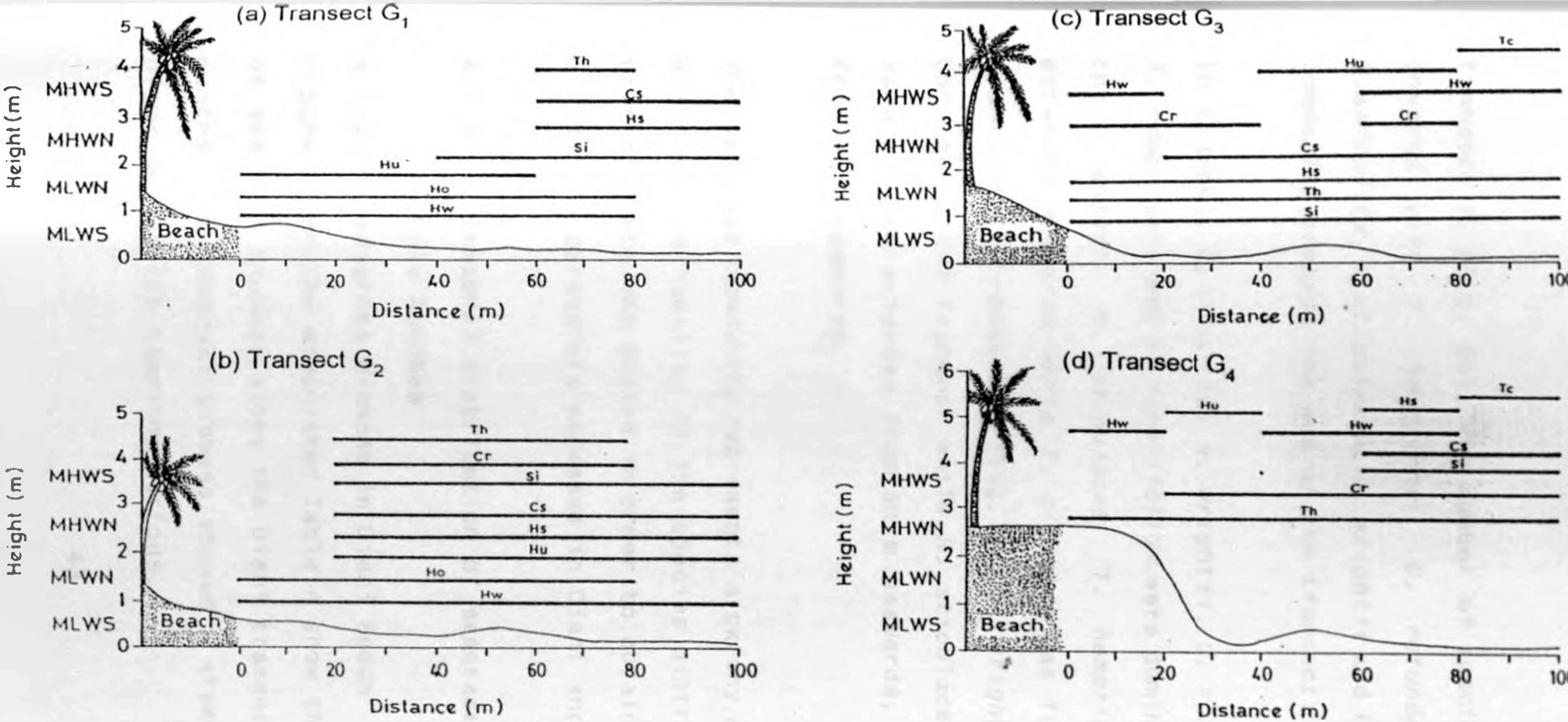
Transects in Diani Beach

Fig. 4. Distribution of seagrass species along transect D_1 (a), transect D_2 (b), transect D_3 (c) and transect D_4 (d) in Diani Beach.

at the seaward end of the transect. Transect D_2 (Fig. 4b) had *H. wrightii, T. hemprichii, H. uninervis* and *C. rotundata* at the start of the transect. The number of species increased from 20 m onwards and there was no decrease in the species number seaward. *H. wrightii* was found both at the beach end and the seaward end of the transect.

Transect D_3 (Fig. 4c) had *H. wrightii, H. stipulacea, C. rotundata* and *T. hemprichii* at the beach end of the transect. The number of species increased between 20 to 60 m from the beach then decreased to *T. ciliatum, H. wrightii. S. isoetifolium* and *T. hemprichii* at the seaward end of the transect. A larger number of seagrass species colonized the beach end of transect D_4 (Fig. 4d). *H. uninervis, H. ovalis, H. wrightii, C. rotundata, H. stipulacea, C. serrulata* and *T. hemprichii* were present at the beach end of the transect. These species were present between 20 and 60 m. However, only *T. ciliatum, S. isoetifolium, C. serrulata* and *T. hemprichii* dominated at the end of the transect.

Figures 5a to 5d illustrate the distribution of the seagrass species along Galu Beach transects. Transect G_1 (Fig. 5a) had *H. uninervis, H. ovalis* and *H. wrightii* at the beach end of the transect. *S. isoetifolium* was found from 40 m and extended seawards to the end of the transect. *T. hemprichii, C. serrulata* and *H. stipulacea* formed the seagrass community at the seaward end of the transect. *H. ovalis* and *H. wrightii* dominated at the beach end of



Seagrass species		Tide levels
Hw: *Halodule wrightii* Hu: *Halodule uninervis* Ho: *Halophila ovalis* Hs: *Halophila stipulacea* Cr: *Cymodocea rotundata*	Cs: *Cymodocea serrulata* Th: *Thalassia hemprichii* Si: *Syringodium isoetifolium* Tc: *Thalassodendron ciliatum*	MHWS: Mean high water springs MHWN: Mean high water neap MLWN: Mean low water neap MLWS: Mean low water springs

Transects in Galu Beach

Fig. 5. Distribution of seagrass species along transect G_1 (a), transect G_2 (b), transect G_3 (c) and transect G_4 (d) in Galu Beach.

transect G_2 (Fig. 5b). The number of species increased from 20 m onwards with *T. hemprichii*, *C. rotundata*, *S. isoetifolium*, *C.serrulata*, *H.stipulacea*, *H. wrightii* and *H. uninervis* forming the community towards the end of the transect.

In transect G_3 (Fig. 5c) *H. wrightii*, *C. rotundata*, *H. stipulacea*, *T. hemprichii* and *S. isoetifolium* were dominant at the beach end of the transect. *H. stipulacea*, *T. hemprichii*, *S. isoetifolium* extended seawards while *T. ciliatum* was found at the end of the transect. In transect G_4 (Fig. 5d) *H. wrightii* occurred in patches throughout the transect while *H. stipulacea*, *C. serrulata* and *S. isoetifolium* extended from 60 m seawards. *T. ciliatum* was found from 80 m seawards.

The seagrass community represents a patchy environment with a high degree of variability in the species distribution. Therefore the transect data was pooled in order to obtain representative values of all the parameters assessed in Diani and Galu Beaches.

4.1.2 Seasonal distribution of seagrass biomass in Diani and Galu Beaches

4.1.2.1 Seagrass biomass in Diani Beach

Figure 6 and the associated Table 4 show the overall distribution of seagrass biomass along the Diani transects during the sampling months. The seagrass biomass showed a steady seaward increase in Diani during the sampling periods.

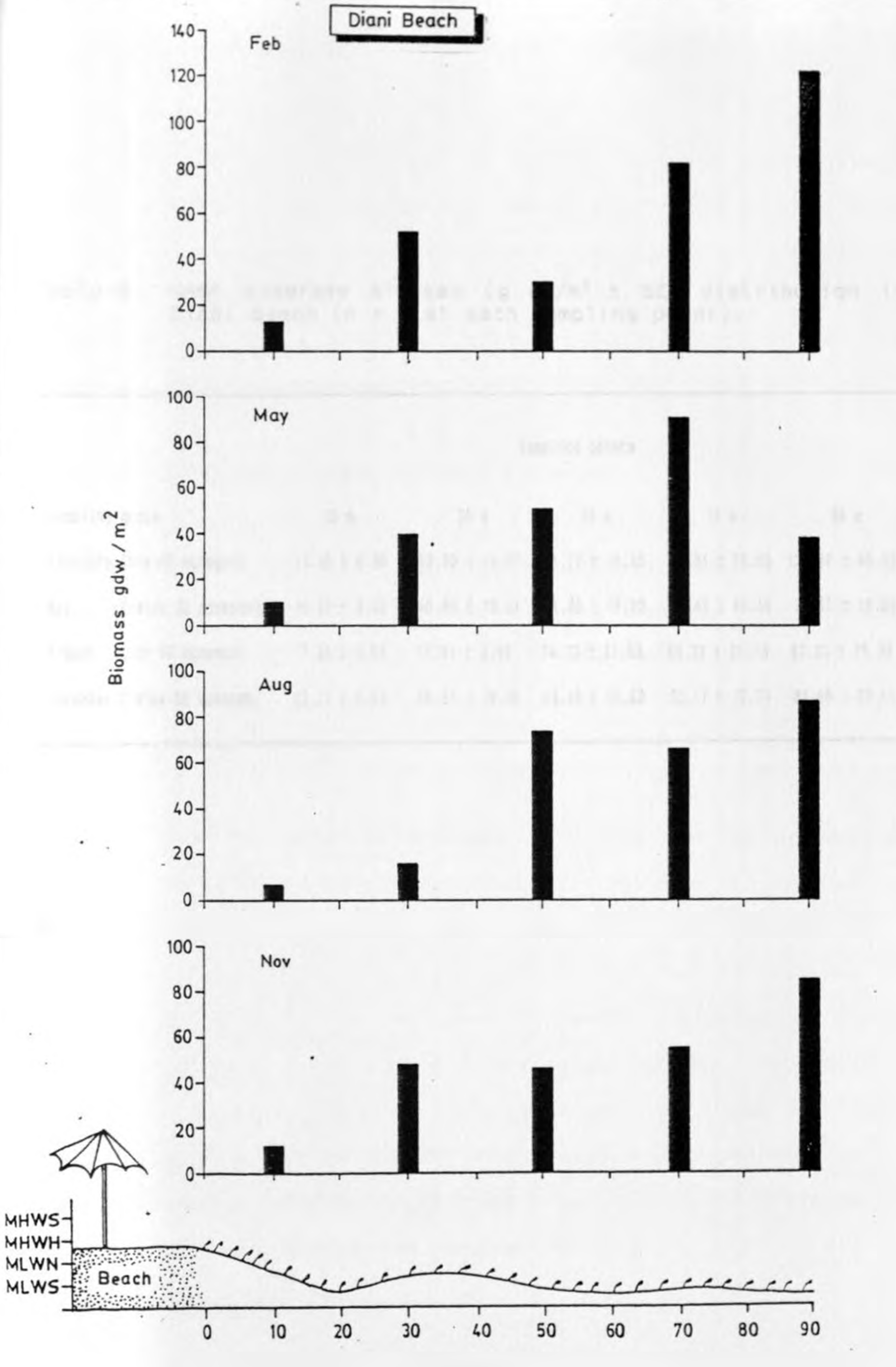


Fig. 6. Distribution of seagrass biomass along the transects in Diani Beach during the sampling months.

Table 4. Mean seagrass biomass (g dw/m^2 ± SE) distribution in Diani Beach (n = 8 at each sampling point).

	Sampling points				
Sampling month	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	13.28 ± 6.90	52.20 ± 14.87	31.72 ± 16.49	80.91 ± 25.89	133.62 ± 40.07
May (rainy SE monsoon)	10.27 ± 3.02	40.65 ± 19.51	51.85 ± 16.22	92.42 ± 41.49	38.81 ± 15.86
August (dry SE monsoon)	7.36 ± 2.04	16.31 ± 3.56	74.73 ± 27.55	65.21 ± 21.78	87.31 ± 25.92
November (rainy SE monsoon)	12.17 ± 4.33	48.21 ± 10.58	45.49 ± 10.83	53.17 ± 10.74	84.86 ± 25.41

The only exception was the wet SE monsoon sampling period (May) where the seagrass biomass at the end of the transects was lower than the other months (Table 4). The highest seagrass biomass of 13.28 ± 6.90 g dw/m^2 at the start of the transects and the highest biomass of 133.62 ± 40.07 g dw/m^2 at the seaward end of the transects were recorded in February.

4.1.2.2 Seagrass biomass in Galu Beach

The overall seagrass biomass distribution along the transects in Galu is illustrated in Fig. 7. The seaward increase in seagrass biomass was evident during the sampling months. The highest seagrass biomass at the beach end of the transects was 14.86 ± 3.94 g dw/m^2 recorded in November while February had the highest biomass at the last sampling point (90 m) of 70.55 ± 18.02 g dw/m^2 (Table 5).

4.1.2.3 Overall seagrass biomass in Diani and Galu Beaches

Figure 8 presents the overall seasonal distribution of seagrasses in Diani and Galu Beaches. There was an overall decrease of seagrass biomass in Diani from February to May then an increase in August and November. The decrease in seagrass biomass in Diani occurred during the rainy SE monsoon season of May. The overall seagrass biomass was lower in Galu Beach and there was a biomass increase recorded during the two rainy seasons (May and November). The Kruskal Wallis analysis confirmed the significant difference in the seagrass biomass recorded in Diani and Galu ($H = 6.96$, $p \leq$

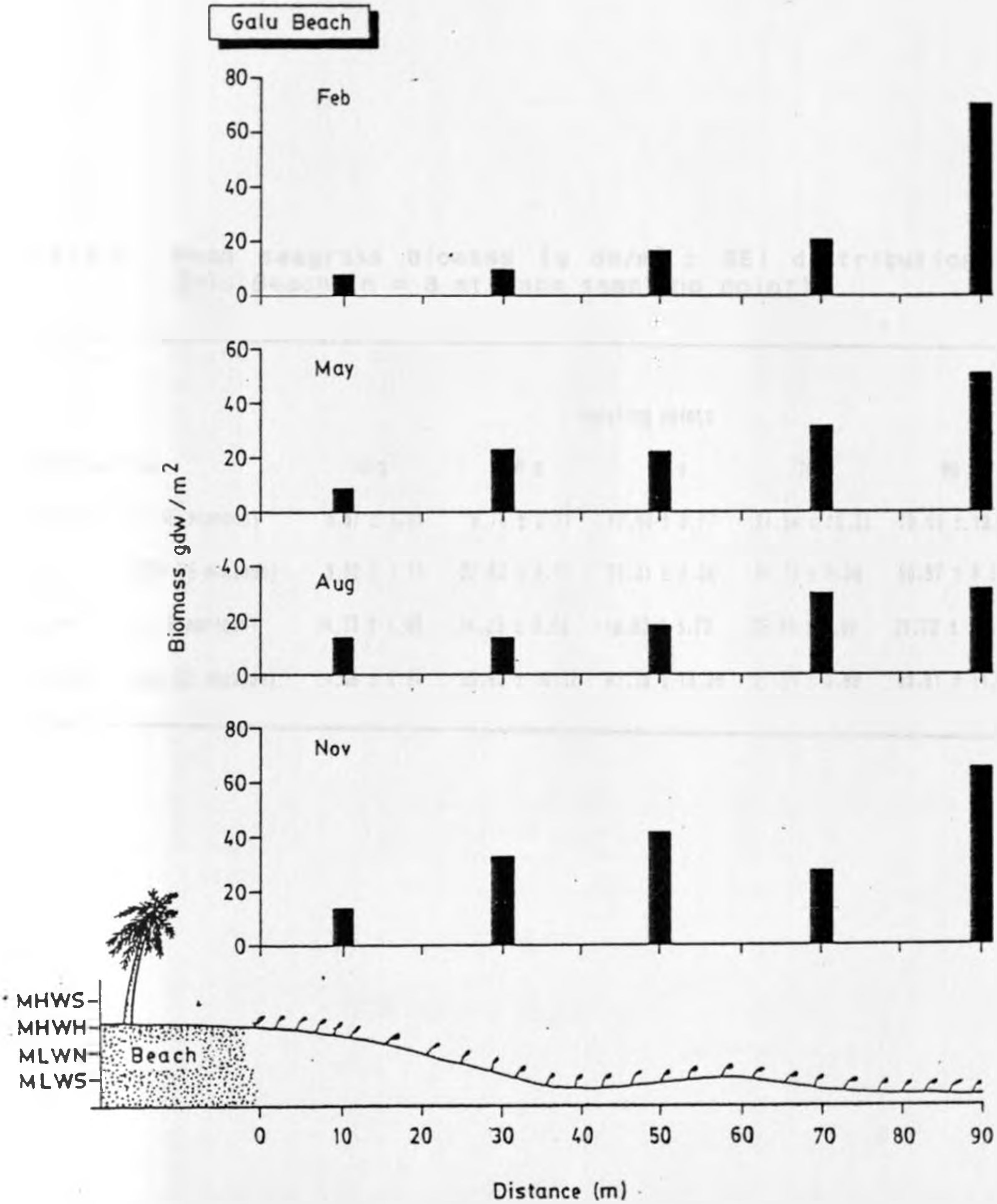


Fig. 7. Distribution of seagrass biomass along the transects in Galu Beach during the sampling months.

Table 5. Mean seagrass biomass (g dw/m² ± SE) distribution in Galu Beach (n = 8 at each sampling point).

	Sampling points				
Sampling month	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	8.67 ± 3.25	9.76 ± 2.71	17.60 ± 6.77	21.54 ± 18.83	70.55 ± 18.02
May (rainy SE monsoon)	9.02 ± 3.79	22.82 ± 6.77	22.31 ± 8.38	31.13 ± 8.08	50.87 ± 6.30
August (dry SE monsoon)	14.33 ± 4.65	14.25 ± 2.68	18.53 ± 5.72	29.69 ± 7.60	31.72 ± 7.10
November (rainy SE monsoon)	14.86 ± 3.94	33.93 ± 10.32	42.16 ± 19.86	27.91 ± 3.99	63.81 ± 14.93

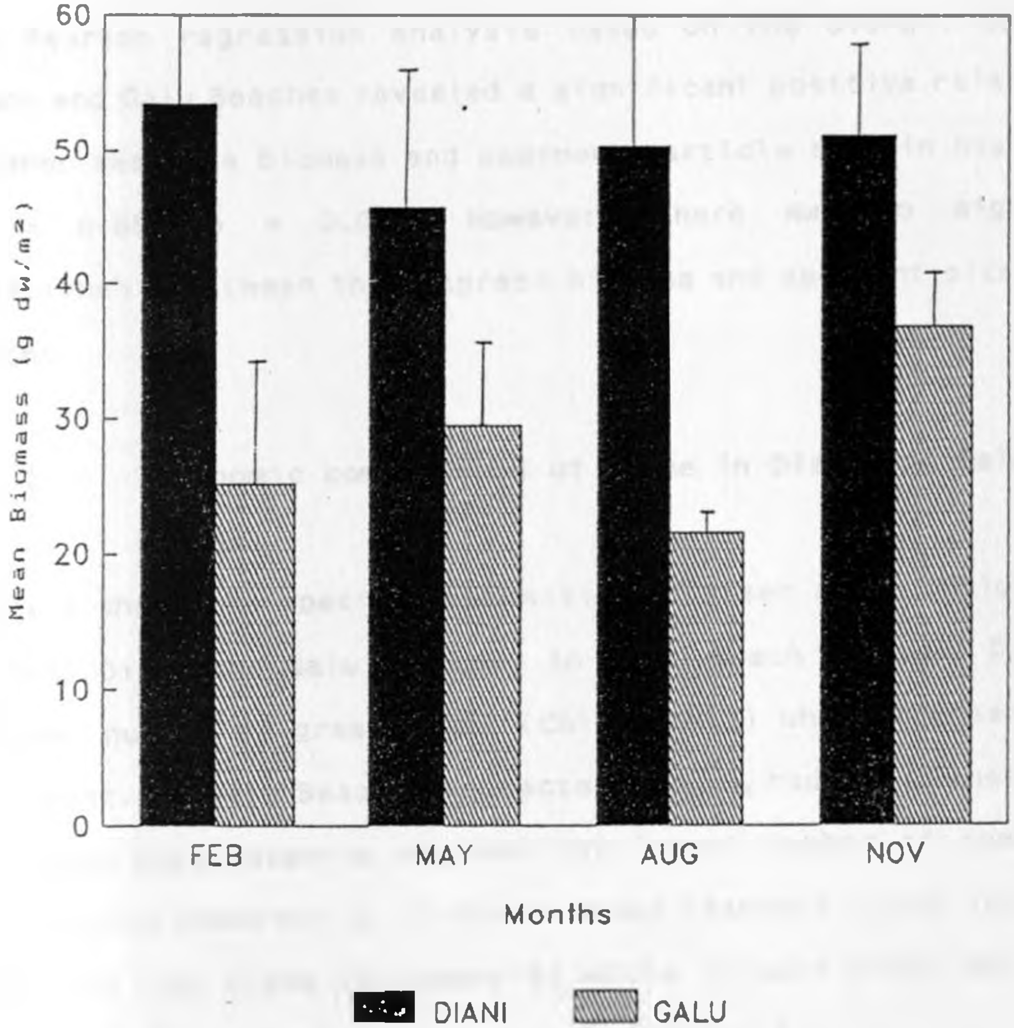


Fig. 8. Seagrass biomass in Diani and Galu Beaches (n = 40 in each month).

0.05) with the biomass being higher in Diani. The seasonal fluctuation in biomass was not significant.

The Pearson regression analysis based on the overall data from Diani and Galu Beaches revealed a significant positive relationship between seagrass biomass and sediment particle size in Diani Beach ($r = 0.65$, $p = 0.04$). However, there was no significant relationship between the seagrass biomass and sediment size in Galu Beach.

4.1.3 Taxonomic composition of algae in Diani and Galu Beaches

Table 6 shows the species composition of green algae (Chlorophyta) in both Diani and Galu Beaches. In Diani Beach transect D_4 had the highest number of green algae (Chlorophyta) while transect D_3 had the least. In Galu Beach, transects G_1 and G_4 had the highest number of green algae species whereas the lowest number of species was recorded in transect G_3. In Diani Beach transect D_4 had the highest number of red algae (Rhodophyta) while in Galu Beach most of the red algae were found in transect G_4 (Table 7).

The number of brown algae (Phaeophyta) species was low in the Diani and Galu transects (Table 8). The highest number of brown algae species were recorded in transect D_4, in Diani Beach, while in Galu Beach the brown algae were absent in transect G_3. The blue-green algae (Cyanophyta) were not identified. Nevertheless, they were

Table 6. Species composition and abundance of green algae (Chlorophyta) in Diani and Galu Beaches.

SPECIES	DIANI BEACH TRANSECTS D1	D2	D3	D4	GALU BEACH TRANSECTS G1	G2	G3	G4
Caulerpa lentillifera J. Ag.	1+	-	-	1+	-	-	-	1+
Caulerpa sertulariodes (Gemlin) Howe	-	-	-	-	1+	1+	1+	-
Chaetomorpha aerea (Dillw.) Kuetz	-	1+	-	-	1+	2+	-	1+
Chaetomorpha crassa (Ag.) Kutz	-	-	-	-	1+	-	-	2+
Boodlea composita (Harvey) Brand	-	-	-	-	-	-	-	1+
Codium capitatum Silva	1+	-	-	1+	-	-	-	-
Dictyosphaeria cavernosa (Forsk.) Boergsen	-	-	-	-	-	-	-	1+
Entermorpha sp.	-	-	-	1+	1+	-	-	-
*Halimeda macroloba** Decaisne	-	1+	-	1+	-	-	1+	1+
*Halimeda opuntia** (L.) Lamouroux	1+	1+	1+	4+	1+	2+	6+	5+
*Halimeda tuna** (Ellis & Soi.) Lamouroux	-	-	1+	1+	1+	-	-	-
*Udotea orientalis** Weber van Bosse	-	-	-	-	1+	1+	1+	-
Ulva pertusa Kjellman	1+	1+	1+	2+	1+	1+	-	1+
Ulva reticulata Forskaal	-	-	-	-	1+	1+	-	-
Ulva rigida C. Ag. f. tropica	1+	1+	1+	2+	1+	2+	1+	1+
TOTAL NO. OF SPECIES	5	5	4	8	10	7	5	9

Legend:
- \- absent in all the quadrats sampled during the year
- 1+ found in 1 - 9% of all the quadrats sampled during the year
- 2+ found in 10 - 19% of all the quadrats sampled during the year
- 3+ found in 20 - 29% of all the quadrats sampled during the year
- 4+ found in 30 - 39% of all the quadrats sampled during the year
- 5+ found in 40 - 49% of all the quadrats sampled during the year
- 6+ found in over 50% of all the quadrats sampled during the year
- * calcareous algae

Table 7. Species composition and abundance of red algae (Rhodophyta) in Diani and Galu Beaches.

SPECIES	DIANI BEACH TRANSECTS D1	D2	D3	D4	GALU BEACH TRANSECTS G1	G2	G3	G4
Acanthophora muscoides (L.) Bory	-	-	-	-	-	-	-	2+
*Amphiora rigida** Lamouroux	4+	4+	2+	4+	1+	2+	2+	5+
Centroceras clavulatum (C. Ag.) Montagne	-	-	1+	-	-	-	-	-
Champia sp.	-	1+	-	1+	1+	1+	-	2+
*Corallina subulata** Ellis & Solander	2+	-	-	-	-	-	-	-
Euchema striata Schmitz	-	-	-	-	-	-	-	1+
Gelidella acerosa (Forsk.) Feldm. & Hamel	-	-	-	1+	-	-	-	1+
Gracillaria corticata J. Agardh.	1+	1+	1+	1+	-	-	1+	1+
Gracillaria edulis (J. Ag.) Silva	-	-	-	-	-	-	-	1+
Gracillaria millardetii J. Ag.	-	-	-	1+	-	-	-	1+
Gracillaria sp.	3+	1+	1+	1+	-	-	-	1+
Hypnea cervicornis J. Ag.	1+	1+	1+	1+	1+	1+	1+	1+
Hypnea cornuta (Lamour.) J. Ag.	3+	1+	2+	3+	3+	5+	5+	3+
Hypnea nidifica J. Agardh	1+	2+	1+	1+	1+	1+	2+	1+
Hypnea musiformis (Wulfen) Lamouroux	-	-	-	-	-	-	-	1+
*Jania adherens** Lamouroux	4+	1+	2+	2+	-	-	-	1+
Laurencia papillosa (Forsk.) Greville.	-	-	-	1+	-	-	-	1+
Nordemannia miniata (Draparnaud) Feldmann et Hammel	5+	1+	1+	2+	-	-	1+	1+
TOTAL NO. OF SPECIES	9	9	9	12	5	5	6	16

Legend:
- \- absent in all the quadrats sampled during the year
- 1+ found in 1 - 9% of all the quadrats sampled during the year
- 2+ found in 10 - 19% of all the quadrats sampled during the year
- 3+ found in 20 - 29% of all the quadrats sampled during the year
- 4+ found in 30 - 39% of all the quadrats sampled during the year
- 5+ found in 40 - 49% of all the quadrats sampled during the year
- 6+ found in over 50% of all the quadrats sampled during the year
- * calcareous algae

Table 8. Species composition and abundance of brown algae (Phaeophyta) and blue-green algae (Cyanophyta) in Diani and Galu Beaches.

PHAEOPHYTA (Brown algae)

SPECIES	DIANI BEACH TRANSECTS				GALU BEACH TRANSECTS			
	D1	D2	D3	D4	G1	G2	G3	G4
Cystoseria myrica (Gemlin) C. Ag.	-	-	1+	1+	-	-	-	1+
Dictyota adnata Zanardini sensu web. v. Bosse	3+	1+	-	1+	1+	-	-	-
Dictyota sp.	1+	1+	1+	-	-	-	-	-
Padina boryana Thivy	-	-	-	1+	-	1+	-	-
Sargassum ilicifolium (Turn.) J. Ag.	1+	-	-	1+	-	-	-	-
Turbinaria conoides (J. Ag.) Kutzing	-	-	1+	1+	-	-	-	-
TOTAL NO. OF SPECIES	3	2	3	5	1	1	-	1

CYANOPHYTA (Blue-Green Algae)

SPECIES	DIANI BEACH TRANSECTS				GALU BEACH TRANSECTS			
	D1	D2	D3	D4	G1	G2	G3	G4
Blue-green algae (sp. unidentified)	3+	1+	2+	1+	1+	-	-	1+

Legend:
- \- absent in all the quadrats sampled during the year
- 1+ found in 1 - 9% of all the quadrats sampled during the year
- 2+ found in 10 - 19% of all the quadrats sampled during the year
- 3+ found in 20 - 29% of all the quadrats sampled during the year
- 4+ found in 30 - 39% of all the quadrats sampled during the year
- 5+ found in 40 - 49% of all the quadrats sampled during the year
- 6+ found in over 50% of all the quadrats sampled during the year

prevalent in all the Diani transects while in Galu Beach they were present in only two transects.

Rhodophyta contributed the most to the species composition in both Diani and Galu Beach comprising 45% of all the species encountered. Chlorophyta was composed of 37.5%, Phaeophtya had 15% while the Cyanophyta contributed the least with 2.5% of all the species encountered.

4.1.4 Seasonal distribution of algal biomass in Diani and Galu Beaches

4.1.4.1 Algal biomass in Diani Beach

In February there was an abundance of green algae on the beach end of the transects (Fig. 9). This was obvious in transect D_1 where a platform of *Ulva* spp. was found at the beach. Lower levels of 0.03 ± 0.03 g dw/m^2 of green algae were recorded at the 50 m sampling point (Table 9). The red algae had a seaward increase from 0.14 ± 0.07 gdw/m^2 at the beach end of the transects to 5.09 ± 2.18 g dw/m^2 at the end of the transects. Brown algae were also high in biomass at the seaward end of the transects while the distribution of the blue-green algae was patchy at 10 m and 50 m from the beach (Table 9). In May, the biomass of green algae was low along the transects (Fig. 9). Red algae dominated in the transects and the highest level of 5.44 ± 4.75 g dw/m^2 was recorded 50 m from the beach. Brown algae were highest at the end of the transects (Table 9).

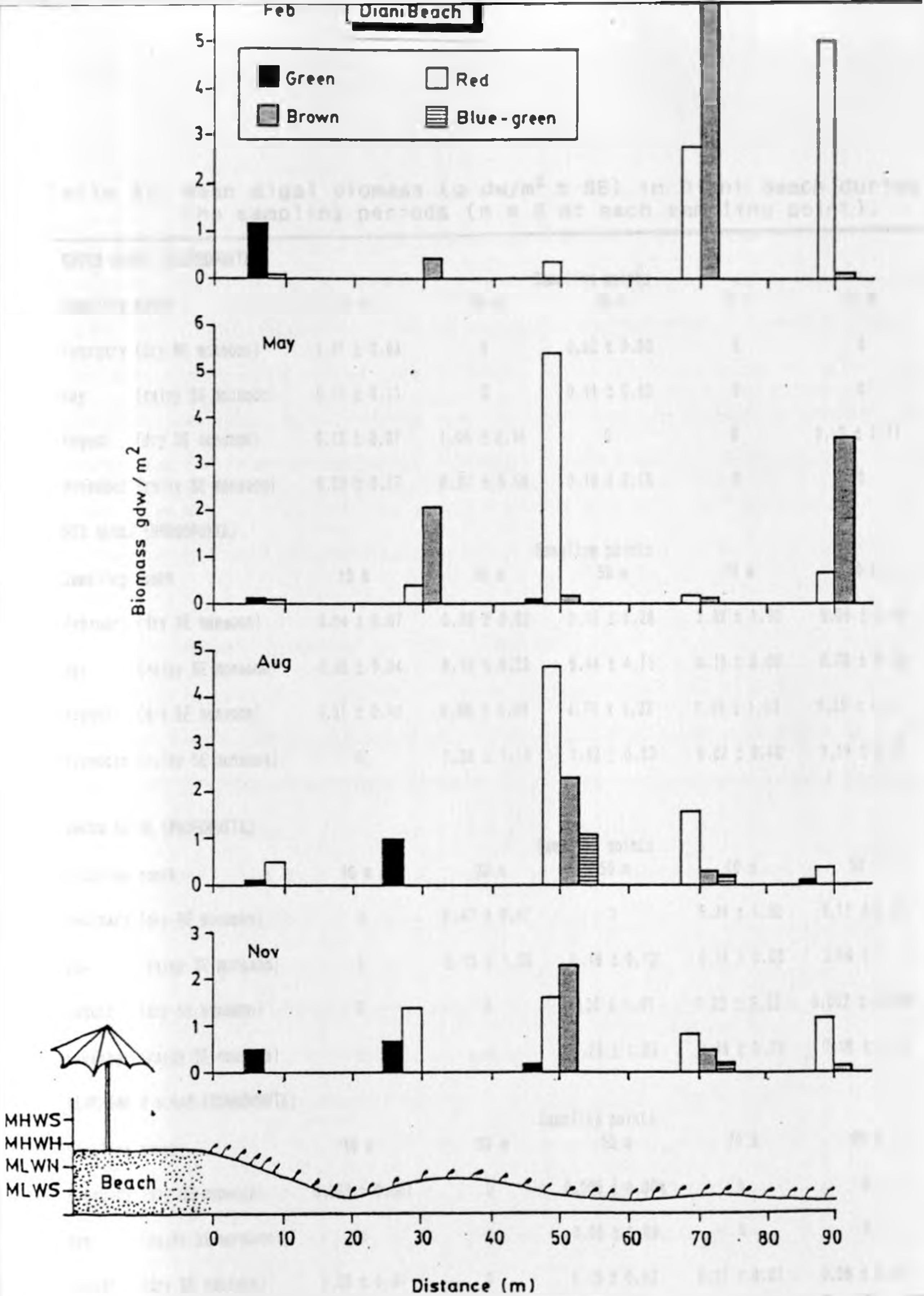


Fig. 9. Distribution of algal biomass along the transects in Diani Beach during the sampling months.

Table 9. Mean algal biomass (g dw/m^2 ± SE) in Diani Beach during the sampling periods (n = 8 at each sampling point).

GREEN ALGAE (CHLOROPHYTA)

Sampling month	Sampling points 10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	1.21 ± 0.63	0	0.03 ± 0.03	0	0
May (rainy SE monsoon)	0.17 ± 0.13	0	0.11 ± 0.10	0	0
August (dry SE monsoon)	0.12 ± 0.07	1.05 ± 0.95	0	0	0.12 ± 0.12
November (rainy SE monsoon)	0.52 ± 0.17	0.67 ± 0.56	0.18 ± 0.18	0	0

RED ALGAE (RHODOPHYTA)

Sampling month	Sampling points 10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	0.14 ± 0.07	0.03 ± 0.02	0.32 ± 0.28	2.82 ± 1.90	5.09 ± 2.18
May (rainy SE monsoon)	0.08 ± 0.04	0.40 ± 0.29	5.44 ± 4.75	0.16 ± 0.05	0.70 ± 0.58
August (dry SE monsoon)	0.51 ± 0.49	0.08 ± 0.06	4.71 ± 4.37	1.55 ± 1.02	0.35 ± 0.21
November (rainy SE monsoon)	0	1.36 ± 1.13	1.63 ± 0.83	0.82 ± 0.46	1.19 ± 0.47

BROWN ALGAE (PHAEOPHYTA)

Sampling month	Sampling points 10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	0	0.47 ± 0.47	0	5.34 ± 4.92	0.11 ± 0.09
May (rainy SE monsoon)	0	2.13 ± 1.99	0.19 ± 0.12	0.14 ± 0.05	3.64 ± 3.53
August (dry SE monsoon)	0	0	2.30 ± 1.87	0.32 ± 0.32	0.002 ± 0.002
November (rainy SE monsoon)	0	0	2.28 ± 1.25	0.48 ± 0.39	0.16 ± 0.16

BLUE-GREEN ALGAE (CYANOPHYTA)

Sampling month	Sampling points 10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	0.009 ± 0.007	0	0.005 ± 0.004	0	0
May (rainy SE monsoon)	0	0	0.05 ± 0.03	0	0
August (dry SE monsoon)	0.02 ± 0.01	0	1.15 ± 0.93	0.27 ± 0.27	0.06 ± 0.04
November (rainy SE monsoon)	0.02 ± 0.01	0	0.06 ± 0.06	0.19 ± 0.14	0

The number of algae groups increased in August. The green algae were highest 10 m from the beach while the red algae reached a peak of 4.71 ± 4.37 g dw/m^2 50 m from the beach (Table 9). Brown algae were also present from 50 m seawards but had a lower biomass than the red algae. Blue-green algae were also present in all the sampling points apart from 30 m but had a lower biomass in comparison to the other algal groups (Table 9). In November, the green algae still dominated at the beach end of the transects while the red and brown algae had the highest biomass from 50 m onwards.

4.1.4.2 Algal biomass in Galu Beach

In February, green algae were found throughout the transects (Fig. 10) with the highest biomass of 0.69 ± 0.54 g dw/m^{2}recorded at the beach end of the transects (Table 10). The red algae were highest at the beach end of the transects and reached a biomass of 3.35 ± 2.12 g dw/m^2. The quantity of brown and blue-green algae was lower than the green and red algae (Table 10).

In May, the red algae dominated with the highest biomass recorded at the seaward end of the transects (Fig 10) while during the August sampling period the red algae also dominated with the highest biomass of 1.65 ± 0.95 g dw/m^2 recorded the 30 m sampling point. In November, the green and red algae were highest at the beach end of the transects and showed a seaward decline in biomass (Fig. 10).

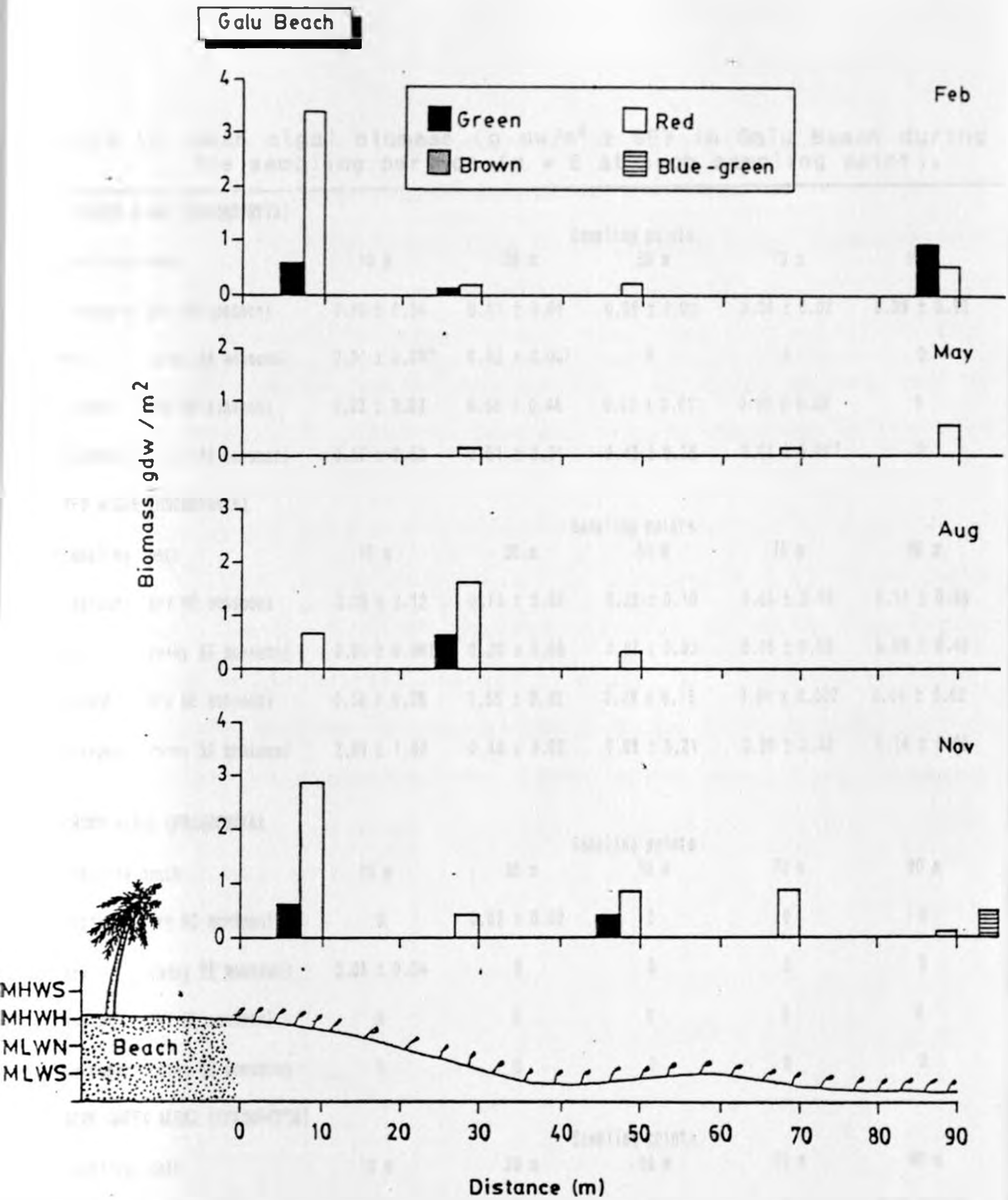


Fig. 10. Distribution of algal biomass along the transects in Galu Beach during the sampling months.

Table 10. Mean algal biomass (g dw/m^2 ± SE) in Galu Beach during the sampling periods (n = 8 at each sampling point).

GREEN ALGAE (CHLOROPHYTA)

	Sampling points				
Sampling month	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	0.69 ± 0.54	0.11 ± 0.09	0.05 ± 0.03	0.04 ± 0.02	0.99 ± 0.93
May (rainy SE monsoon)	0.01 ± 0.007	0.02 ± 0.007	0	0	0
August (dry SE monsoon)	0.03 ± 0.03	0.65 ± 0.48	0.02 ± 0.01	0.03 ± 0.02	0
November (rainy SE monsoon)	0.57 ± 0.53	0.01 ± 0.01	0.48 ± 0.38	0.01 ± 0.007	0

RED ALGAE (RHODOPHYTA)

	Sampling points				
Sampling month	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	3.35 ± 2.12	0.14 ± 0.07	0.22 ± 0.10	0.04 ± 0.02	0.57 ± 0.38
May (rainy SE monsoon)	0.01 ± 0.007	0.20 ± 0.08	0.07 ± 0.03	0.16 ± 0.56	0.62 ± 0.48
August (dry SE monsoon)	0.58 ± 0.26	1.65 ± 0.95	0.29 ± 0.16	0.01 ± 0.007	0.04 ± 0.02
November (rainy SE monsoon)	2.89 ± 1.82	0.46 ± 0.03	0.86 ± 0.21	0.90 ± 0.42	0.14 ± 0.08

BROWN ALGAE (PHAEOPHYTA)

	Sampling points				
Sampling month	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	0	0.02 ± 0.02	0	0	0
May (rainy SE monsoon)	0.05 ± 0.04	0	0	0	0
August (dry SE monsoon)	0	0	0	0	0
November (rainy SE monsoon)	0	0	0	0	0

BLUE-GREEN ALGAE (CYANOPHYTA)

	Sampling points				
Sampling month	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	0	0	0	0	0.02 ± 0.02
May (rainy SE monsoon)	0	0	0	0	0.01 ± 0.004
August (dry SE monsoon)	0	0	0	0.01 ± 0.003	0
November (rainy SE monsoon)	0	0	0	0	0.49 ± 0.49

4.1.4.3 Overall algal biomass in Diani and Galu Beaches

The number of algal groups decreased with the onset of the SE monsoon in May in Diani and Galu Beaches. There was a recovery in Diani in August with the reappearance of all groups (Fig. 11). In Galu, the low number of algae groups persisted till November (Fig. 12). Diani experienced a high biomass of algae during the SE monsoon, particularly in May, whereas in Galu there was an increase of algal biomass during the NE monsoon periods (Fig. 13). Calcareous algae were not included in the estimates of total algal biomass as they would have caused an exaggeration of the biomass estimates. The statistical analysis did not reveal a significant difference in the overall biomass of algae found in Diani and Galu, as a result of the large variability in the data collected. However, the biomass of the brown algae was significantly different in the two areas ($H = 9.74$, $p \leq 0.05$) with higher biomass levels recorded in Diani.

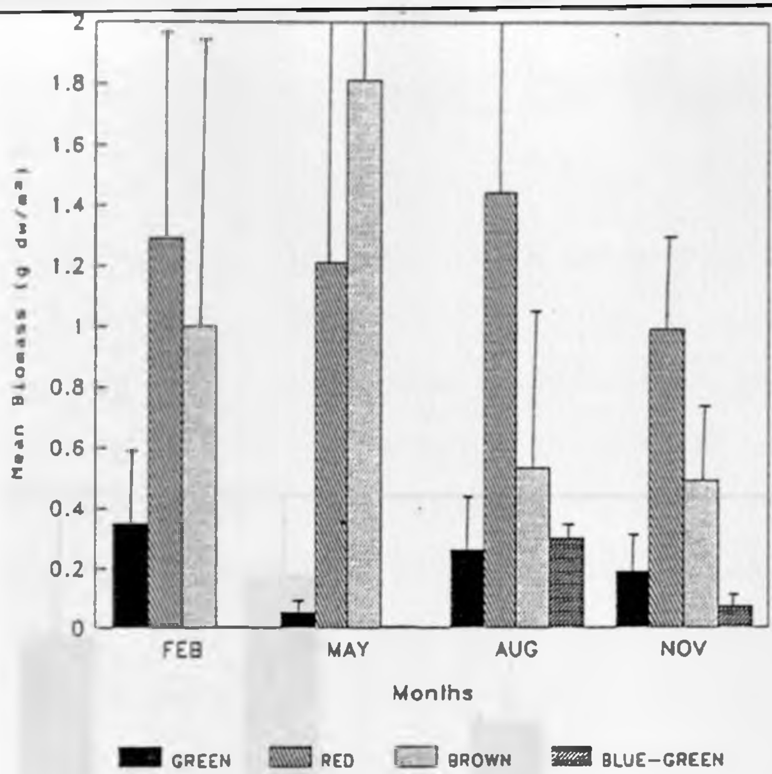


Fig. 11. Biomass of green, red, brown and blue-green algae in Diani Beach (n = 40 in each month).

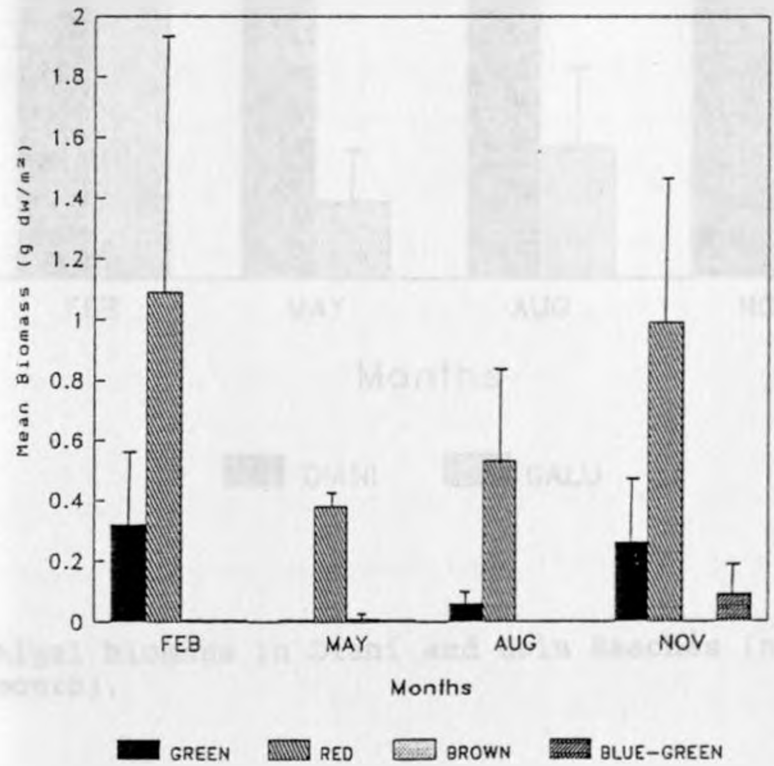


Fig. 12. Biomass of green, red, brown and blue-green algae in Galu Beach (n = 40 in each month).

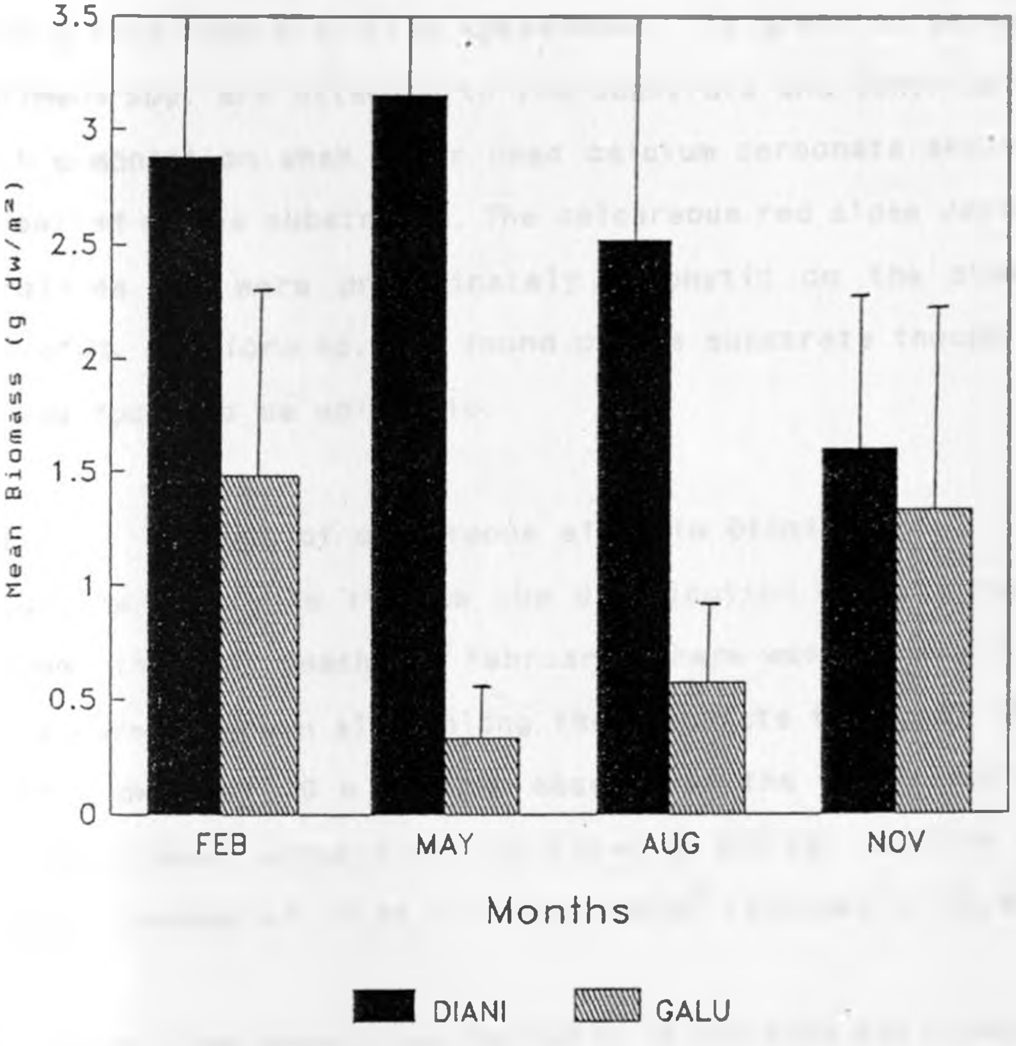


Fig. 13. Algal biomass in Diani and Galu Beaches (n = 40 in each month).

4.1.5 Seasonal distribution of calcareous algal biomass in Diani and Galu Beaches

The green and red calcareous algae (indicated on Tables 6 and 7 by *) have their cell walls reinforced with calcium carbonate ($CaCO_3$) thus giving them a brittle appearance. The green calcareous algae *Halimeda* spp. are attached to the substrate and contribute to the soil composition when their dead calcium carbonate skeletons are deposited on the substratum. The calcareous red algae *Jania* sp. and *Corallina* sp. were predominately epiphytic on the stems of *T. ciliatum*. *Amphiora* sp. was found on the substrate though at times it was found to be epiphytic.

4.1.5.1 Biomass of calcareous algae in Diani Beach

Figure 14 and Table 11 show the distribution of calcareous algal biomass in Diani Beach. In February, there was a seaward increase in calcareous green algae along the transects to a peak of 19.58 ± 10.77 g dw/m^2 at 70 m then an absence at the last sampling point Red calcareous algae also exhibited a similar pattern with the highest biomass of 16.69 ± 11.42 g dw/m^2 recorded at 70 m.

The green calcareous algae dominated in May with the biomass of the red calcareous algae being lower than that of the green calcareous algae. The red calcareous algae were encountered from 50 m seawards.

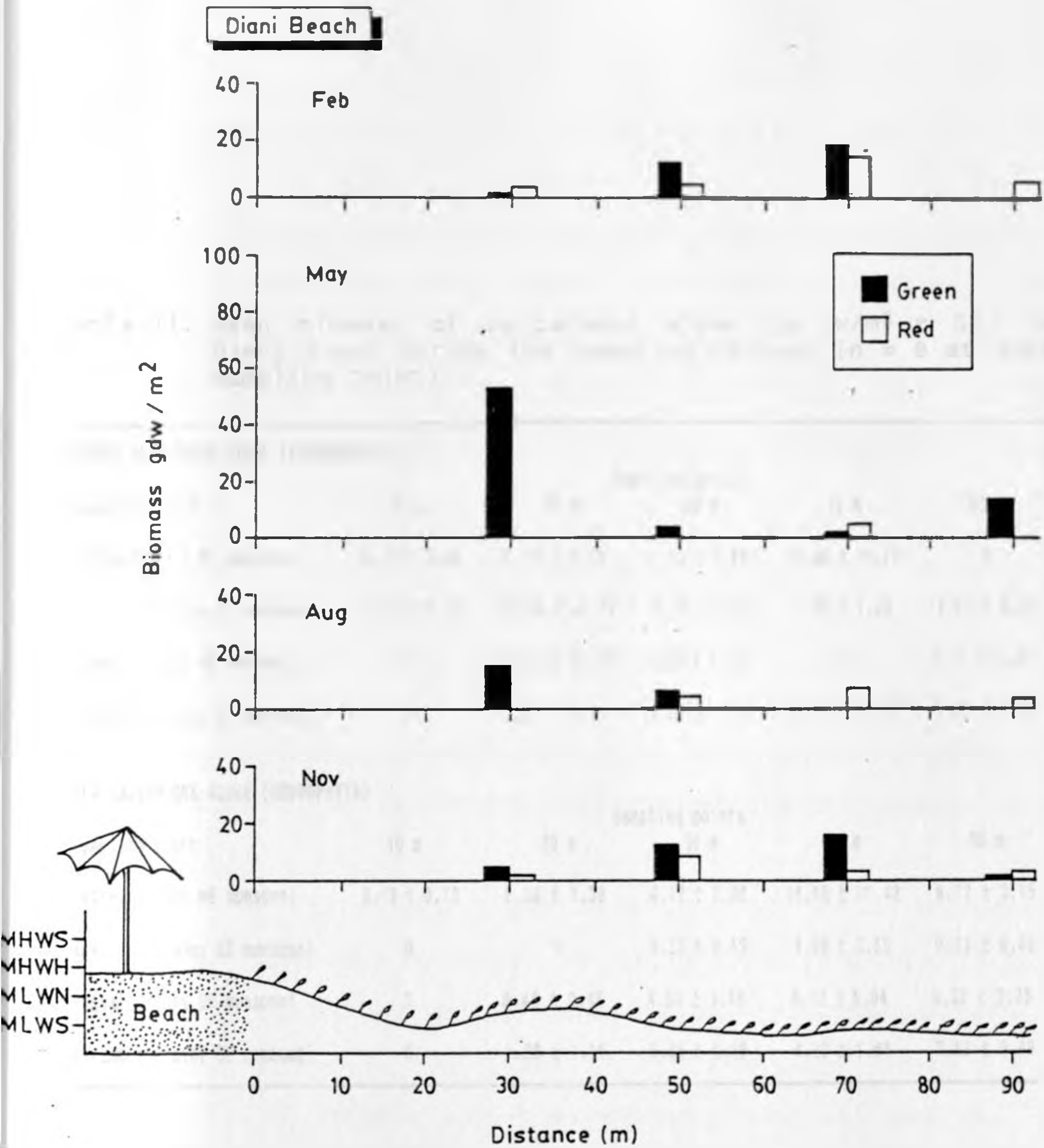


Fig. 14. Distribution of calcareous algal biomass along the transects in Diani Beach during the sampling months.

Table 11. Mean biomass of calcareous algae (g dw/m² ± SE) in Diani Beach during the sampling periods (n = 8 at each sampling point).

GREEN CALCAREOUS ALGAE (CHLOROPHYTA)

	Sampling points				
Sampling month	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	0.37 ± 0.36	0.79 ± 0.65	11.58 ± 9.95	19.58 ± 10.77	0
May (rainy SE monsoon)	0.25 ± 0.23	53.96 ± 47.76	3.25 ± 1.95	1.49 ± 1.39	12.93 ± 8.69
August (dry SE monsoon)	0	15.80 ± 15.79	6.39 ± 7.53	0	0.37 ± 0.37
November (rainy SE monsoon)	0	3.57 ± 2.76	12.62 ± 12.47	17.31 ± 12.82	1.23 ± 1.23

RED CALCAREOUS ALGAE (RHODOPHYTA)

	Sampling points				
Sampling month	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	0.13 ± 0.13	2.88 ± 1.38	4.12 ± 2.06	16.69 ± 11.42	6.72 ± 3.15
May (rainy SE monsoon)	0	0	0.35 ± 0.15	4.08 ± 3.55	0.83 ± 0.48
August (dry SE monsoon)	0	0.46 ± 0.46	4.51 ± 3.49	8.12 ± 5.04	3.32 ± 2.35
November (rainy SE monsoon)	0	1.28 ± 1.11	9.51 ± 4.19	4.22 ± 1.61	3.53 ± 0.89

During the August sampling period the biomass of green calcareous algae peaked to 15.80 ± 15.79 g dw/m^2 at 30 m then declined seawards. Red calcareous algae occurred in the same areas as the green calcareous algae but in lower quantities. In November, green and red calcareous algae were absent at the start of the transects. The green calcareous algae increased to 17.31 ± 12.62 gdw/m^2 at 70 m while the red calcareous algae was high at 50 m then fell to lower levels seawards.

4.1.5.2 Biomass of calcareous algae in Galu Beach

The distribution of calcareous algae is shown in Figure 15 and Table 12. In February, the green calcareous algae was absent at the start of the transects but occurred at various points along the transects in higher levels than the red calcareous algae.

In May, red calcareous algae were absent, while the green calcareous algae rose to levels of 193.40 ± 166.41 g dw/m^2 at 50 m (Table 12). During the August sampling period, green calcareous algae were absent at the start of the transects. There was a seaward rise to 18.84 ± 6.01 g dw/m^2 then a decline seawards. The red calcareous algae were present during this sampling period compared to the absence in May and a peak of 9.55 ± 9.49 g dw/m^2 recorded at 50 m. In November, there was a seaward increase in both the red and the green calcareous algae with a peak in both algal groups at 70 m. The green calcareous algae were dominant and reached levels of 27.85 ± 11.7 g dw/m^2 at 70 m (Table 12).

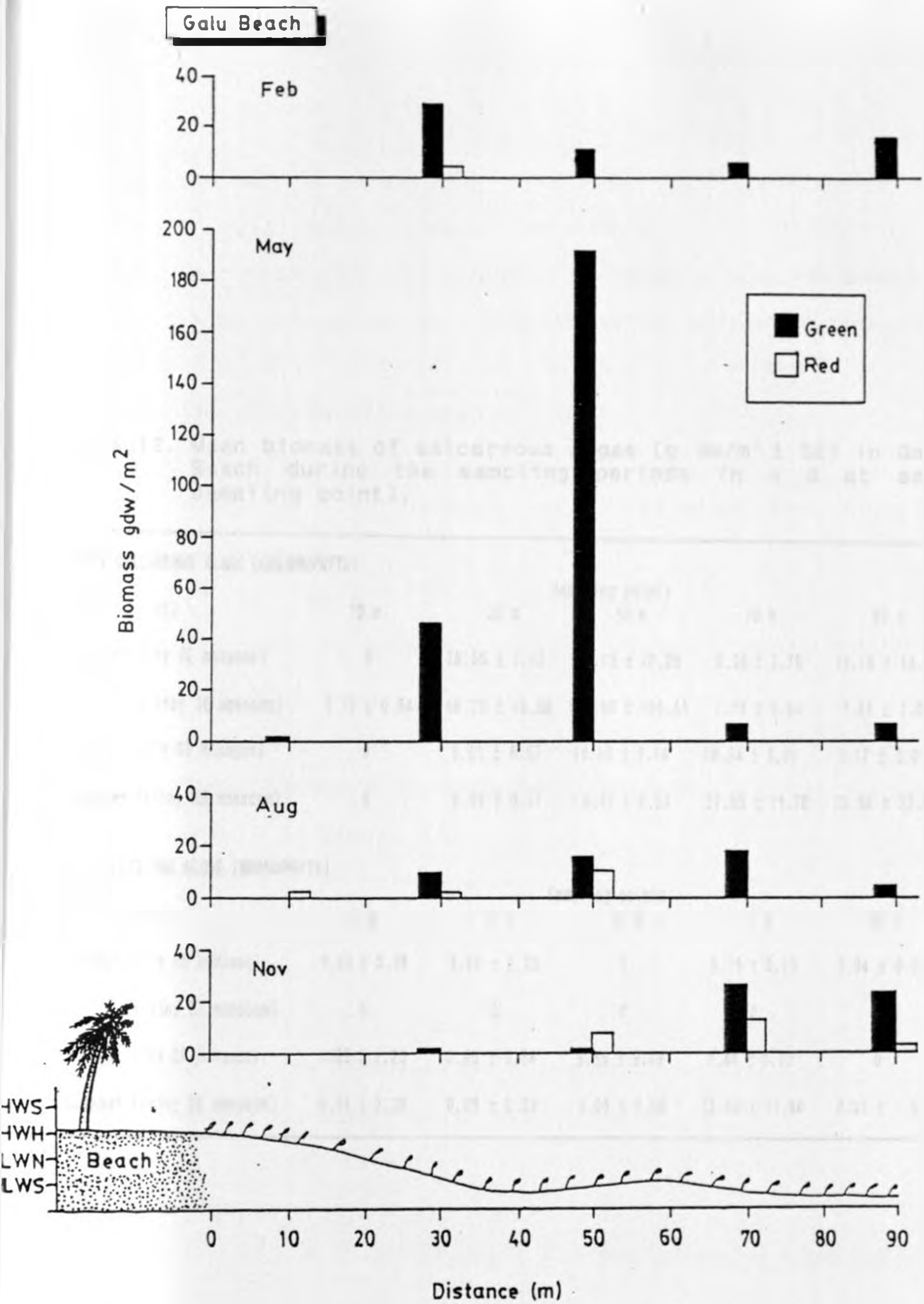


Fig. 15. Distribution of calcareous algal biomass along the transects in Galu Beach during the sampling months.

Table 12. Mean biomass of calcareous algae (g dw/m^2 ± SE) in Galu Beach during the sampling periods (n = 8 at each sampling point).

GREEN CALCAREOUS ALGAE (CHLOROPHYTA)

Sampling month	Sampling points 10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	0	28.55 ± 1.13	11.15 ± 10.25	5.34 ± 3.78	16.15 ± 14.13
May (rainy SE monsoon)	0.73 ± 0.64	46.26 ± 40.88	193.40 ± 166.41	7.76 ± 6.34	7.61 ± 7.02
August (dry SE monsoon)	0	9.81 ± 6.57	16.10 ± 9.14	18.84 ± 6.01	5.17 ± 5.00
November (rainy SE monsoon)	0	0.95 ± 0.47	0.87 ± 0.54	27.85 ± 11.70	23.58 ± 23.09

RED CALCAREOUS ALGAE (RHODOPHYTA)

Sampling month	Sampling points 10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	0.43 ± 0.36	3.24 ± 2.33	0	0.19 ± 0.19	0.04 ± 0.04
May (rainy SE monsoon)	0	0	0	0	0
August (dry SE monsoon)	1.85 ± 1.23	0.89 ± 0.64	9.55 ± 9.49	0.44 ± 0.23	0
November (rainy SE monsoon)	0.41 ± 0.38	0.29 ± 0.29	4.05 ± 3.00	13.44 ± 11.64	2.01 ± 1.58

The red calcareous algae was positively correlated with the seagrass biomass in Diani Beach ($r = 0.54$, $p = 0.01$) indicating an increase in red calcareous algae with increasing seagrass biomass. The red calcareous algae were predominantly epiphytic thus this indicates that the biomass of the red calcareous algae depends on the quantity of seagrass present.

4.1.6 Seasonal distribution of *T.ciliatum* and attached epiphytes

The stems of the seagrass *T. ciliatum* provided a suitable substrate for the attachment of epiphytic algae. The most common epiphytic algae species seen were:

Ulva spp. (G)

Amphiora fragilissima (L.) Lamouroux. (R)*

Cermamium taylorii Dawson. (R)

Corallina subulata Ellis & Solander. (R)*

Gracillaria corticata J. Agardh. (R)

Hypnea spp. (R)

Jania sp. (R)*

Wurdemannia miniata (Draparnaud) Feldmann et Hammel. (R)

Dictyota adnata Zanardini sensu web v. Bosse. (B)

Unidentified blue-green algae

(G = green algae; R = red algae; B = brown algae; * = calcareous algae)

The red algae group (Rhodophyta) comprised 70% of the epiphytic species. Table 13 shows the biomass of *T. ciliatum* in Diani and Galu and a combined estimate of all the epiphytic algae attached on the stems of the *T. ciliatum* plants. *T. ciliatum* was found in the Diani transects in all sampling periods unlike Galu where it was absent in August and November. The epipytic load was also low in Galu Beach compared to Diani Beach.

The biomass of *T. ciliatum* and the epiphytic load in Diani and Galu Beaches were significantly different ($H = 15.83$, $p \leq 0.05$; $H = 18.13$, $p \leq 0.05$ respectively). There was no significant difference in the biomass distribution of the *T. ciliatum* or the epiphytic load between the seasons.

Table 13. Mean biomass estimates (g dw/m^2 ± SE) of *T. ciliatum* and the epiphytic load.

	MONTH	T. CILIATUM (g dw/m^2)	EPIPHYTIC LOAD (g dw/m^2)
DIANI	Feb	263.01 ± 137.10	34.89 ± 24.11
	May	303.03 ± 113.71	31.04 ± 12.16
	Aug	374.90 ± 180.19	50.53 ± 50.05
	Nov	179.68 ± 49.51	30.02 ± 25.56
GALU	Feb	81.23 ± 47.0	0.41 ± 0.41
	May	40.35 ± 16.46	1.11 ± 1.12
	Aug	0	0
	Nov	0	0

4.1.7 Taxonomic composition of epibenthic fauna in Diani and Galu Beaches

The following groups of surface dwelling organisms were encountered during the transect surveys in Diani and Galu Beach. The epibenthic animals were classified accórding to Day (1978) and Barnes (1980).

PHYLUM: MOLLUSCA
 Class: Gastropoda (Limpets, Whelks, Slugs)

PHYLUM: ARTHROPODA
 Subphylum: Crustacea
  Subclass: Eumalocostraca
   Superorder: Eucarida
    Order: Decapoda
     Infra order: Anomura (Hermit crabs)
     Infra order: Brachyura (True crabs)
     Infra order: Macrura (Lobsters, Shrimps and Prawns)

PHYLUM: ECHINODERMATA
 Class: Stelleroidea
  Subclass: Asteroidea (Star fish)
  Subclass: Ophiuroidea (Brittle stars)

 Class: Echinoidea (Sea urchins)
 Class: Holothuroidea (Sea cucumbers)

PHYLUM: CHORDATA
 Subphylum: Vertebrata
  Super class: Pisces (Fishes)
   Class: Osteichthyes (Bony fishes)

Table 14 shows the species composition of epibenthic fauna in both Diani and Galu Beaches.

Table 14. Species composition and abundance of epibenthic faun
found in Diani and Galu Beaches.

SPECIES	DIANI BEACH TRANSECTS				GALU BEACH TRANECTS			
	D1	D2	D3	D4	G1	G2	G3	G4
MOLLUSCA: GASTROPODA								
Strombus sp.	1+	1+	1+	1+	1+	1+	1+	1+
Nassa sp.	-	-	1+	1+	-	1+	-	-
Drupa granulata	-	1+	-	-	-	1+	-	1+
Morula sp.	-	-	-	-	-	-	-	1+
Nerita sp.	-	1+	-	-	-	-	-	1+
Cypraea annulus (Linné)	-	-	-	-	-	-	-	1+
Cypraea tigris (Linné)	-	-	-	-	-	-	-	1+
Bullaria ampulla (Linné)	-	-	-	-	-	-	-	1+
Natica sp.	-	-	-	-	-	-	-	1+
Conus sp.	-	-	-	1+	1+	-	-	1+
Cypraecassis rufa (Linné)	-	-	-	-	1+	-	-	1+
ECHINODERMATA: ASTEROIDEA								
Plectaster decanus (Muller & Troschel, 1834)	1+	-	1+	1+	-	-	-	-
Protoreaster linckii (de Blainville, 1834)	-	-	1+	-	-	-	-	-
Euretaster cribrosus (v. Martens, 1867)	1+	-	-	-	-	-	-	-
Culciata schmideliana (Retzius, 1805)	-	-	-	-	-	-	-	-
ECHINODERMATA: OPHIUROIDEA								
Ophiocoma sp.	1+	-	-	1+	-	-	-	2+
ECHINODERMATA: ECHINOIDEA								
Echinometra mathaei (de Blainville, 1825)	1+	-	2+	2+	-	-	1+	1+
Tripneustes gratilla (Linnaeus, 1758)	-	-	1+	-	1+	1+	1+	1+
Diadema setosum (Leske, 1778)	-	-	1+	-	-	1+	1+	-
Diadema savignii (Michelin, 1845)	-	-	-	-	-	-	1+	-
ECHINODERMATA: HOLOTHUROIDEA								
Holothuria parva (Krauss in Lampert)	1+	-	-	-	-	-	-	-
Holothuria scabra (Linnaeus, 1967)	1+	1+	1+	1+	-	-	-	-
Holothuria atra (Jaeger, 1957)	-	-	-	1+	-	-	-	-
Synapta sp.	1+	1+	1+	1+	-	1+	1+	-
Stichopus sp.	-	-	-	1+	-	-	-	-
CHORDATA: OSTEICHTHYES								
Diodon sp.	1+	1+	1+	1+	-	-	1+	-
Pterois sp.	-	1+	1+	-	-	-	-	-
Solea sp.	-	-	-	-	-	-	1+	-
Unidentified coral fish	-	-	1+	1+	-	-	-	1+
Unidentified pipe fish	-	-	-	-	-	-	1+	-
ARTHROPODA: BRACHYURA								
Calappa sp.	-	1+	-	-	-	-	1+	-
ARTHROPODA:ANOMURA								
Clibanarius virescens	-	-	1+	-	-	-	-	-
Unidentified hermit crabs	-	-	1+	1+	-	1+	-	1+

Legend:
- absent
1+ found in 1 - 9% of the quadrats sampled during the year
2+ found in 10 - 19% of the quadrats sampled during the year

The gastropod, *Strombus* sp., was common in Diani and Galu Beach. However, the majority of the gastropods were found in transect G_4 of Galu Beach. Asteroidea were found only in Diani Beach. Echinoidea and Holothuriodea were found in both areas with *Echinometra mathaei* (de Blainville, 1825) an echinoid being the most abundant species found in Diani Beach. Only one brachyuran crab was identified and the anomurans were unidentified.

4.1.8 Seasonal distribution of epibenthic fauna in Diani and Galu Beaches

4.1.8.1 Distribution of epibenthic fauna in Diani Beach

Figure 16 illustrates the distribution of epibenthos in Diani Beach during the sampling periods. The densities varied randomly along the transects with no distinct seaward increase or decrease. Table 15 shows the distribution of the epibenthic faunal groups during the February sampling period.

In the upper seagrass zone, the Mollusca dominated with Gastropoda such as *Strombus* sp. The arthropods encountered consisted of unidentified anomurans and macrurans and these were found at the start and the mid sections of the transects. Echinodermata especially the Echinoidea *E. mathaei* contributed significantly to the epifaunal numbers during this period and reached numbers of upto 3.25 ± 1.69 individuals/m^2 (at the 30 m sampling point) compared to the other epibenthic groups. Other echinoderms encountered were the Holothuria, *Holothuria parva* (Krauss in

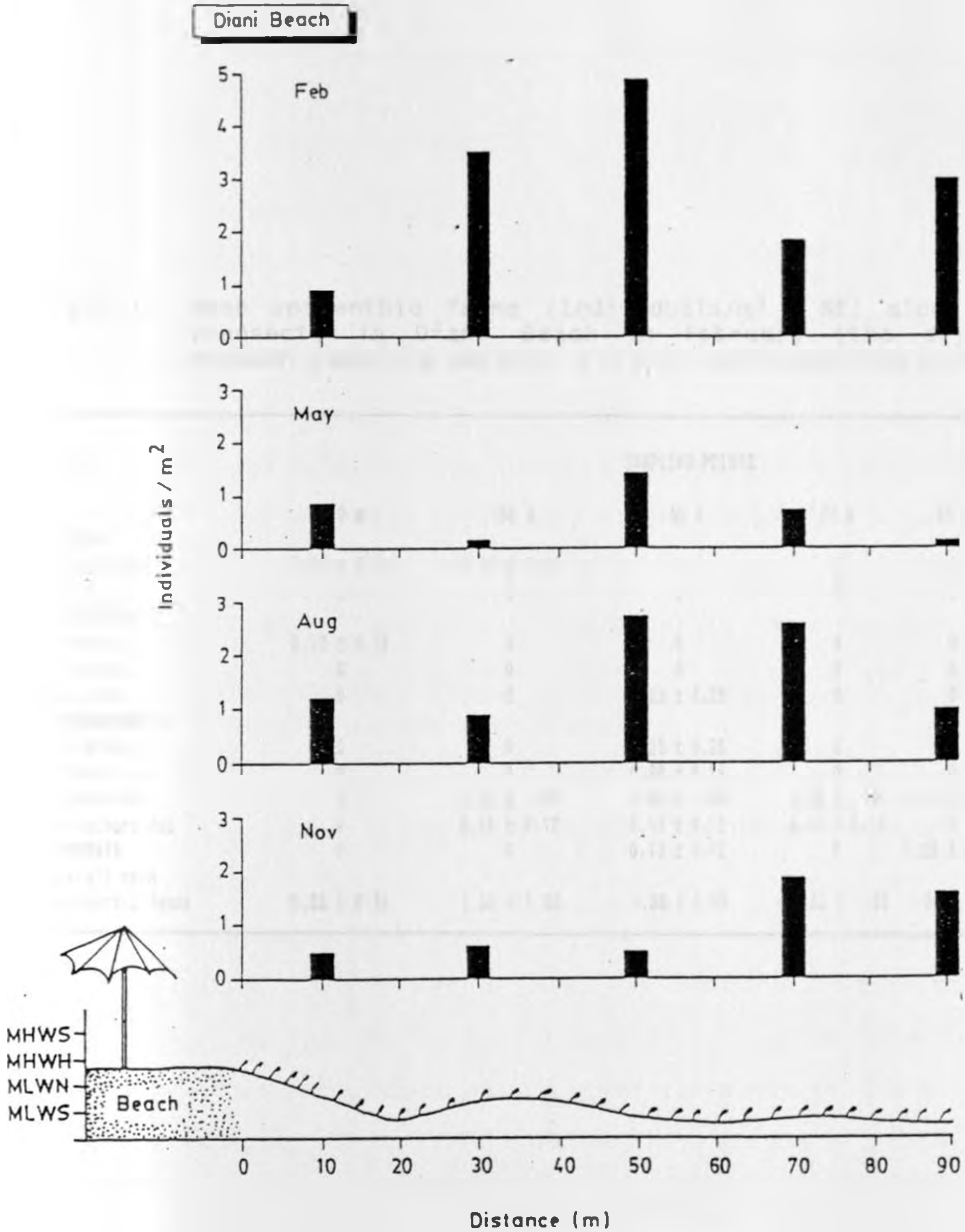


Fig. 16. Distribution of epibenthic fauna along the transects in Diani Beach during the sampling periods.

Table 15. Mean epibenthic fauna (Individuals/m^2 ± SE) along the transects in Diani Beach in February (the dry NE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS				
	10 m	30 m	50 m	70 m	90 m
MOLLUSCA					
Gastropoda	0.75 ± 0.41	0.13 ± 0.13	0	0	0
Bivalvia	0	0	0	0	0
ARTHROPODA					
Anomura	0.13 ± 0.12	0	0	0	0
Brachyura	0	0	0	0	0
Macrura	0	0	0.25 ± 0.25	0	0
ECHINODERMATA					
Asteroidea	0	0	0.25 ± 0.25	0	0
Ophiuroidea	0	0	0.26 ± 0.16	0	0
Echinoidea	0	3.25 ± 1.69	2.50 ± 1.85	1.25 ± 1.44	1.50 ± 1.16
Holothuroidea	0	0.13 ± 0.12	0.13 ± 0.12	0.13 ± 0.14	0
CHORDATA	0	0	0.13 ± 0.12	0	0.25 ± 0.29
Overall mean epibenthic fauna	0.88 ± 0.39	3.50 ± 1.83	4.88 ± 2.09	1.83 ± 1.59	3.00 ± 1.16

Lampert), *Synapta* sp. and the Ophiuroidea *Ophioneris* sp. The echinoderms contributed to the peak at the 50 m sampling point from the beach (Fig. 16). The only chordate encountered was the porcupine fish *Diodon* sp. and this was found in the deeper seaward side of the transects.

During the May sampling session, there was a general decrease in animal densities along the transects (Fig. 16). Molluscans were absent during this sampling period (Table 16). The brachyuran crab *Calappa* sp. was seen in the first sampling point. Echinoderms persisted in May with the occurrence of the Asteroidea *Plectaster decanus* (Muller & Troschel, 1834), the Ophuriodea *Ophioneris* sp and the Echinoidea *E. mathaei*. The holothurian, *Stichopus* sp. was also encountered. The chordates seen in the field were small unidentified coral fish and *Diodon* sp.

In August, the number of epibenthic fauna increased from the low levels recorded in May (Table 17). The molluscans (Gastropoda) and arthropods (Anomura) were present in the first two sampling points from the beach. There was a peak in number of echinoderms especially *E. mathaei* at the 50 m sampling point after which there was a seaward decline. There was no great variation in the numbers of chordates along the transects though in addition to *Diodon* sp. a juvenile scorpion fish *Pterois* sp. was seen.

Table 16. Mean epibenthic fauna (Individuals/m^2 ± SE) along the transects in Diani Beach in May (the rainy SE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS				
	10 m	30 m	50 m	70 m	90 m
MOLLUSCA					
Gastropoda	0	0	0	0	0
Bivalvia	0	0	0	0	0
ARTHROPODA					
Anomura	0	0	0	0	0
Brachyura	0.17 ± 0.14	0	0	0	0
Macrura	0	0	0	0	0
ECHINODERMATA					
Asteroidea	0	0	0	0	0.13 ± 0.12
Ophiuroidea	0	0	0.13 ± 0.12	0	0
Echinoidea	0	0	0.88 ± 0.64	1.01 ± 0.68	0
Holothuroidea	0	0	0.13 ± 0.12	0.13 ± 0.12	0
CHORDATA	0.13 ± 0.12	0	0.13 ± 0.12	0	0
Overall mean epibenthic fauna	0.88 ± 0.61	0	1.43 ± 0.61	0.75 ± 0.62	0.13 ± 0.12

Table 17. Mean epibenthic fauna (Individuals/m^2 ± SE) along the transects in Diani Beach in August (the dry SE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS				
	10 m	30 m	50 m	70 m	90 m
MOLLUSCA					
Gastropoda	1.25 ± 0.59	0.13 ± 0.12	0	0	0
Bivalvia	0	0	0	0	0
ARTHROPODA					
Anomura	0.25 ± 0.16	0.13 ± 0.12	0	0.13 ± 0.12	0
Brachyura	0	0	0	0	0
Macrura	0	0	0	0	0
ECHINODERMATA					
Asteroidea	0	0	0	1.00 ± 0.59	0
Ophiuroidea	0	0	0	0	0
Echinoidea	0	0.13 ± 0.12	2.13 ± 1.39	2.38 ± 1.21	0.38 ± 0.26
Holothuroidea	0	0.38 ± 0.18	0.50 ± 0.27	0.13 ± 0.12	0.75 ± 0.37
CHORDATA	0.13 ± 0.12	0.13 ± 0.12	0.13 ± 0.12	0.13 ± 0.12	0
Overall mean epibenthic fauna	1.25 ± 0.41	0.88 ± 0.35	2.75 ± 1.49	2.63 ± 1.28	1.00 ± 0.39

Arthropods were absent along the transects in November (Table 18). Echinoderms were absent at the beach end of the transects but increased in number seawards. Ophuroidea were absent whereas the Echinoidea and Holothuroidea dominated the Echinodermata group.

Table 18. Mean epibenthic fauna (Individuals/m^2 ± SE) along the transects in Diani Beach in November (the rainy NE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS				
	10 m	30 m	50 m	70 m	90 m
MOLLUSCA					
Gastropoda	0.50 ± 0.33	0.25 ± 0.16	0	0.25 ± 0.16	0
Bivalvia	0	0	0	0	0
ARTHROPODA					
Anomura	0	0	0	0	0
Brachyura	0	0	0	0	0
Macrura	0	0	0	0	0
ECHINODERMATA					
Asteroidea	0	0	0.13 ± 0.12	0	1.25 ± 0.84
Ophiuroidea	0	0	0	0	0
Echinoidea	0	0.75 ± 0.41	0.25 ± 0.25	1.38 ± 1.37	0.88 ± 0.87
Holothuroidea	0	0.63 ± 0.33	0.13 ± 0.12	0.38 ± 0.26	0.13 ± 0.12
CHORDATA	0.25 ± 0.16	0.13 ± 0.12	0	0.13 ± 0.12	0.38 ± 0.26
Overall mean epibenthic fauna	0.51 ± 0.27	1.53 ± 0.68	0.50 ± 0.27	1.88 ± 1.33	1.63 ± 0.98

4.1.8.2 Distribution of epibenthic fauna in Galu Beach

The overall distribution of epibentic fauna in Galu Beach was varied with no patterns seen apart from the month of August where the number of epibenthos had a distinct decrease seawards (Fig. 17).

In February, the molluscans were spread along the transects and not restricted to the first two sampling points (Table 19). Gastropods such as *Strombus* sp. and *Nassa* sp. comprised the Mollusca group and they contributed to the high numbers of epibenthic fauna at the beach end of the transect. Arthropods present were unidentified hermit crabs. Echinoidea were present with high densities of *E. mathaei* and *Diadema* sp. at the seaward end of the transects. The phylum Chordata was comprised of the porcupine fish *Diodon* which was seen in the deeper parts of the transects.

The numbers of epibenthos were lower in May compared to February. There was a peak in the numbers of epibenthos to 1.75 ± 1.05 individuals/m^2 at 30 m after which there was a seaward decline (Fig. 17). The molluscans were restricted to the beach end of the transects (Table 20). Arthropods were also low in abundance and were composed of unidentified hermit crabs. The Echinoidea dominated during this period. Those seen were *E. mathaei* and *Tripneustes gratilla* (Linnaeus, 1967). *Ophioneris* sp. also occurred in the transects. The holothurian *Stichopus* sp. was also seen. Chordates encountered included the flat fish, *Solea* sp and

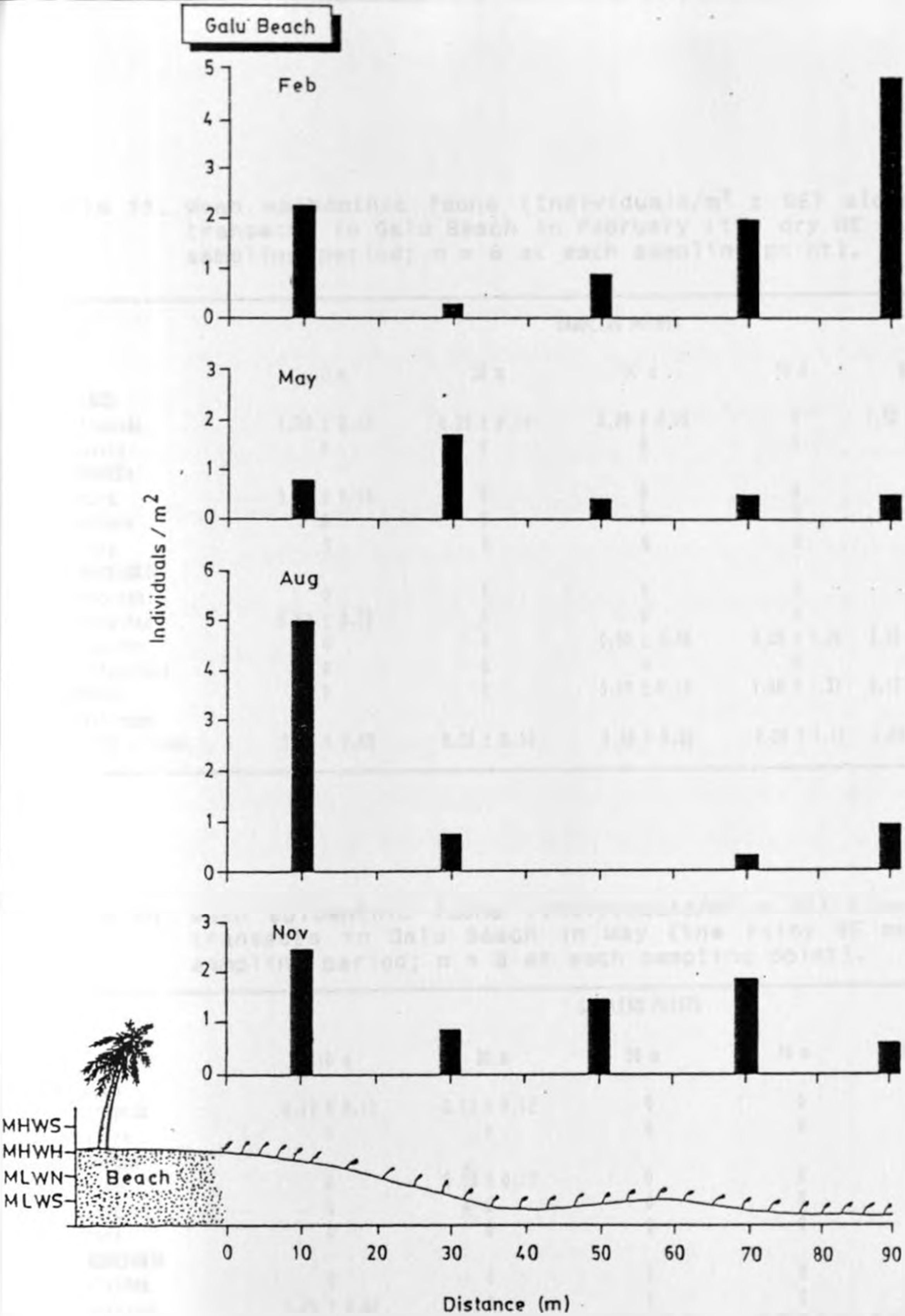


Fig. 17. Distribution of epibenthic fauna along the transects in Galu Beach during the sampling periods.

Table 19. Mean epibenthic fauna (Individuals/m^2 ± SE) along the transects in Galu Beach in February (the dry NE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS				
	10 m	30 m	50 m	70 m	90 m
MOLLUSCA					
Gastropoda	1.00 ± 0.45	0.25 ± 0.16	0.25 ± 0.25	0	1.50 ± 1.49
Bivalvia	0	0	0	0	0
ARTHROPODA					
Anomura	0.17 ± 0.14	0	0	0	0
Brachyura	0	0	0	0	0
Macrura	0	0	0	0	0
ECHINODERMATA					
Asteroidea	0	0	0	0	0
Ophiuroidea	0.83 ± 0.72	0	0	0	0
Echinoidea	0	0	0.50 ± 0.49	0.38 ± 0.26	3.25 ± 2.20
Holothuroidea	0	0	0	0	0
CHORDATA	0	0	0.13 ± 0.12	1.38 ± 1.37	0.13 ± 0.12
Overall mean epibenthic fauna	2.33 ± 0.69	0.25 ± 0.16	0.88 ± 0.52	2.00 ± 1.72	4.88 ± 2.47

Table 20. Mean epibenthic fauna (Individuals/m^2 ± SE) along the transects in Galu Beach in May (the rainy SE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS				
	10 m	30 m	50 m	70 m	90 m
MOLLUSCA					
Gastropoda	0.13 ± 0.12	0.13 ± 0.12	0	0	0
Bivalvia	0	0	0	0	0
ARTHROPODA					
Anomura	0	0.13 ± 0.12	0	0	0
Brachyura	0	0	0	0	0
Macrura	0	0	0	0	0
ECHINODERMATA					
Asteroidea	0	0	0	0	0
Ophiuroidea	1.25 ± 0.82	0	0	0	0
Echinoidea	0	2.63 ± 1.07	1.13 ± 0.87	0.38 ± 0.37	0.63 ± 0.63
Holothuroidea	0	0	0.13 ± 0.12	0	0
CHORDATA	0.13 ± 0.12	0	0	0.13 ± 0.35	0
Overall mean epibenthic fauna	0.88 ± 0.61	1.75 ± 1.05	0.38 ± 0.26	0.50 ± 0.38	0.50 ± 0.35

the porcupine fish, *Diodon* sp.

In August, the high number of epibenthos at the beach end of the transects was due to the Mollusca and the Ophuroidea (Table 21). There was an increase in the number of molluscs in August compared to the May sampling period. Gastropoda *Nassa* sp. and *Strombus* sp. were seen. The arthropods remained low in number along the transects. The Echinoidea were low in density and contributed to the seaward peak of the Phylum Echinodermata. Chordates were absent during this period.

The mollusca were found the first two sampling points in November (Table 22). Echinoderms especially the ophuriods were low at the start of the transects. This is an area where they were previously high during the August sampling period.

Table 21. Mean epibenthic fauna (Individuals/m^2 ± SE) along the transects in Galu Beach in August (the dry SE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS				
	10 m	30 m	50 m	70 m	90 m
MOLLUSCA					
Gastropoda	0.63 ± 0.33	0.25 ± 0.16	0	0.25 ± 0.16	0
Bivalvia	0	0	0	0	0
ARTHROPODA					
Anomura	0	0	0	0.13 ± 0.12	0
Brachyura	0	0	0	0	0
Macrura	0	0	0	0	0
ECHINODERMATA					
Asteroidea	0	0	0	0	0
Ophiuroidea	4.38 ± 2.90	1.50 ± 1.00	0	0	0
Echinoidea	0	0	0	0	0.75 ± 0.41
Holothuroidea	0	0	0	0	0
CHORDATA	0	0	0	0	0
Overall mean epibenthic fauna	5.00 ± 2.97	0.75 ± 0.75	0	0.33 ± 0.18	1.00 ± 0.45

Table 22. Mean epibenthic fauna (Individuals/m^2 ± SE) along the transects in Galu Beach in November (the rainy NE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS				
	10 m	30 m	50 m	70 m	90 m
MOLLUSCA					
Gastropoda	1.63 ± 0.88	0.63 ± 0.33	0	0	0
Bivalvia	0	0	0	0	0
ARTHROPODA					
Anomura	0.75 ± 0.52	0.13 ± 0.12	0	0.13 ± 0.12	0
Brachyura	0	0	0.13 ± 0.12	0	0
Macrura	0	0	0	0	0
ECHINODERMATA					
Asteroidea	0	0	0	0	0
Ophiuroidea	0.13 ± 0.12	0	1.25 ± 1.10	0	0
Echinoidea	0	0	0	0.88 ± 0.74	0.50 ± 0.38
Holothuroidea	0	0.13 ± 0.12	0.13 ± 0.12	0.13 ± 0.12	0
CHORDATA	0	0	0	0.13 ± 0.12	0.13 ± 0.12
Overall mean epibenthic fauna	2.50 ± 0.89	0.88 ± 0.29	1.50 ± 1.22	1.88 ± 0.83	0.63 ± 0.37

4.1.8.3 Overall distribution of epibenthic fauna in Diani and Galu Beaches

Figure 18 shows the overall abundance of epibenthos. With the exception of May, there were more animals in Diani Beach although their numbers were not significantly different from that at Galu. Nevertheless, here was a significant difference between the seasons ($H = 8.24$, $p \leq 0.05$) of the overall epibenthic densities.

In both Diani and Galu Beaches, the Echinodermata contributed the highest percentage of individuals (Tables 23 & 24) to the epibenthic group. In Galu Beach, the Mollusca had a higher abundance in comparison to Diani Beach. A comparison of the individual epibenthic taxa in the two areas did not reveal any significant differences between Diani and Galu Beach.

The Pearson regression analysis revealed a significant negative relationship between the epifaunal molluscans and the seagrass biomass and sediment particle size ($r = -0.56$, $p = 0.01$; $r = -0.68$, $p = 0.03$ respectively).

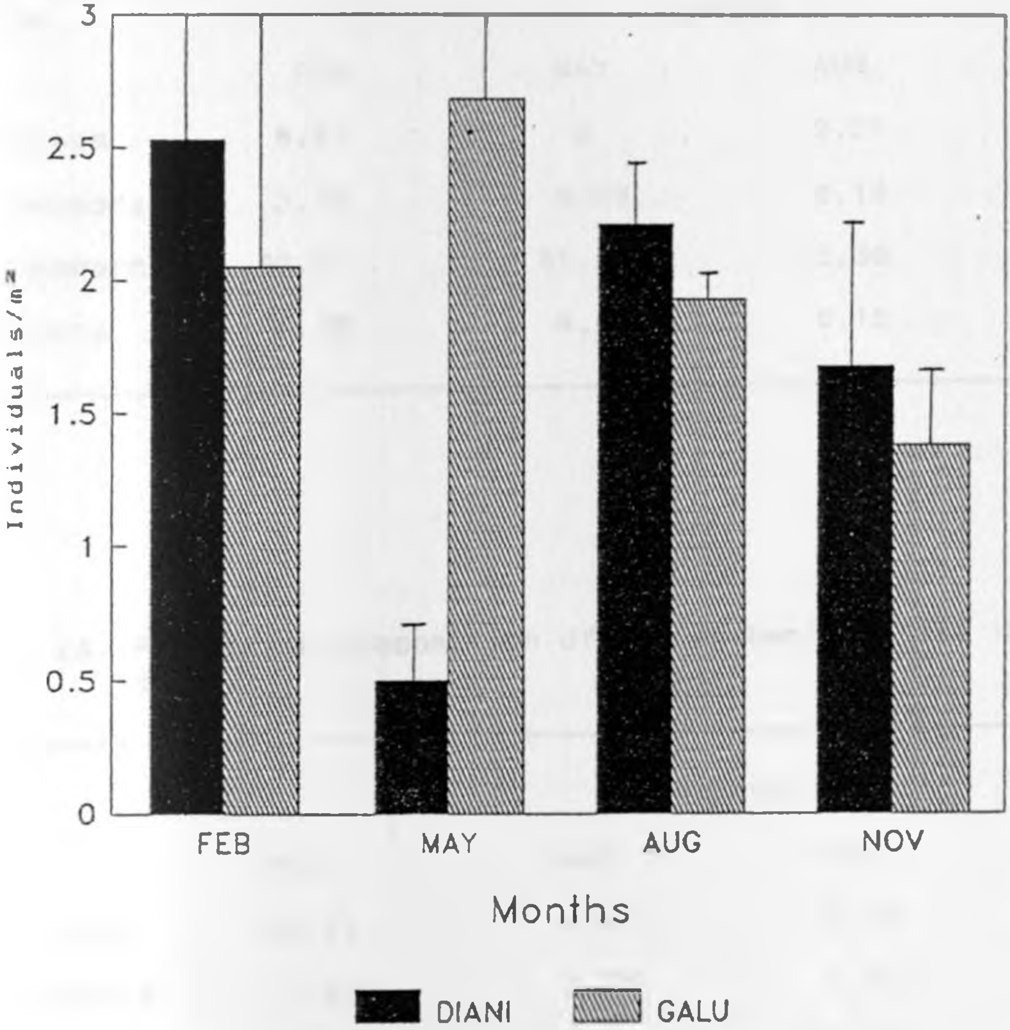


Fig. 18. Density of epibenthic fauna in Diani and Galu Beaches (n = 40 in each month).

Table 23. Percentage composition of the epibenthic taxa in Diani Beach.

Taxa	Month			
	FEB	MAY	AUG	NOV
Mollusca	6.67	0	12.31	9.80
Arthropoda	3.33	9.09	6.15	0
Echinodermata	83.33	81.82	75.38	76.47
Chordata	6.66	9.09	6.15	13.73

Table 24. Percentage composition of the epibenthic taxa in Galu Beach.

Taxa	Month			
	FEB	MAY	AUG	NOV
Mollusca	30.26	6.45	16.00	39.13
Arthropoda	1.32	3.22	2.00	2.17
Echinodermata	50.00	83.87	82.00	54.34
Chordata	18.42	6.45	0	4.35

4.1.8.4 Diversity of the epibenthic fauna

In this study, the diversity of the epibenthic fauna based on phylum and species levels of identification was calculated using the Shanonn-Weiner equation. The results are shown in table 25. At the phylum level the diversity indices were lower than those calculated at the species level of identification. However, in both cases, the diversity of epibenthic fauna was found to be similar in the two areas in all months except February where the diversity was higher in Galu Beach. The seasonal variation in the diversity indices was clearly seen in Galu Beach where lower diversities were recorded during the SE monsoon months of May and August. Evenness was variable but it was higher in Galu Beach in February and November.

Table 25. The diversity of epibenthic fauna in Diani and Galu Beaches and the t-test results (The diversity index (H') is indicated with the measure of evenness (J') in brackets).

	DIANI		GALU		t-test
	Phylum	Species	Phylum	Species	
FEB	0.27 (0.45)	0.34 (0.23)	0.47 (0.78)	0.88 (0.59)	*
MAY	0.26 (0.43)	0.72 (0.48)	0.27 (0.45)	0.51 (0.34)	NS
AUG	0.35 (0.58)	0.53 (0.36)	0.23 (0.38)	0.40 (0.27)	NS
NOV	0.31 (0.51)	0.80 (0.54)	0.39 (0.65)	0.88 (0.59)	NS

* - significant at $p \leq 0.05$
NS - non significant

4.1.9 Taxonomic composition of infauna in Diani and Galu Beaches

The soil samples obtained from the study area revealed the following groups of infaunal animals classified according to Day (1978) and Barnes (1980).

PHYLUM: PLATYHELMINTHES (Flatworms)

PHYLUM: NEMERTINA (RHYNCHLOCOELA)

PHYLUM: SIPUNCULIDA

PHYLUM: NEMATODA (Roundworms)

PHYLUM: ANNELIDA (Segmented worms)
- Class: Polychaeta
- Class: Oligochaeta

PHYLUM: MOLLUSCA
- Class: Bivalvia (Bivalves, Oysters and Mussels)
- Class: Gastropoda

PHYLUM: ARTHROPODA
- Subphylum: Chelicerata
  - Class: Arachnida (Mites)
  - Class: Pycnogonida (Sea spiders)
- Subphylum: Crustacea
  - Class: Ostracoda
  - Class: Copepoda
  - Class: Malocostraca
    - Subclass: Phyllocarida
      - Order: Leptostraca
    - Subclass: Eumalocostraca
      - Super order: Eucarida
        - Order: Decapoda
          - Infra order: Anomura (Hermit crabs)
          - Infra order: Brachyura (True crabs)
          - Infra order: Macura (Lobsters, Shrimps and Prawns)
      - Super order: Peracarida
        - Order: Mysidacea
        - Order: Cumacea
        - Order: Tanaidacea
        - Order: Isopoda
        - Order: Amphipoda

PHYLUM: ECHINODERMATA
Class: Stelleroidea
Subclass: Ophiuroidea

PHYLUM: CHORDATA
Subphylum: Cephalochordata (Lancelets)

The seagrass infauna in this part of the Kenyan coastal waters is poorly documented. Therefore the identification of infauna to species level was not possible due to the lack of adequate identification keys.

4.1.10 Seasonal distribution of infauna in Diani and Galu Beaches

4.1.10.1 Distribution of infauna in Diani Beach

The distribution of infauna in the Diani transects was varied during the sampling months (Fig. 19) with November being the only month with a distinct seaward decrease in the infaunal density.

In Diani, the density of infauna in the sediment was high at the start of the transects in February (Fig. 19). At this point Nematoda dominated. Polychaetes contributed the highest number of annelids while the amphipods were the most abundant arthropods throughout the transects (Table 26).

The onset of the rainy SE monsoon (May) was marked by a decline in animal numbers in the sediment (Table 27). The decrease was from 20,000 individuals/m^2 recorded in February to 2,000 individuals/m^2 in May. Platyhelminthes, nemerteans and sipunculids

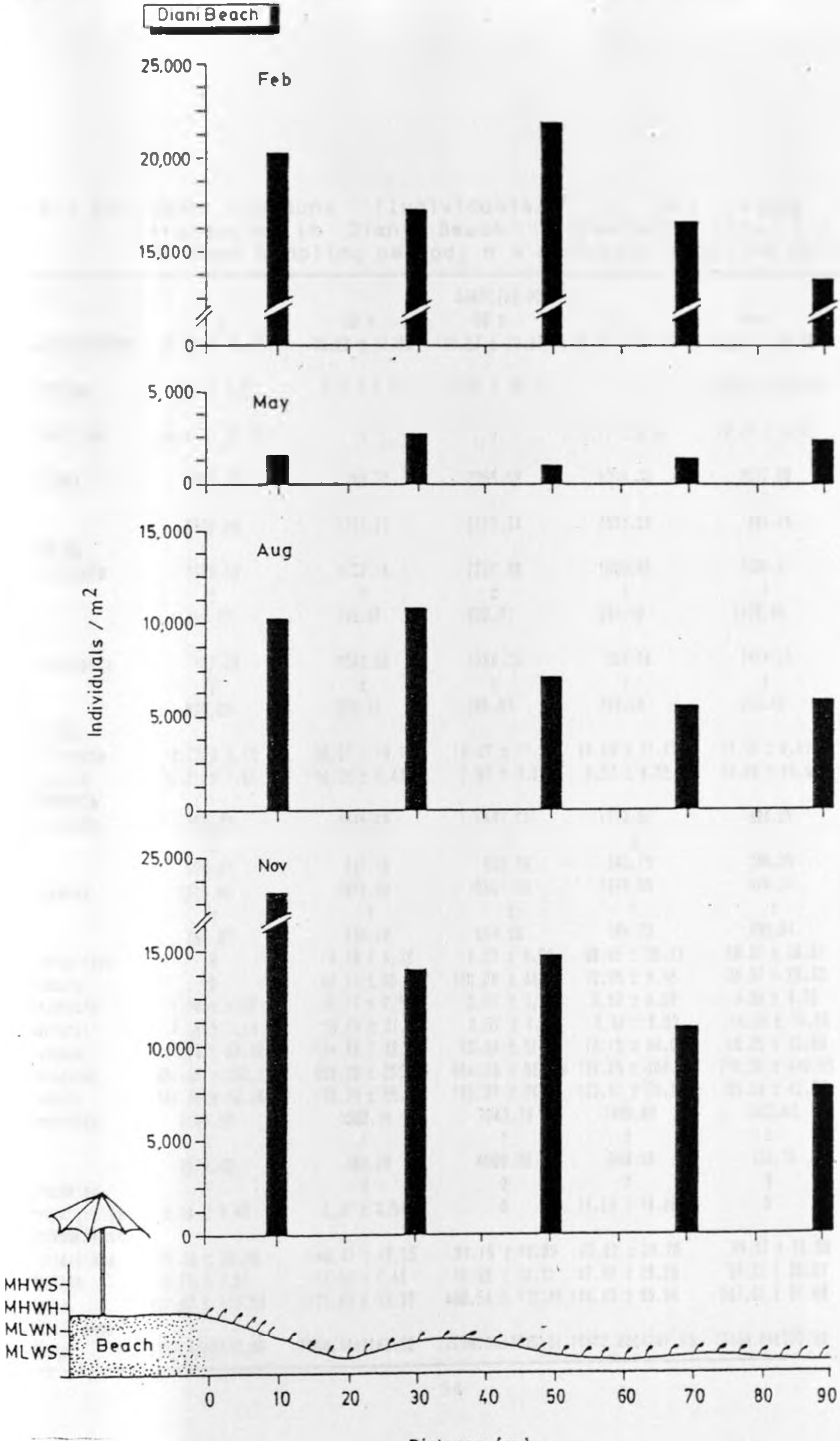


Fig. 19. Distribution of infauna along the transects in Diani Beach during the sampling months.

Table 26. Mean infauna (Individuals/m² ± SE) along the transects in Diani Beach in February (the dry NE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS				
	10 m	30 m	50 m	70 m	30 m
PLATYHELMINTHES	26.86 ± 10.27	39.28 ± 11.99	10.37 ± 10.87	28.57 ± 12.77	23.81 ± 18.68
NEMERTINA	3.57 ± 3.57	7.14 ± 4.67	25.31 ± 16.13	0	295.74 ± 294.66
SIPUNCULIDA	54.44 ± 22.31	0	0	10.71 ± 8.68	19.22 ± 19.01
NEMATODA	9691.77 ± 2530.46	7260.72 ± 1741.93	7355.59 ± 2175.31	8314.29 ± 2585.89	2017.06 ± 564.75
ANNELIDA					
Polychaeta	1059.16 ± 311.17	1132.14 ± 155.47	1751.86 ± 630.71	1809.52 ± 393.99	2390.87 ± 1126.34
Oligochaeta	787.55 ± 326.29	1242.36 ± 335.41	1036.34 ± 265.61	904.76 ± 227.05	1414.28 ± 513.16
MOLLUSCA					
Gastropoda	19.72 ± 9.73	28.57 ± 16.19	19.37 ± 11.26	33.33 ± 11.47	25.39 ± 9.27
Bivalvia	10.71 ± 7.51	14.29 ± 5.41	3.57 ± 3.57	9.52 ± 6.02	13.89 ± 13.89
ARTHROPODA					
Ostracoda	993.63 ± 326.57	1646.43 ± 497.33	1551.71 ± 542.76	1228.57 ± 543.79	824.21 ± 368.29
Copepoda	2015.68 ± 782.67	1074.90 ± 230.09	10601.39 ± 554.28	1276.19 ± 564.73	670.24 ± 499.84
Leptostraca	0	14.29 ± 5.39	9.01 ± 6.06	38.09 ± 28.17	28.57 ± 28.57
Anomura	0	60.71 ± 60.68	100.00 ± 88.35	19.05 ± 9.48	28.57 ± 23.32
Brachyura	7.14 ± 4.67	10.71 ± 7.51	3.57 ± 3.56	9.52 ± 6.02	9.52 ± 9.52
Macrura	7.14 ± 7.14	35.71 ± 27.91	3.57 ± 3.56	9.52 ± 6.02	14.29 ± 14.28
Cumacea	91.15 ± 34.32	124.99 ± 32.79	93.94 ± 57.31	76.19 ± 44.05	68.85 ± 33.89
Tanadacea	851.39 ± 333.59	589.29 ± 203.64	954.35 ± 621.34	795.25 ± 406.32	710.52 ± 410.59
Isopoda	105.90 ± 42.26	199.99 ± 55.56	191.77 ± 74.22	123.81 ± 70.23	95.24 ± 42.79
Amphipoda	4048.29 ± 1279.43	3582.14 ± 553.29	7043.79 ± 4086.28	1938.09 ± 848.59	2422.42 ± 522.10
Arachnida	0	0	0	0	0
Pyconogonida	5.44 ± 5.43	3.57 ± 3.57	0	14.29 ± 14.28	0
ECHINODERMATA					
Ophiuroidea	39.29 ± 23.48	146.47 ± 42.65	91.15 ± 42.99	47.52 ± 26.25	59.33 ± 35.09
CHORDATA	10.71 ± 7.51	11.09 ± 7.45	30.59 ± 12.31	47.62 ± 26.25	59.33 ± 35.01
Others	224.07 ± 117.63	171.43 ± 52.32	480.54 ± 131.59	148.45 ± 55.94	297.62 ± 91.86
Overall mean infauna	20054.49±5148.80	17396.44±2183.53	22238.66±7720.51	16842.83±4281.09	13464.84±356.89

Table 27. Mean infauna (Individuals/m^2 ± SE) along the transects m Diani Beach in May (the rainy SE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS				
	10 m	30 m	50 m	70 m	90 m
PLATYHELMINTHES	0	0	0	0	0
NEMERTINA	0	0	0	0	0
SIPUNCULIDA	0	0	0	0	0
NEMATODA	1044.93 ± 331.73	1312.23 ± 539.43	320.72 ± 166.11	708.27 ± 323.76	959.98 ± 378.01
ANNELIDA					
Polychaeta	17.90 ± 8.76	47.42 ± 31.30	106.26 ± 53.60	26.97 ± 23.24	395.17 ± 241.59
Oligochaeta	42.46 ± 23.75	60.15 ± 34.26	75.32 ± 32.39	44.91 ± 37.16	230.03 ± 172.33
MOLLUSCA					
Gastropoda	0	0	0	0	0
Bivalvia	0	0	0	4.69 ± 4.69	0
ARTHROPODA					
Ostracoda	87.66 ± 31.93	65.68 ± 27.00	28.19 ± 19.77	62.66 ± 35.77	90.59 ± 64.20
Copepoda	65.74 ± 18.76	38.17 ± 38.14	23.49 ± 18.70	21.04 ± 14.79	34.08 ± 26.34
Leptostraca	0	0	0	0	0
Anomura	0	0	0	0	0
Brachyura	4.07 ± 4.00	3.47 ± 3.47	3.85 ± 3.44	0	0
Macrura	0	0	0	0	0
Cumacea	8.71 ± 5.72	9.92 ± 9.49	0	0	11.36 ± 11.06
Tanadacea	62.38 ± 25.25	104.53 ± 77.46	12.87 ± 5.37	13.89 ± 13.38	60.15 ± 46.93
Isopoda	0	17.66 ± 11.60	4.69 ± 4.69	3.47 ± 3.47	21.83 ± 12.08
Amphipoda	127.77 ± 93.43	349.31 ± 283.73	106.54 ± 60.45	67.19 ± 61.97	574.73 ± 340.20
Arachnida	0	0	0	0	0
Pyconogonida	0	0	0	0	0
ECHINODERMATA					
Ophiuroidea	0	0	4.69 ± 4.69	0	9.39 ± 9.39
CHORDATA	0	0	0	0	3.79 ± 3.78
Others	8.71 ± 5.72	9.89 ± 9.89	5.95 ± 5.95	0	56.39 ± 34.79
Overall mean infauna	1469.18 ± 377.47	2691.55 ± 997.63	922.96 ± 291.42	1270.31±421.13	2446.75 ± 1224.75

were absent from the transects during this period while the numbers of the other animal groups were lower than those recorded in February.

In Diani Beach, there was an increase in the density of infauna in August compared to the low densities recorded in May. A seaward decrease in infaunal densities was recorded along the transects. Platyhelminthes and Nemertina reemerged in the transects while the Sipunculids were absent (Table 28). Nematoda exhibited a seaward decline and this may have contributed to the overall decline in animal numbers.

In November, there was a marked increase in the infauna numbers especially at the beach end of the Diani transects in comparison to August (Fig 19). This could be attributed to the higher number of polychaetes at this sampling point compared to the previous months (Table 29). Sipunclids were still absent.

Table 28. Mean infauna (Individuals/m^2 ± SE) along the transects in Diani Beach in August (the dry SE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS				
	10 m	30 m	50 m	70 m	90 m
PLATYHELMINTHES	12.82 ± 8.77	8.12 ± 8.11	0	0	4.69 ± 4.69
NEMERTINA	97.99 ± 48.57	108.30 ± 40.31	104.29 ± 47.54	17.41 ± 11.44	22.68 ± 13.99
SIPUNCULIDA	0	0	0	0	0
NEMATODA	5181.78 ± 2056.52	3319.15 ± 641.22	2262.74 ± 812.75	1402.38 ± 469.76	1830.53 ± 1190.22
ANNELIDA					
Polychaeta	1381.01 ± 595.07	1303.39 ± 268.92	1330.79 ± 523.90	1539.04 ± 571.37	790.45 ± 246.39
Oligochaeta	477.14 ± 183.88	728.54 ± 214.02	538.64 ± 201.90	483.21 ± 209.07	311.19 ± 106.38
MOLLUSCA					
Gastropoda	8.12 ± 8.11	36.90 ± 16.95	4.01 ± 4.00	0	0
Bivalvia	0	4.69 ± 4.69	0	0	12.82 ± 11.42
ARTHROPODA					
Ostracoda	645.63 ± 263.78	942.27 ± 246.30	379.17 ± 211.35	377.95 ± 173.14	130.45 ± 61.28
Copepoda	378.45 ± 225.58	323.72 ± 124.35	364.92 ± 208.62	145.27 ± 78.83	126.56 ± 86.89
Leptostraca	0	0	8.01 ± 8.01	15.58 ± 11.69	0
Anomura	0	0	0	0	9.52 ± 6.12
Brachyura	0	16.23 ± 16.23	4.01 ± 4.00	4.01 ± 4.00	3.88 ± 3.88
Macrura	16.23 ± 16.23	0	8.12 ± 8.11	9.77 ± 9.35	3.88 ± 3.88
Cumacea	53.29 ± 25.90	78.07 ± 22.59	8.01 ± 5.24	37.69 ± 12.95	57.55 ± 23.30
Tanadacea	137.99 ± 87.10	436.34 ± 301.90	165.51 ± 98.99	12.02 ± 12.01	71.19 ± 45.20
Isopoda	97.40 ± 63.73	43.74 ± 14.95	91.49 ± 36.13	112.92 ± 45.44	65.73 ± 35.34
Amphipoda	1373.89 ± 382.43	2635.82 ± 1301.98	1154.64 ± 487.23	847.26 ± 324.49	688.18 ± 283.66
Mysidacea	4.01 ± 4.00	17.89 ± 11.43	16.03 ± 12.10	4.01 ± 4.00	0
Arachnida	0	0	0	4.01 ± 4.01	0
Pyconogonida	0	0	0	0	0
ECHINODERMATA					
Ophiuroidea	0	30.33 ± 12.05	8.71 ± 5.72	15.71 ± 11.66	6.31 ± 5.62
CHORDATA	12.82 ± 8.77	16.72 ± 8.77	9.58 ± 5.59	8.71 ± 5.72	11.65 ± 11.64
Others	443.12 ± 221.48	669.76 ± 213.73	694.84 ± 429.96	356.38 ± 146.39	142.33 ± 81.73
Overall mean infauna	10363.52±4032.42	10719.61±2694.47	7152.27±2600.90	5391.81±1961.27	5711.59±1856.94

Table 29. Mean infauna (Individuals/m^2 ± SE) along the transects m Diani Beach in November (the rainy NE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS				
	10 m	30 m	50 m	70 m	90 m
PLATYHELMINTHES	4.69 ± 4.69	24.35 ± 17.07	0	0	0
NEMERTINA	33.75 ± 16.25	14.09 ± 9.88	33.33 ± 19.66	28.63 ± 20.07	28.19 ± 13.75
SIPUNCULIDA	0	0	0	0	0
NEMATODA	6673.36 ± 3029.54	2652.09 ± 868.22	2947.31 ± 1399.79	2648.46 ± 1412.39	1898.49 ± 548.08
ANNELIDA					
Polychaeta	9895.71 ± 3794.52	682.24 ± 261.57	1866.18 ± 729.38	1184.34 ± 455.45	1118.42 ± 312.17
Oligochaeta	498.55 ± 193.47	857.40 ± 233.10	257.03 ± 134.39	111.67 ± 61.56	959.28 ± 661.31
MOLLUSCA					
Gastropoda	146.11 ± 61.57	37.17 ± 24.09	9.54 ± 9.54	18.94 ± 13.09	4.69 ± 4.69
Bivalvia	0	0	0	0	0
ARTHROPODA					
Ostracoda	527.17 ± 219.05	787.46 ± 517.17	594.34 ± 433.53	368.07 ± 207.32	226.19 ± 93.99
Copepoda	1248.72 ± 997.81	453.25 ± 157.54	788.97 ± 507.81	146.58 ± 68.53	244.39 ± 91.25
Leptostraca	0	0	9.54 ± 9.54	0	4.69 ± 4.69
Anomura	0	0	4.69 ± 4.69	57.25 ± 57.21	4.69 ± 4.69
Brachyura	16.23 ± 16.23	12.94 ± 8.75	0	9.54 ± 8.92	4.69 ± 4.69
Macrura	0	0	19.08 ± 19.08	4.69 ± 4.69	4.69 ± 4.69
Cumacea	91.42 ± 24.93	51.26 ± 15.08	215.23 ± 137.63	83.65 ± 65.43	33.52 ± 19.22
Tanaidacea	41.01 ± 21.67	977.02 ± 591.89	1166.78 ± 692.52	185.71 ± 108.75	259.08 ± 135.57
Isopoda	65.36 ± 29.55	310.70 ± 191.39	239.71 ± 124.64	115.59 ± 72.99	104.01 ± 44.57
Amphipoda	523.33 ± 186.49	5284.09 ± 2903.07	4232.80 ± 1956.79	1532.66 ± 882.35	1663.53 ± 1001.45
Mysidacea	0	0	0	0	0
Arachnida	0	0	0	0	0
Pyconogonida	4.69 ± 4.69	8.12 ± 8.11	0	0	4.69 ± 4.69
ECHINODERMATA					
Ophiuroidea	0	34.37 ± 16.07	20.19 ± 10.55	0	9.39 ± 6.15
CHORDATA	29.05 ± 24.12	46.57 ± 25.88	81.38 ± 47.39	18.94 ± 12.39	23.49 ± 14.09
Others	494.69 ± 182.52	162.77 ± 90.45	358.37 ± 167.37	276.19 ± 139.05	169.17 ± 56.36
Overall mean infauna	23077.59±11161.28	14165.61±5106.39	14780.89±5589.98	10773.02±3468.69	7728.24±1696.74

4.1.10.2 Distribution of infauna in Galu Beach

In Galu Beach, the number of infauna in the sediment increased seawards in May while in August the opposite occurred with a seaward decrease in number (Fig. 20).

In February, Nematoda, Polychaeta and Amphipoda dominated in number (Table 30). In May, the density of infauna dropped from a maximum of 12,000 individuals/m^2 in February to around 1,500 individuals/m^2 in May. There was a seaward increase in the number of infauna (Fig. 20). Platyhelminthes, nemerteans and chordates were absent while Nematoda and Amphipoda dominated in number along the transects (Table 31). The other groups were low in number and the seaward peak could be attributed to the Nematoda (Table 31).

In August, there was a seaward decrease in the infaunal density (Fig. 20). The highest number was recorded at the start of the transects while in May the highest number was recorded at the end of the transects. There was a reoccurrence of Platyhelminthes and Nemertina (Table 32). Nematoda increased seawards while the amphipods, were highest at the beach end of the transects (Table 32). In November, the density of infauna was similar to that recorded in August. During this sampling period, Nematoda, Polychaeta and Amphipoda dominated in the samples (Table 33).

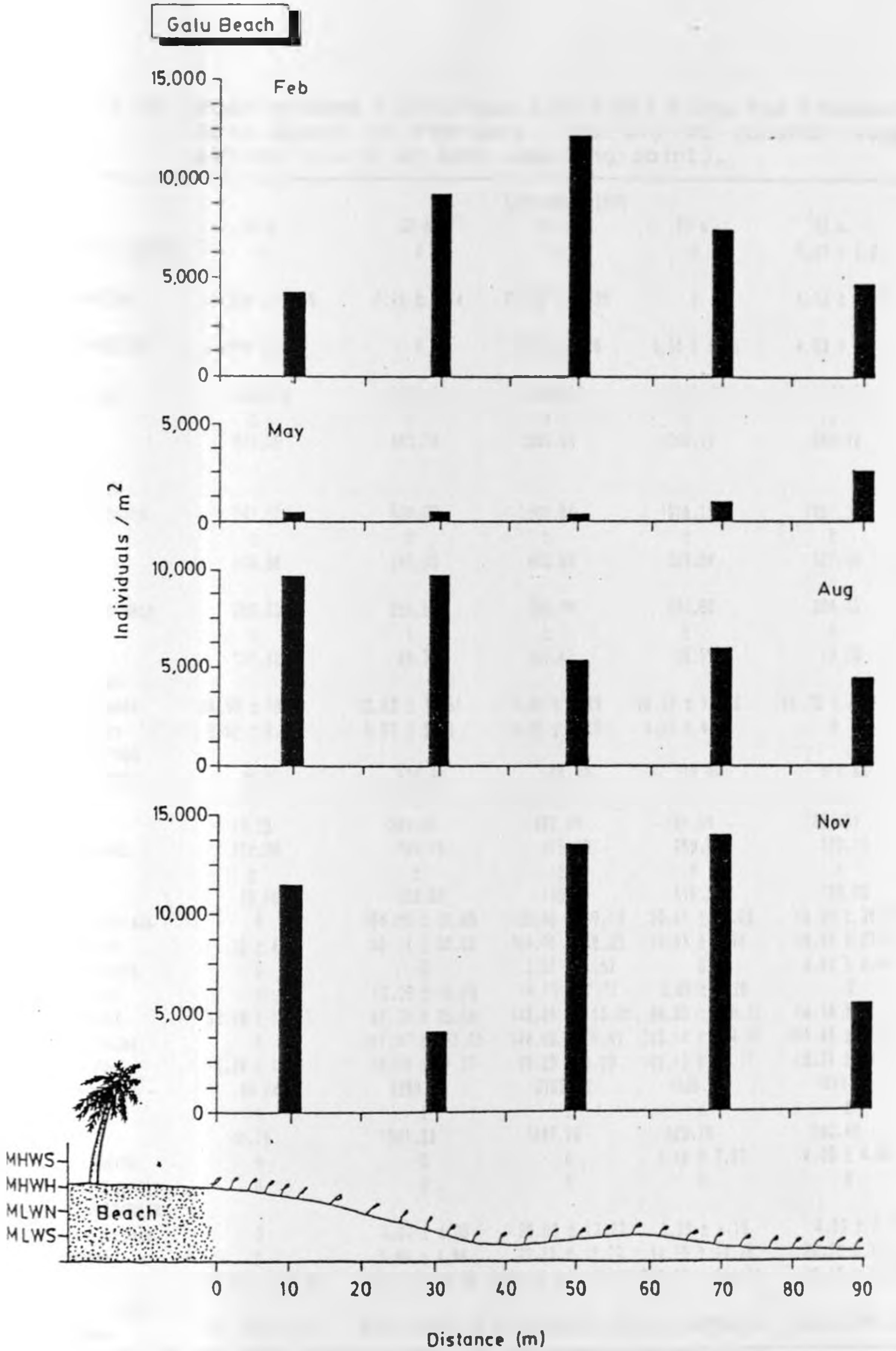


Fig. 20. Distribution of infauna along the transects in Galu Beach during the sampling months.

Table 30. Mean infauna (Individuals/m^2 ± SE) along the transects in Galu Beach in February (the dry NE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS				
	10 m	30 m	50 m	70 m	90 m
PLATYHELMINTHES	0	0	0	0	5.53 ± 3.34
NEMERTINA	17.86 ± 17.85	7.14 ± 7.14	20.08 ± 11.95	0	4.03 ± 4.02
SIPUNCULIDA	11.09 ± 7.45	0	8.07 ± 8.06	5.56 ± 5.55	4.03 ± 4.03
NEMATODA	1585.19 ± 674.08	2933.75 ± 693.78	2788.83 ± 1066.65	2417.10 ± 1260.11	1437.56 ± 386.16
ANNELIDA					
Polychaeta	381.57 ± 114.98	896.08 ± 246.88	1600.81 ± 483.65	1019.16 ± 329.89	1081.34 ± 327.46
Oligochaeta	296.93 ± 127.33	255.51 ± 86.72	258.76 ± 104.47	237.66 ± 79.59	284.45 ± 93.25
MOLLUSCA					
Gastropoda	34.56 ± 19.56	33.52 ± 14.51	7.60 ± 4.39	18.32 ± 10.78	14.75 ± 7.77
Bivalvia	9.52 ± 5.21	8.07 ± 5.28	8.07 ± 5.28	4.03 ± 4.03	0
ARTHROPODA					
Ostracoda	26.27 ± 13.29	530.64 ± 209.88	752.99 ± 482.09	377.79 ± 161.06	276.84 ± 104.81
Copepoda	176.34 ± 70.96	745.16 ± 163.65	675.23 ± 143.17	269.79 ± 110.52	252.19 ± 103.03
Leptostraca	0	104.95 ± 91.86	50.00 ± 39.19	20.41 ± 19.08	48.39 ± 36.55
Anomura	5.38 ± 4.65	60.71 ± 60.58	100.00 ± 88.35	19.05 ± 9.48	28.57 ± 23.32
Brachyura	0	0	3.57 ± 3.57	0	4.03 ± 4.03
Macrura	0	12.09 ± 12.09	14.75 ± 7.77	8.59 ± 5.26	0
Cumacea	32.26 ± 19.07	61.75 ± 28.88	142.05 ± 115.05	98.62 ± 160.55	44.36 ± 17.17
Tanadacea	0	547.47 ± 502.09	146.08 ± 78.42	205.14 ± 164.67	181.45 ± 111.5
Isopoda	4.76 ± 4.12	76.15 ± 51.37	56.25 ± 8.09	101.12 ± 46.17	16.31 ± 10.55
Amphipoda	86.94 ± 41.76	3266.13 ± 1541.39	3109.22 ± 1467.20	1630.06 ± 823.76	1011.52 ± 263.42
Arachnida	0	0	0	8.16 ± 7.63	4.03 ± 4.03
Pyconogonida	0	0	0	0	0
ECHINODERMATA					
Ophiuroidea	0	4.03 ± 4.03	29.03 ± 13.23	6.35 ± 4.19	4.53 ± 3.38
CHORDATA	0	7.60 ± 4.38	23.27 ± 15.77	14.29 ± 14.28	36.29 ± 17.5
Others	130.86 ± 109.60	99.31 ± 48.58	2522.93 ± 1675.39	793.57 ± 646.78	60.49 ± 33.0
Overall mean infauna	4278.34±947.88	9611.37±2183.48	12273.96±3466.48	7748.50±2202.83	4786.06±967.58

Table 31. Mean infauna (Individuals/m^2 ± SE) along the transects in Galu Beach in May (the rainy SE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS 10 m	30 m	50 m	70 m	90 m
PLATYHELMINTHES	0	0	0	0	0
NEMERTINA	0	0	0	0	0
SIPUNCULIDA	5.31 ± 5.30	0	3.13 ± 3.12	0	0
NEMATODA	165.84 ± 74.07	292.27 ± 177.84	111.12 ± 37.37	399.15 ± 141.22	1064.28 ± 133.99
ANNELIDA					
Polychaeta	85.95 ± 52.55	134.38 ± 134.30	104.69 ± 72.01	40.63 ± 40.50	336.32 ± 155.27
Oligochaeta	65.63 ± 43.00	43.93 ± 36.79	35.42 ± 17.99	50.75 ± 33.15	108.96 ± 28.47
MOLLUSCA					
Gastropoda	0	0	0	0	7.40 ± 4.91
Bivalvia	9.38 ± 9.37	0	6.25 ± 4.09	0	3.31 ± 3.12
ARTHROPODA					
Ostracoda	31.25 ± 31.23	3.31 ± 3.30	24.72 ± 10.13	32.66 ± 15.02	135.14 ± 38.46
Copepoda	20.32 ± 15.65	10.25 ± 7.25	85.88 ± 46.88	57.94 ± 35.87	55.26 ± 18.48
Leptostraca	0	0	0	12.50 ± 12.49	15.05 ± 5.42
Anomura	0	0	0	0	0
Brachyura	0	0	0	3.79 ± 3.78	0
Macrura	0	0	0	2.55 ± 2.55	3.13 ± 3.12
Cumacea	6.25 ± 4.09	6.43 ± 4.21	0	3.13 ± 3.12	13.73 ± 7.06
Tanadacea	3.13 ± 3.12	0	0	5.68 ± 3.74	19.63 ± 15.35
Isopoda	0	0	8.04 ± 8.03	9.38 ± 9.37	19.72 ± 10.18
Amphipoda	28.31 ± 18.55	28.31 ± 24.73	23.96 ± 20.61	385.04 ± 349.45	663.44 ± 396.43
Arachnida	0	0	0	3.31 ± 3.30	0
Pycnogonida	0	0	0	0	0
ECHINODERMATA					
Ophiuroidea	3.13 ± 3.12	0	0	3.13 ± 3.12	3.13 ± 3.12
CHORDATA	0	0	0	0	0
Others	3.13 ± 3.12	0	11.57 ± 11.57	31.25 ± 31.23	48.64 ± 26.38
Overall mean infauna	488.68±241.59	518.87±373.34	414.78±116.39	1040.86±621.41	2498.02±676.71

Table 32. Mean infauna (Individuals/m^2 ± SE) along the transects in Galu Beach in August (the dry SE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS 10 m	30 m	50 m	70 m	90 m
PLATYHELMINTHES	5.68 ± 5.68	0	0	8.01 ± 5.34	0
NEMERTINA	34.72 ± 34.70	19.59 ± 13.09	0	0	12.71 ± 8.69
SIPUNCULIDA	0	0	0	0	0
NEMATODA	1756.57 ± 875.21	1709.15 ± 857.88	811.78 ± 239.98	478.41 ± 339.43	1321.65 ± 454.92
ANNELIDA					
Polychaeta	1605.25 ± 1220.96	2074.56 ± 1241.66	669.45 ± 207.63	432.46 ± 186.42	790.45 ± 246.39
Oligochaeta	228.86 ± 121.73	401.53 ± 181.86	144.17 ± 49.16	95.83 ± 53.49	310.56 ± 107.24
MOLLUSCA					
Gastropoda	4.01 ± 4.00	31.61 ± 21.64	8.01 ± 8.01	4.01 ± 4.00	0
Bivalvia	4.01 ± 4.00	0	0	0	11.57 ± 11.57
ARTHROPODA					
Ostracoda	477.49 ± 181.82	224.61 ± 78.34	335.20 ± 137.96	61.39 ± 25.87	130.45 ± 61.28
Copepoda	187.09 ± 159.20	304.04 ± 167.19	202.55 ± 148.28	111.24 ± 49.87	126.66 ± 86.89
Leptostraca	0	8.01 ± 8.01	85.32 ± 57.46	15.58 ± 11.59	0
Anomura	27.59 ± 15.08	112.18 ± 90.65	11.32 ± 5.55	0	9.52 ± 6.15
Brachyura	12.19 ± 11.49	0	15.58 ± 11.69	4.01 ± 4.00	4.01 ± 3.86
Macrura	8.01 ± 8.01	11.57 ± 11.57	8.01 ± 8.01	9.39 ± 9.39	3.88 ± 3.88
Cumacea	86.36 ± 43.11	175.69 ± 112.75	108.81 ± 55.47	37.69 ± 12.95	58.18 ± 23.09
Tanadacea	675.75 ± 675.15	1497.06 ± 1226.82	247.51 ± 229.21	12.02 ± 12.01	71.69 ± 45.09
Isopoda	90.81 ± 44.57	158.92 ± 123.66	31.35 ± 20.09	112.92 ± 45.43	65.61 ± 35.37
Amphipoda	3160.38 ± 2465.59	2526.01 ± 1650.27	1741.51 ± 1025.91	346.26 ± 324.86	687.55 ± 285.64
Mysidacea	0	0	0	0	0
Arachnida	0	0	0	4.01 ± 4.00	0
Pyconogonida	0	0	0	0	0
ECHINODERMATA					
Ophiuroidea	9.69 ± 6.46	4.01 ± 4.00	8.01 ± 8.01	12.71 ± 8.68	7.31 ± 4.81
CHORDATA	11.36 ± 11.36	19.96 ± 11.95	35.61 ± 18.39	8.01 ± 8.01	9.71 ± 5.57
Others	324.46 ± 179.25	368.14 ± 238.06	238.92 ± 165.96	161.57 ± 116.53	57.63 ± 26.44
Overall mean infauna	9952.91±6248.91	9656.27±5880.57	5375.67±2051.61	6032.28±2731.66	4494.71±911.38

Table 33. Mean infauna (Individuals/m^2 ± SE) along the transects in Galu Beach in November (the rainy NE monsoon sampling period; n = 8 at each sampling point).

TAXA	SAMPLING POINTS 10 m	30 m	50 m	70 m	90 m
PLATYHELMINTHES	0	0	4.13 ± 3.99	0	12.02 ± 12.01
NEMERTINA	14.42 ± 9.67	12.39 ± 8.36	25.57 ± 9.16	14.42 ± 9.67	0
SIPUNCULIDA	0	0	4.01 ± 4.00	0	4.01 ± 4.00
NEMATODA	3424.38 ± 1853.26	1226.44 ± 532.01	2187.45 ± 779.49	3190.57 ± 840.57	1871.33 ± 349.63
ANNELIDA					
Polychaeta	3721.62 ± 2359.03	902.88 ± 298.61	2727.14 ± 1380.61	1075.67 ± 221.84	1142.64 ± 80.68
Oligochaeta	1277.49 ± 842.07	548.57 ± 232.11	528.48 ± 266.14	367.64 ± 107.42	183.04 ± 45.11
MOLLUSCA					
Gastropoda	143.16 ± 73.47	162.66 ± 64.31	49.61 ± 15.14	55.52 ± 20.24	16.72 ± 8.77
Bivalvia	24.04 ± 24.02	27.09 ± 18.64	4.01 ± 4.00	4.01 ± 4.00	0
ARTHROPODA					
Ostracoda	313.29 ± 121.66	220.86 ± 54.38	520.01 ± 395.33	442.88 ± 150.71	116.34 ± 28.43
Copepoda	325.58 ± 114.09	276.44 ± 80.98	1265.38 ± 911.30	2107.43 ± 1035.45	329.82 ± 48.98
Leptostraca	4.01 ± 4.00	0	40.06 ± 31.31	124.05 ± 123.98	0
Anomura	4.01 ± 4.00	4.01 ± 4.00	9.54 ± 9.54	0	13.40 ± 6.57
Brachyura	4.01 ± 4.00	0	9.54 ± 9.54	19.09 ± 12.49	0
Macrura	4.01 ± 4.00	4.01 ± 4.00	12.02 ± 8.43	40.65 ± 28.13	12.02 ± 5.86
Cumacea	43.12 ± 25.04	12.02 ± 5.86	55.72 ± 30.74	239.37 ± 143.89	69.49 ± 42.13
Tanadacea	0	24.04 ± 15.73	490.07 ± 320.71	142.55 ± 90.57	116.64 ± 49.96
Isopoda	33.58 ± 17.66	47.13 ± 23.60	153.62 ± 94.09	94.84 ± 51.27	70.34 ± 30.08
Amphipoda	688.95 ± 394.64	633.52 ± 306.36	4637.07 ± 2895.34	5759.81 ± 3489.45	1434.41 ± 680.19
Mysidacea	0	0	0	0	0
Arachnida	0	0	0	0	0
Pyconogonida	0	0	4.01 ± 4.00	4.01 ± 4.00	0
ECHINODERMATA					
Ophiuroidea	0	13.55 ± 9.80	24.09 ± 12.00	42.18 ± 28.35	16.72 ± 8.77
CHORDATA	9.54 ± 9.54	4.01 ± 4.00	16.53 ± 12.01	19.08 ± 19.07	16.03 ± 10.48
Others	121.35 ± 41.67	61.63 ± 15.49	791.77 ± 455.15	186.62 ± 69.63	167.88 ± 48.14
Overall mean infauna	10155.91±5020.18	4177.37±1159.89	13558.06±6854.23	13929.12±5467.21	5587.86±777.20

4.1.10.3 Overall distribution of infauna in Diani and Galu Beaches

Figure 21 shows the seasonal distribution of infauna in the study area. The density of infauna was higher in Diani Beach compared to Galu Beach though a decrease was noted particularly during the SE monsoon month of May. In both Diani and Galu Beaches, Nematoda, Annelida and the Arthropoda contributed the highest percentage of individuals to the infaunal densities (Tables 34 & 35).

The Kruskal Wallis analysis did not reveal a significant difference between the two areas. However, there was a significant seasonal variation in the total infauna ($H = 15.39$, $p \leq 0.05$). The occurrence of Chordata, Nematoda, Echinodermata, Sipunculida, Annelida, Nemertea, Arthropoda and Mollusca varied significantly with the seasons (H = 16.99, 13.98, 13.79, 8.91, 13.51, 15.57, 21.13, 17.19 respectively; $p \leq 0.05$ in all cases).

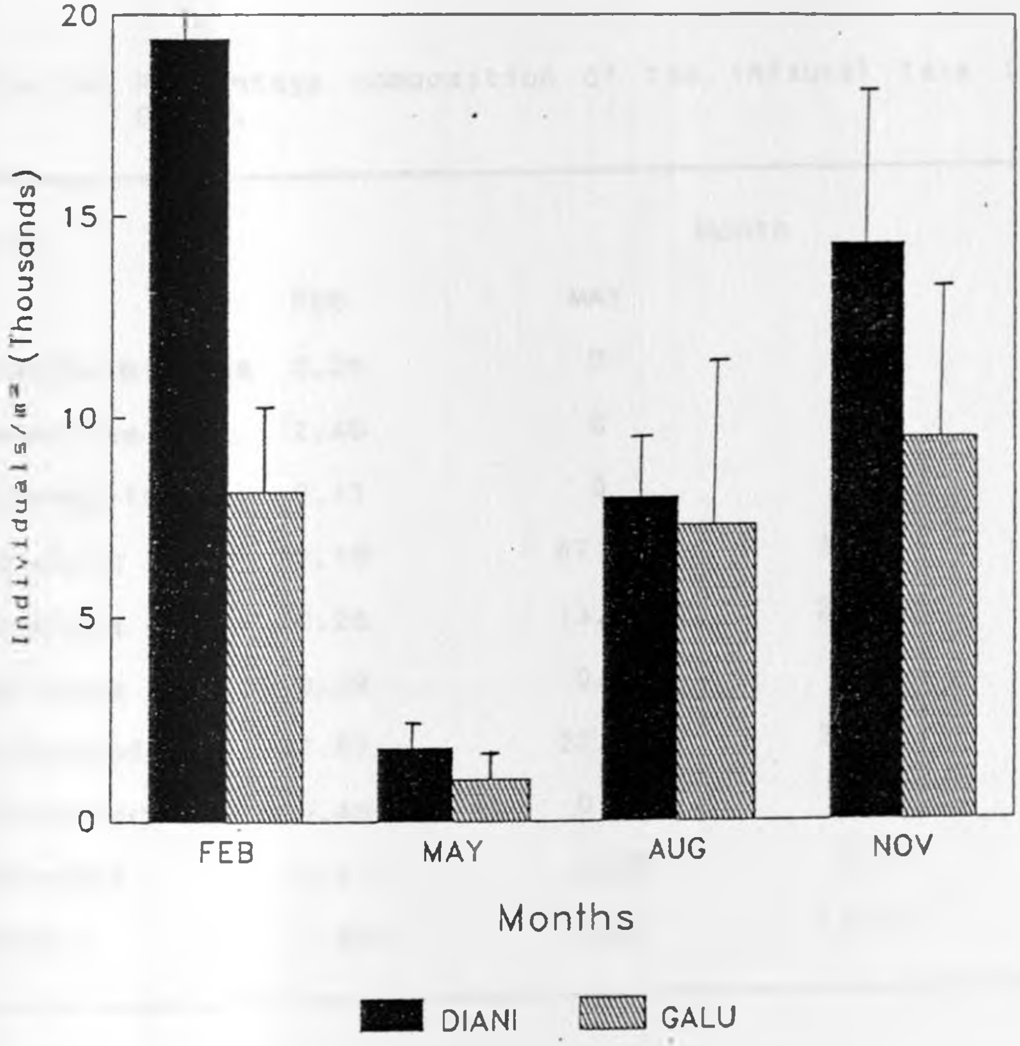


Fig. 21. Density of infauna in Diani and Galu Beaches (n = 40 in each month).

Table 34. Percentage composition of the infaunal taxa in Diani Beach.

Taxa	Month			
	FEB	MAY	AUG	NOV
Platyhelminthes	0.26	0	0.07	0.05
Nemertina	2.40	0	0.92	0.22
Sipunculida	0.11	0	0	0
Nematoda	31.19	57.37	36.83	31.22
Annelida	16.26	13.79	23.38	32.35
Mollusca	0.22	0.06	0.17	0.40
Arthropoda	47.57	27.53	32.14	32.64
Echinodermata	0.49	0.19	0.16	0.12
Chordata	0.11	0.05	0.15	0.35
Others	1.49	1.07	6.07	2.53

Table 35. Percentage composition of the infaunal taxa in Galu Beach.

Taxa	Month			
	FEB	MAY	AUG	NOV
Platyhelminthes	0.02	0.06	0.05	0.03
Nemertina	0.14	0	0.23	0.13
Sipunculida	0.08	0.17	0	0.02
Nematoda	30.22	41.48	21.23	23.62
Annelida	16.80	20.54	21.81	24.76
Mollusca	0.36	0.54	0.18	0.96
Arthropoda	41.79	35.00	51.88	6.21
Echinodermata	0.12	0.19	0.15	41.59
Chordata	0.23	0	0.29	0.13
Others	10.14	1.93	4.02	2.39

4.1.10.4 Diversity of infauna in Diani and Galu Beaches

The diversity of infauna in the two areas is shown in Table 36. The infauna were not identified to species level hence the indices were calculated on the phylum level. A significant difference in infauna diversity was recorded during the rainy SE monsoon month of May. The infauna had a similar evenness.

Table 36. The diversity of infauna in Diani and Galu Beaches and the t-test results (The diversity index (H') is indicated with the measure of evenness (J') in brackets).

	DIANI	GALU	t-test
FEB	0.55 (0.55)	0.58 (0.58)	NS
MAY	0.44 (0.44)	0.54 (0.54)	*
AUG	0.58 (0.58)	0.51 (0.51)	NS
NOV	0.55 (0.55)	0.59 (0.59)	NS

* - significant at $p \leq 0.05$
NS - non significant

4.2 Physico-chemical factors

4.2.1 Seasonal pattern of air and water temperatures in Diani and Galu Beaches

4.2.1.1 Air and water temperatures in Diani Beach

The air and water temperatures were higher at the beach end of the Diani transects and decreased seawards during the sampling months (Fig. 22). The air temperatures were lower than the water temperatures (Table 37) while the temperatures were higher during the NE monsoon months of February and November compared to the SE monsoon months of May and November.

4.2.1.2 Air and water temperatures in Galu Beach

A general seaward decrease in both the air and water temperatures was recorded (Fig. 23). The temperatures recorded during the SE monsoons (May and August) were lower than those recorded in the NE monsoon months of February and November (Table 38). The air temperatures were lower than the water temperatures as was the case in Diani.

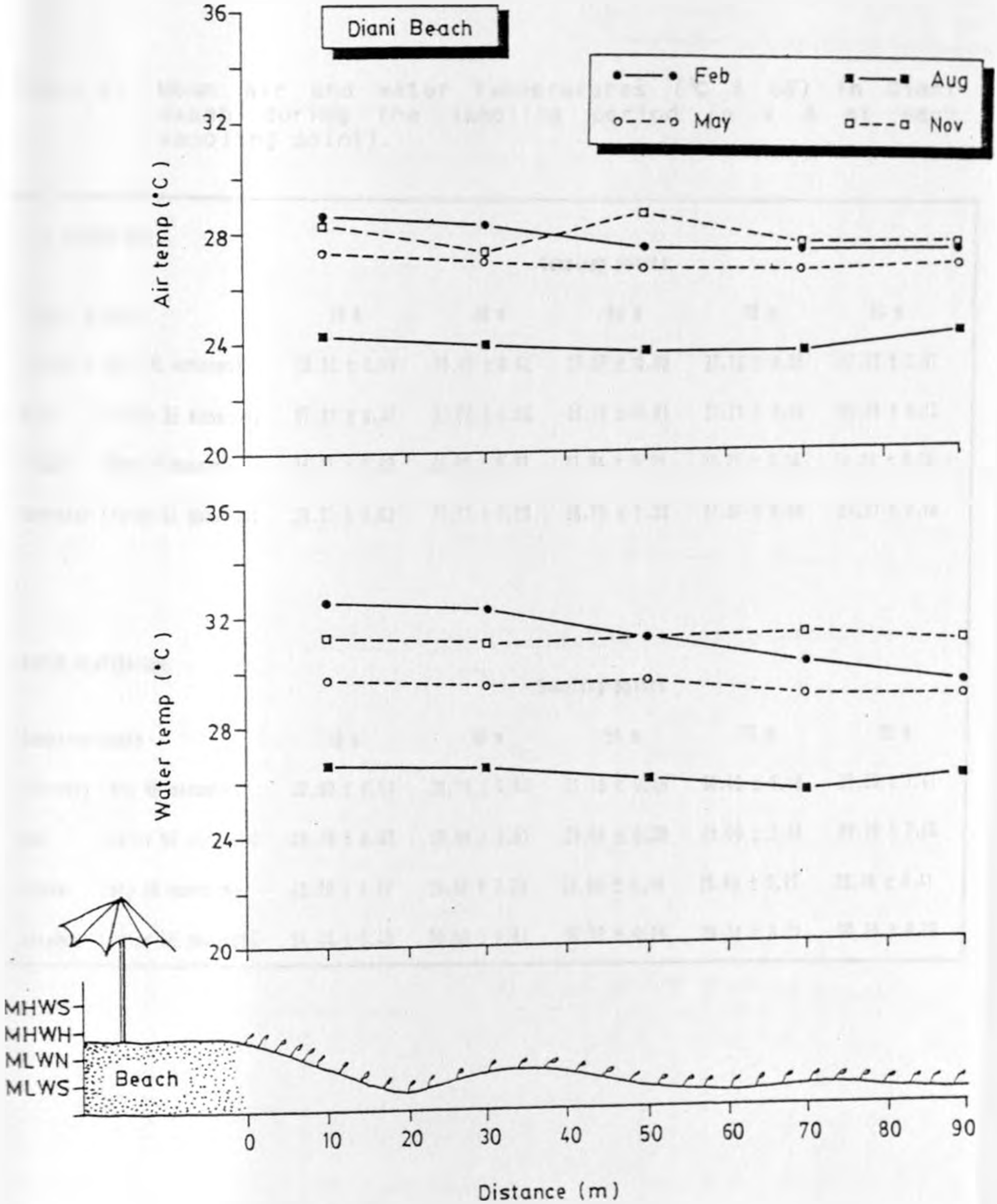


Fig. 22. Variation of air and water temperature in Diani Beach during the sampling period.

Table 37. Mean air and water temperatures (℃ ± SE) in Diani Beach during the sampling period (n = 8 at each sampling point).

AIR TEMPERATURE

Sampling month	Sampling points				
	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	28.51 ± 0.18	28.20 ± 0.42	27.57 ± 0.08	27.22 ± 0.05	27.21 ± 0.07
May (rainy SE monsoon)	27.21 ± 0.37	27.00 ± 0.08	26.71 ± 0.21	27.71 ± 0.14	26.75 ± 0.13
August (dry SE monsoon)	24.31 ± 0.29	24.00 ± 0.07	23.94 ± 0.24	23.75 ± 0.16	24.31 ± 0.36
November (rainy SE monsoon)	28.31 ± 0.63	27.13 ± 0.23	28.75 ± 1.33	27.31 ± 0.28	27.31 ± 0.16

WATER TEMPERATURE

Sampling month	Sampling points				
	10 m	30 m	50 m	70 m	30 m
February (dry NE monsoon)	32.50 ± 0.57	32.19 ± 0.42	31.19 ± 0.15	30.43 ± 0.19	29.50 ± 1.41
May (rainy SE monsoon)	29.70 ± 0.42	29.50 ± 0.31	29.60 ± 0.39	29.00 ± 0.34	29.00 ± 0.46
August (dry SE monsoon)	26.70 ± 0.27	26.50 ± 0.18	26.00 ± 0.16	25.69 ± 0.27	26.06 ± 0.41
November (rainy SE monsoon)	31.14 ± 0.48	30.38 ± 0.67	30.13 ± 0.29	30.31 ± 0.21	30.25 ± 0.39

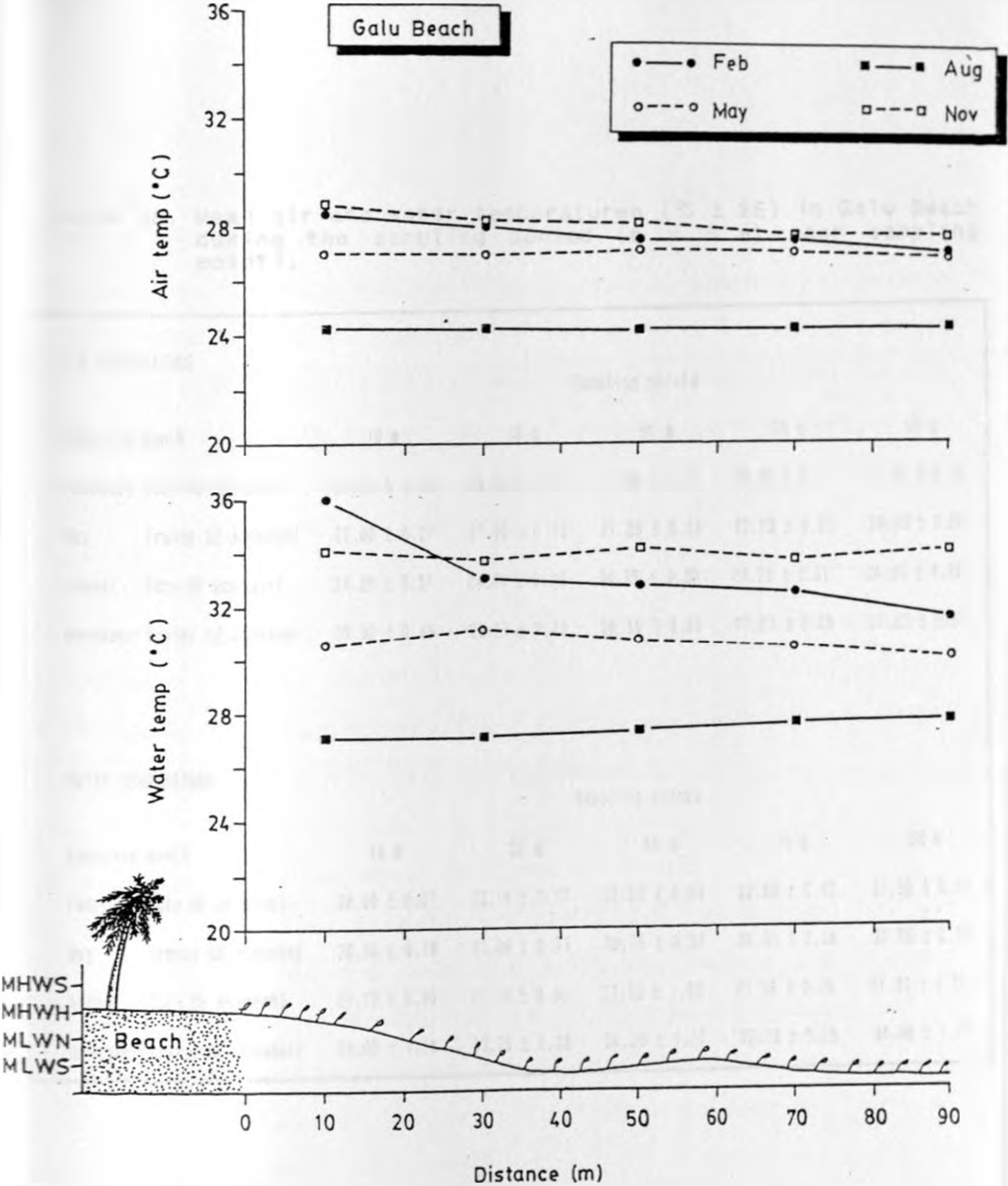


Fig. 23. Variation of air and water temperature in Galu Beach during the sampling period.

Table 38. Mean air and water temperatures (℃ ± SE) in Galu Beach during the sampling period (n = 8 at each sampling point).

AIR TEMPERATURE

Sampling month	Sampling points				
	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	28.50 ± 0.43	28.00 ± 0.24	27.50 ± 0.15	27.50 ± 0.15	27.00 ± 0.08
May (rainy SE monsoon)	27.00 ± 0.27	27.00 ± 0.33	27.25 ± 0.39	27.13 ± 0.23	26.90 ± 0.20
August (dry SE monsoon)	24.25 ± 0.31	24.44 ± 0.48	24.25 ± 0.30	24.25 ± 0.31	24.28 ± 0.26
November (rainy SE monsoon)	29.00 ± 0.49	28.25 ± 0.41	28.19 ± 0.59	27.81 ± 0.39	27.63 ± 0.53

WATER TEMPERATURE

Sampling month	Sampling points				
	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	36.00 ± 0.07	33.14 ± 0.77	32.88 ± 0.65	32.50 ± 0.62	31.50 ± 0.16
May (rainy SE monsoon)	30.50 ± 0.19	31.06 ± 0.75	30.75 ± 0.57	30.31 ± 0.34	30.00 ± 0.27
August (dry SE monsoon)	27.19 ± 0.96	27.19 ± 0.82	27.38 ± 1.03	27.56 ± 0.76	27.81 ± 0.72
November (rainy SE monsoon)	34.00 ± 1.14	33.75 ± 1.33	34.20 ± 1.37	33.75 ± 0.75	34.00 ± 1.13

4.2.2 Seasonal pattern of salinity and pH in Diani and Galu Beaches

4.2.2.1 Salinity and pH in Diani Beach

During the sampling periods there was a general seaward increase in the salinity levels recorded along the transects in Diani Beach (Fig. 24). The highest salinity was recorded in November (dry NE monsoon period) while August (dry SE monsoon sampling period) had the lowest mean salinity recorded (Table 39).

The pH levels were relatively constant throughout the transects (Fig. 24) with no distinct seaward increase or seaward decrease (Table 39). However, the pH levels recorded during the SE monsoon months of May and August were lower than those recorded during the NE monsoon months of February and November.

4.2.2.2 Salinity and pH in Galu Beach

The salinity showed a seaward increase (Fig. 25) though this was not as distinct as the increase in Diani Beach. The highest salinity was recorded during the rainy NE monsoon (November) while the lowest levels were recorded during the SE monsoon period of May and August (Table 40). The salinity levels in February (dry NE monsoon) were lower than those recorded in May. This was in contrast to Diani where the February salinity levels were higher than the May levels.

The pH levels were constant along the transects (Fig. 25) though

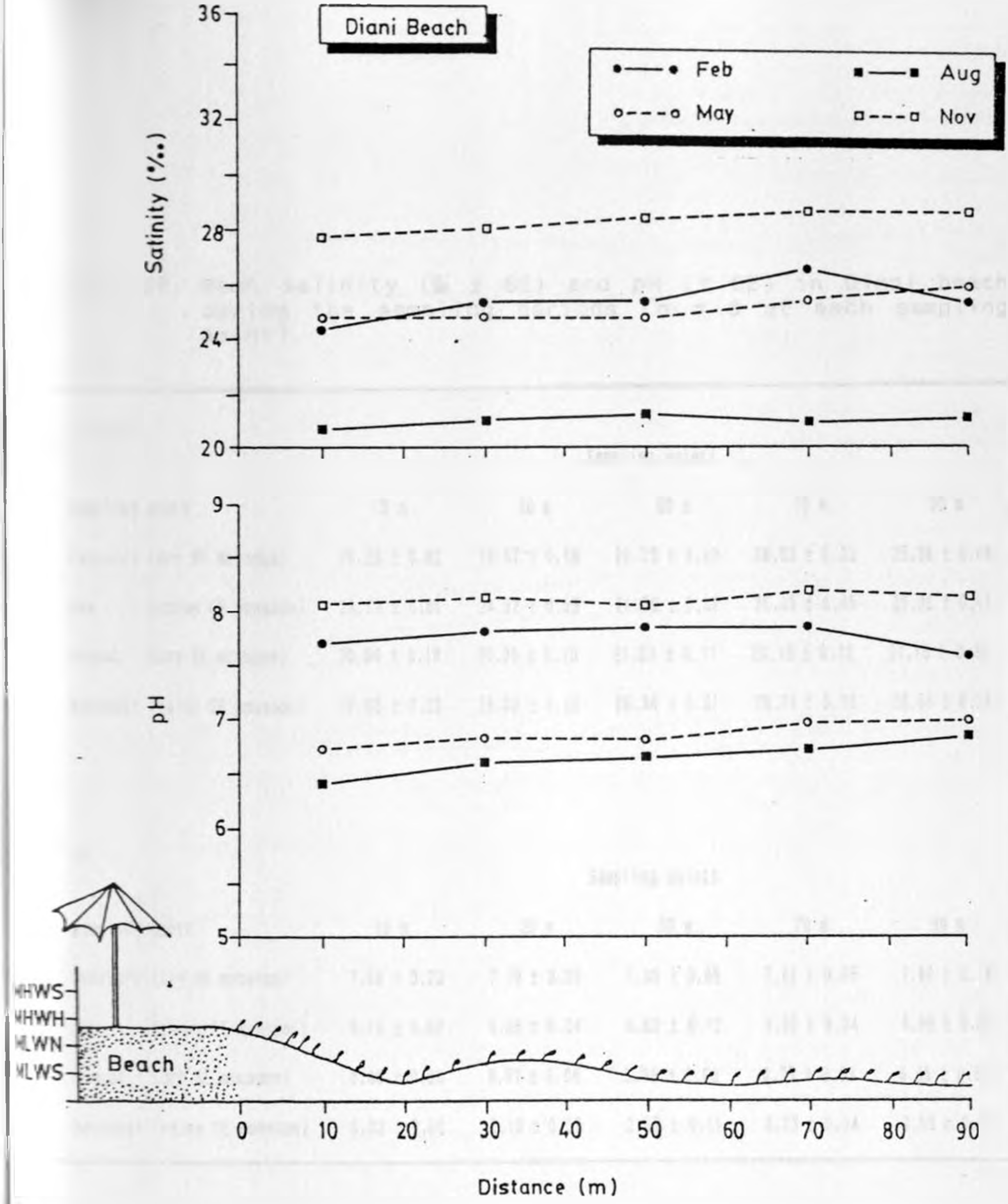


Fig. 24. Salinity and pH patterns in Diani Beach during the sampling period.

Table 39. Mean salinity (‰ ± SE) and pH (± SE) in Diani beach during the sampling periods (n = 8 at each sampling point).

SALINITY

Sampling month	Sampling points 10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	24.28 ± 0.82	25.47 ± 0.18	25.35 ± 0.49	26.53 ± 0.33	25.38 ± 0.46
May (rainy SE monsoon)	24.72 ± 0.61	24.92 ± 0.59	24.76 ± 0.62	25.35 ± 0.45	25.98 ± 0.41
August (dry SE monsoon)	20.64 ± 0.19	20.95 ± 0.18	21.24 ± 0.11	20.99 ± 0.22	21.15 ± 0.19
November (rainy SE monsoon)	27.65 ± 0.23	28.00 ± 0.30	28.34 ± 0.21	28.71 ± 0.16	28.56 ± 0.39

pH

Sampling month	Sampling points 10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	7.68 ± 0.23	7.76 ± 0.06	7.80 ± 0.05	7.82 ± 0.05	7.52 ± 0.14
May (rainy SE monsoon)	6.74 ± 0.07	6.86 ± 0.04	6.83 ± 0.12	6.92 ± 0.04	6.99 ± 0.06
August (dry SE monsoon)	6.40 ± 0.06	6.61 ± 0.05	6.66 ± 0.02	6.75 ± 0.03	6.88 ± 0.03
November (rainy SE monsoon)	8.02 ± 0.06	8.13 ± 0.07	8.05 ± 0.11	8.23 ± 0.04	8.19 ± 0.02

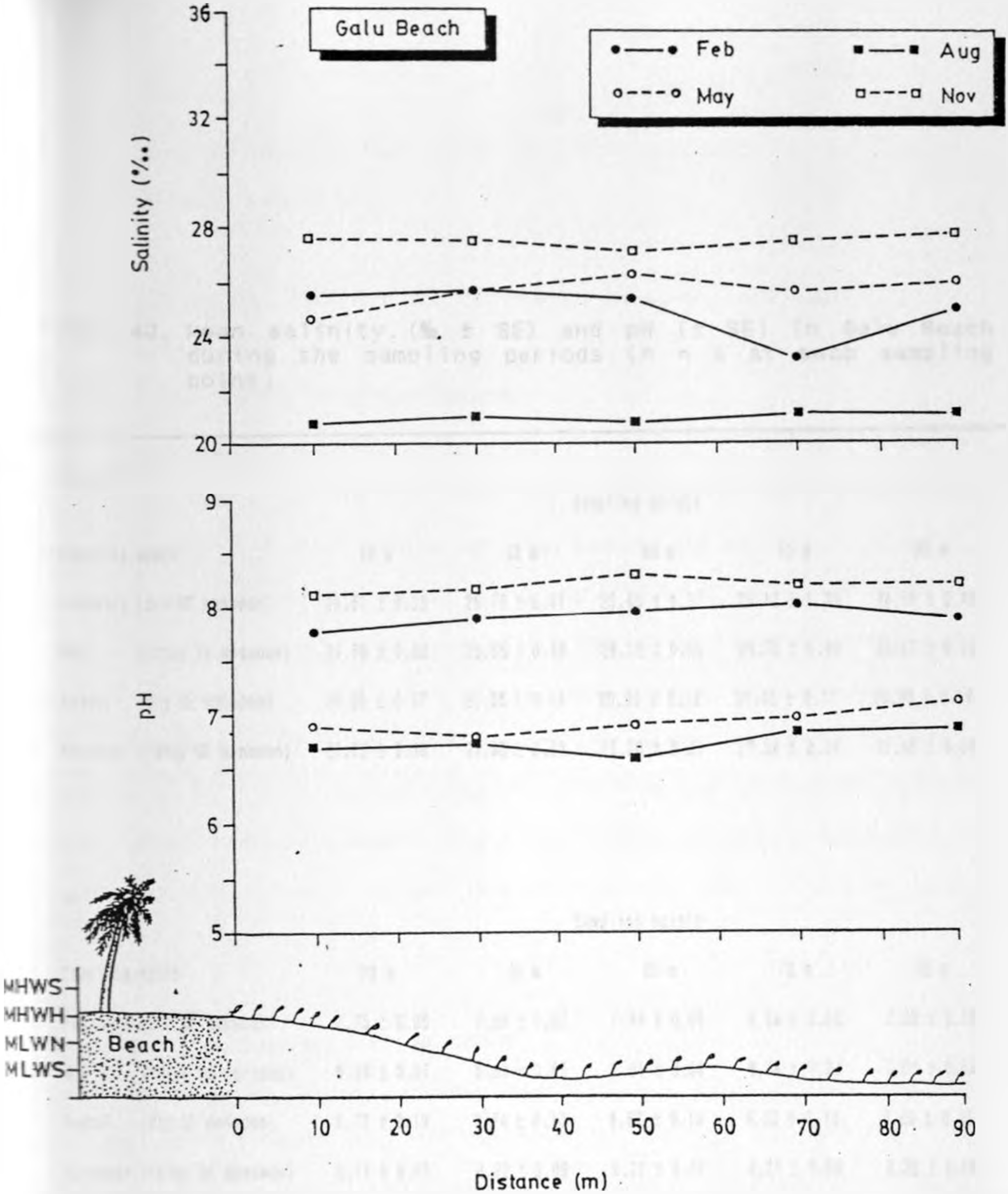


Fig. 25. Salinity and pH patterns in Galu Beach during the sampling period.

Table 40. Mean salinity (‰ ± SE) and pH (± SE) in Galu Beach during the sampling periods (n = 8 at each sampling point).

SALINITY

Sampling month	Sampling points				
	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	25.51 ± 0.39	25.76 ± 0.47	25.45 ± 0.37	23.13 ± 1.39	24.91 ± 0.46
May (rainy SE monsoon)	24.68 ± 0.62	25.65 ± 0.39	26.12 ± 0.28	25.70 ± 0.49	25.87 ± 0.59
August (dry SE monsoon)	20.85 ± 0.37	21.05 ± 0.14	20.92 ± 0.19	21.02 ± 0.17	20.39 ± 0.19
November (rainy SE monsoon)	27.73 ± 0.36	27.65 ± 0.22	27.20 ± 0.21	27.54 ± 0.34	27.68 ± 0.35

pH

Sampling month	Sampling points				
	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	7.75 ± 0.05	7.89 ± 0.07	7.94 ± 0.05	8.04 ± 0.08	7.88 ± 0.06
May (rainy SE monsoon)	6.99 ± 0.07	6.84 ± 0.05	6.91 ± 0.04	6.98 ± 0.04	7.03 ± 0.04
August (dry SE monsoon)	6.72 ± 0.19	6.74 ± 0.13	6.67 ± 0.10	6.83 ± 0.16	6.89 ± 0.21
November (rainy SE monsoon)	8.17 ± 0.05	8.22 ± 0.09	8.37 ± 0.07	8.27 ± 0.06	8.26 ± 0.09

the SE monsoon months had lower pH levels compared to the NE monsoon months (Table 40).

4.2.3 Seasonal pattern of nutrients in Diani and Galu Beaches

4.2.3.1 Nutrients in Diani Beach

There was a general seaward decrease in all the nutrient levels recorded in Diani during the sampling months (Fig. 26). There was a peak in the nitrate levels at the beach end of the transects during the wet SE monsoon month of May and the wet NE monsoon month of November (Table 41). The level of ammonium recorded was less than the 3 µg-at N/l (µM). Phosphate levels were high at beach end of the transects (3.51 ± 2.35 µM) in November, while the lowest levels of 0.48 ± 0.19 µM were recorded during the SE monsoon month of May (Fig. 26). In both Diani and Galu Beaches, records of nitrate in August were absent due to a mechanical breakdown that made analysis of the samples difficult.

4.2.3.2 Nutrients in Galu Beach

The nitrate levels in Galu Beach were not as high as those recorded in Diani at the beach end of the transects (Fig. 27), though the levels recorded in May were higher than the other months (Table 42). In February, there was no distinct seaward decrease in all the nutrient levels. Ammonium levels were comparable to those recorded in Diani Beach but the seaward decrease was not distinct. Phosphate levels were higher than the other nutrients in February and August

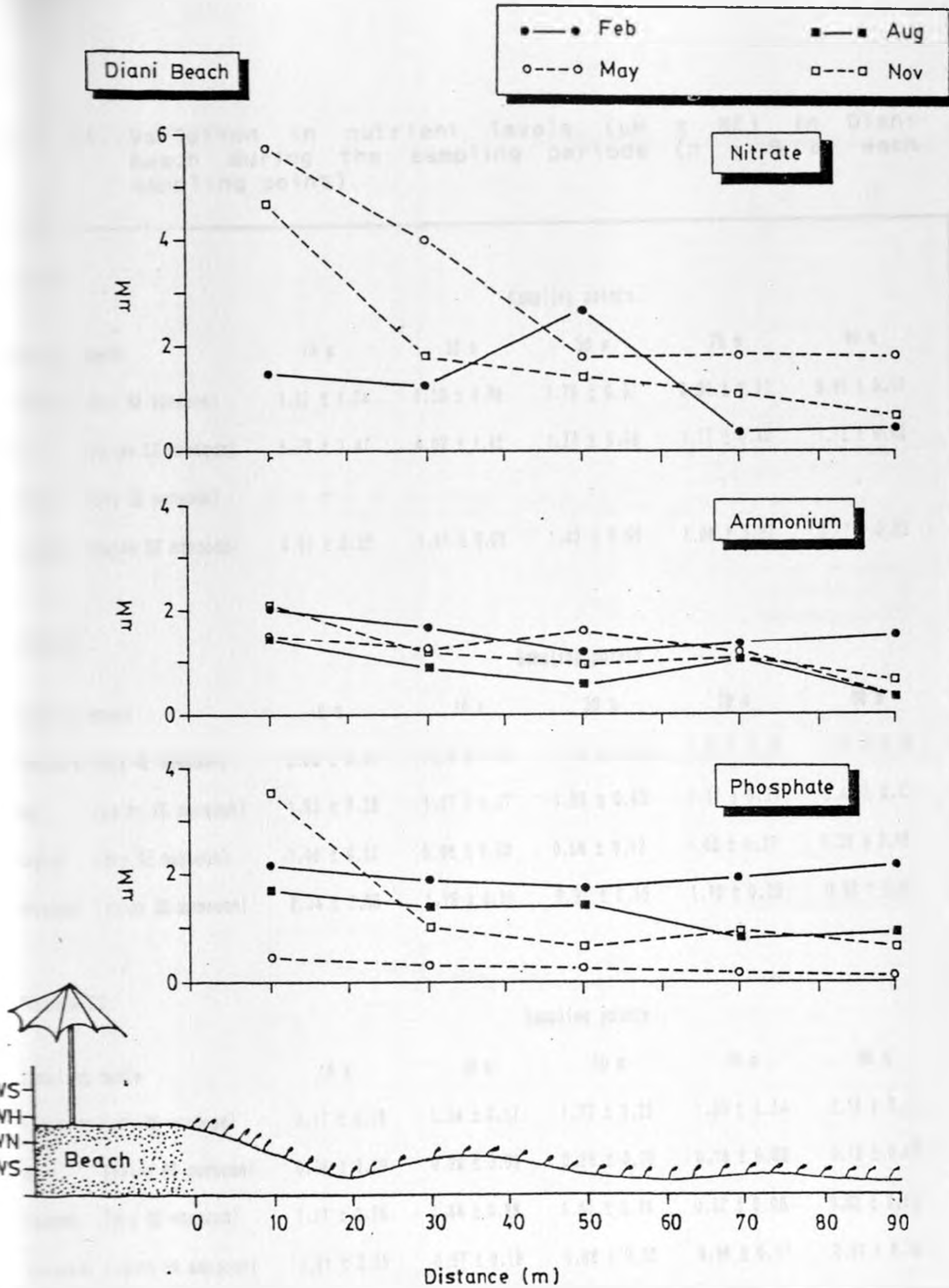


Fig. 26. Distribution of nutrients in Diani Beach.

Table 41. Variation in nutrient levels (µM ± SE) in Diani Beach during the sampling periods (n = 8 at each sampling point).

NITRATES

Sampling month	Sampling points				
	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	1.52 ± 1.04	1.33 ± 0.99	2.75 ± 0.67	0.37 ± 0.17	0.45 ± 0.11
May (rainy SE monsoon)	5.73 ± 1.47	4.02 ± 1.45	1.77 ± 0.49	1.77 ± 0.42	1.72 ± 0.43
August (dry SE monsoon)	-	-	-	-	-
November (rainy SE monsoon)	4.67 ± 0.92	1.91 ± 0.66	1.42 ± 0.55	1.08 ± 0.27	0.17 ± 0.23

AMMONIUM

Sampling month	Sampling points				
	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	2.03 ± 0.37	1.74 ± 0.29	1.19 ± 0.38	1.37 ± 0.39	1.48 ± 0.74
May (rainy SE monsoon)	1.53 ± 0.39	1.27 ± 0.37	1.59 ± 0.43	1.17 ± 0.31	0.48 ± 0.12
August (dry SE monsoon)	1.46 ± 0.37	0.98 ± 0.30	0.56 ± 0.12	1.08 ± 0.37	0.39 ± 0.19
November (rainy SE monsoon)	2.04 ± 0.68	1.19 ± 0.39	0.97 ± 0.15	1.10 ± 0.28	0.62 ± 0.14

PHOSPHATES

Sampling month	Sampling points				
	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	2.17 ± 0.15	1.94 ± 0.17	1.77 ± 0.23	1.89 ± 0.14	2.16 ± 0.28
May (rainy SE monsoon)	0.48 ± 0.19	0.28 ± 0.09	0.26 ± 0.70	0.16 ± 0.08	0.12 ± 0.05
August (dry SE monsoon)	1.71 ± 0.25	1.44 ± 0.29	1.47 ± 0.24	0.82 ± 0.08	0.92 ± 0.19
November (rainy SE monsoon)	3.51 ± 2.35	0.37 ± 0.19	0.66 ± 0.03	0.96 ± 0.17	0.61 ± 0.06

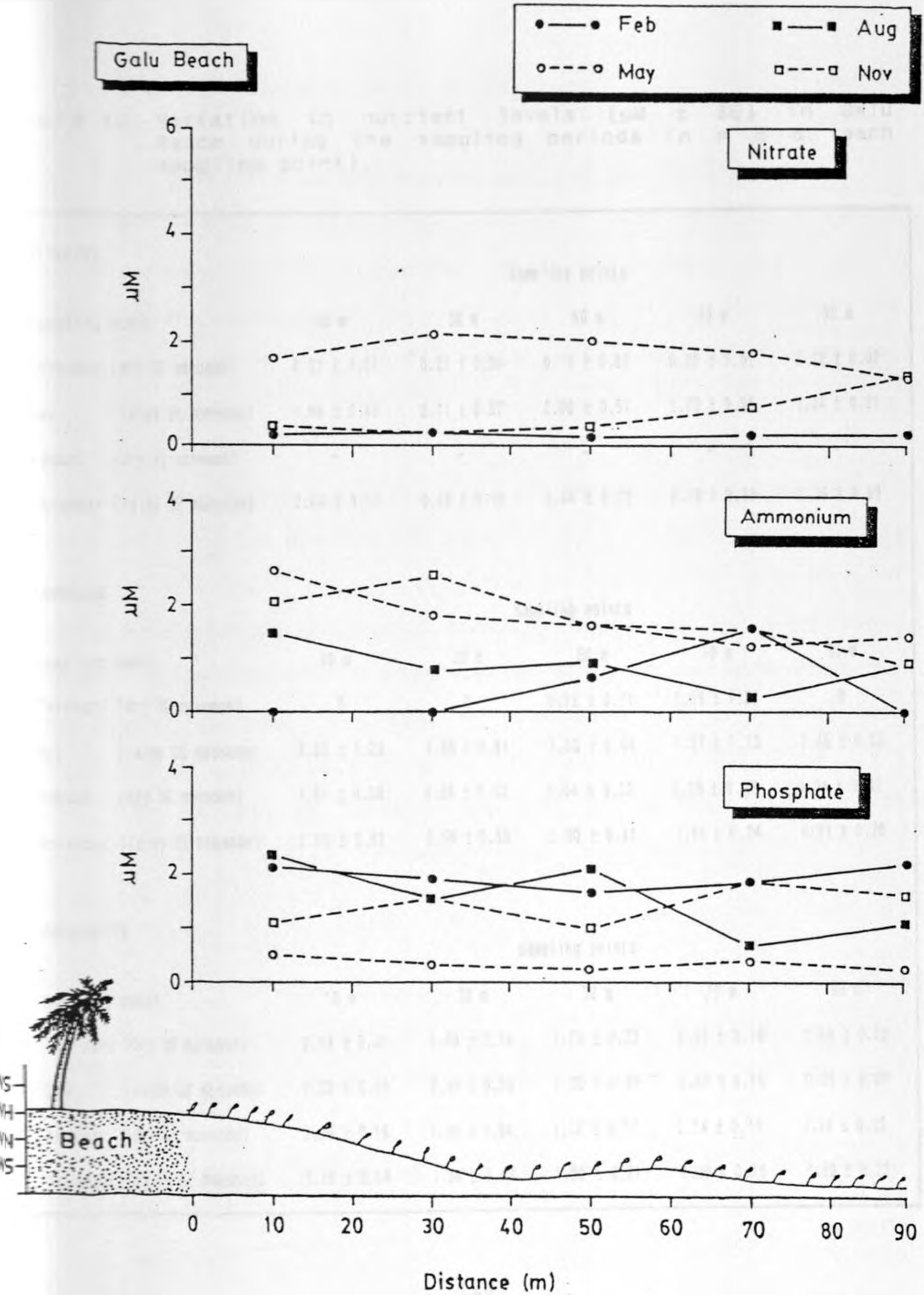


Fig. 27. Distribution of nutrients in Galu Beach.

Table 42. Variation in nutrient levels (µM ± SE) in Galu Beach during the sampling periods (n = 8 at each sampling point).

NITRATES

	Sampling points				
Sampling month	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	0.21 ± 0.01	0.25 ± 0.04	0.19 ± 0.02	0.22 ± 0.02	0.22 ± 0.02
May (rainy SE monsoon)	1.66 ± 0.43	2.11 ± 0.57	2.00 ± 0.51	1.79 ± 0.31	1.34 ± 0.31
August (dry SE monsoon)	-	-	-	-	-
November (rainy SE monsoon)	0.44 ± 0.17	0.26 ± 0.10	0.44 ± 0.12	0.78 ± 0.35	1.39 ± 0.69

AMMONIUM

	Sampling points				
Sampling month	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	0	0	0.72 ± 0.71	1.59 ± 1.31	0
May (rainy SE monsoon)	2.65 ± 1.23	1.83 ± 0.61	1.63 ± 0.44	1.27 ± 0.13	1.48 ± 0.33
August (dry SE monsoon)	1.51 ± 0.28	0.88 ± 0.42	1.04 ± 0.33	0.38 ± 0.22	0.94 ± 0.42
November (rainy SE monsoon)	2.06 ± 0.52	2.56 ± 0.58	1.60 ± 0.41	1.54 ± 0.24	0.91 ± 0.28

PHOSPHATES

	Sampling points				
Sampling month	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	2.13 ± 0.31	1.99 ± 0.14	1.75 ± 0.23	1.91 ± 0.18	2.06 ± 0.19
May (rainy SE monsoon)	0.52 ± 0.19	0.31 ± 0.09	0.20 ± 0.60	0.42 ± 0.15	0.25 ± 0.09
August (dry SE monsoon)	2.35 ± 0.19	1.64 ± 0.64	1.12 ± 0.77	0.74 ± 0.11	1.13 ± 0.22
November (rainy SE monsoon)	1.12 ± 0.14	1.56 ± 0.43	1.00 ± 0.21	1.90 ± 0.75	1.59 ± 0.23

(Table 42) while in May the level decreased.

4.2.3.3 Overall nutrient levels in Diani and Galu Beaches

The highest level of nitrate was recorded in May (rainy SE monsoon) in both Diani and Galu Beaches (Figs. 28 & 29). There was a significant difference in the nitrate concentration recorded in the two areas ($H = 4.57$, $p \leq 0.05$) though the seasonal variation was not significant.

In Diani Beach the highest levels of ammonium were recorded in February (Fig. 28) whereas the seasonal patterning of ammonium was distinct in Galu with peaks occurring during the rainy seasons of May and November (Fig. 29). However, there was no significant difference between the levels recorded in Diani and Galu or during the sampling months. The levels of phosphate were similar in both Diani and Galu Beaches with a decline recorded in May (Figs. 28 & 29). The difference between the two areas was found to be insignificant. However, the monthly variation was significant ($H = 22.46$, $p \leq 0.05$).

In this study, nutrient levels particularly phosphates and nitrates seemed to be affected by the tides. The overall phosphate levels decreased in May in both Diani and Galu Beaches (Fig 28 & 29) when the maximum spring tidal height was low whereas the levels of nitrate showed an increase during this period.

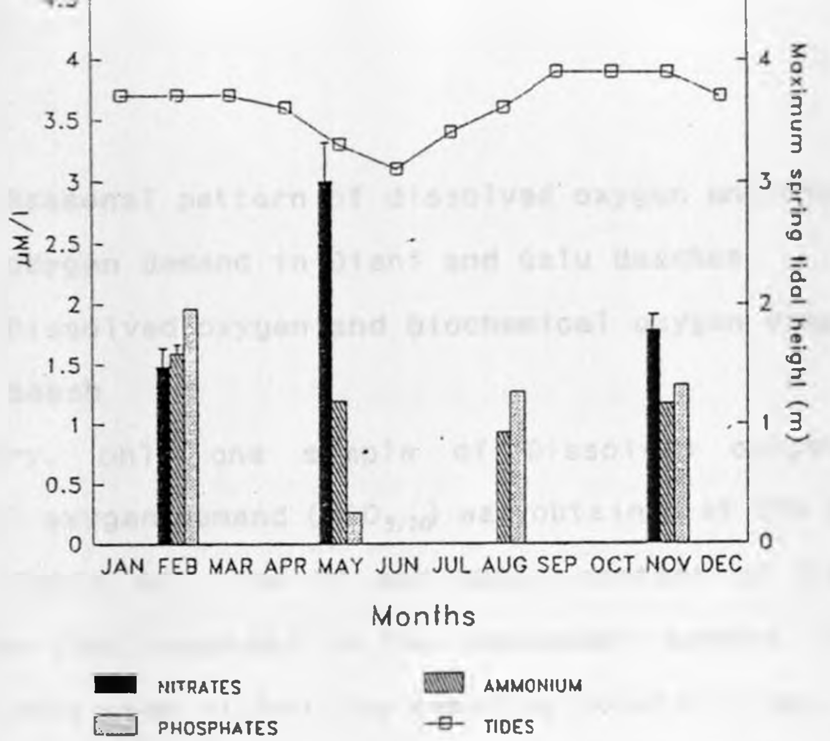


Fig. 28. Nutrient levels and the maximum spring tidal heights in Diani Beach (n = 40 in each month).

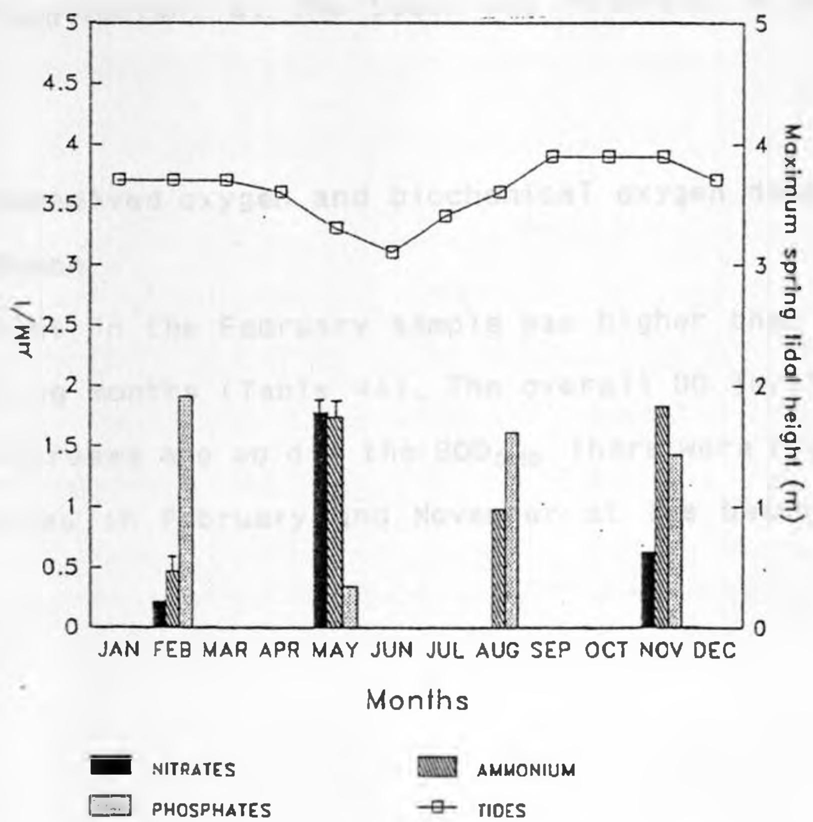


Fig. 29. Nutrient levels and the maximum spring tidal heights in Galu Beach (n = 40 in each month).

4.2.4 Seasonal pattern of dissolved oxygen and biochemical oxygen demand in Diani and Galu Beaches

4.2.4.1 Dissolved oxygen and biochemical oxygen demand in Diani Beach

In February, only one sample of Dissolved oxygen (DO) and Biochemical oxygen demand ($BOD_{5/20}$) was obtained at the start of the transect (Table 43). The DO and $BOD_{5/20}$ content of the water was higher than that recorded in the subsequent months. The DO level was relatively even within the sampling points in May, August and November. $BOD_{5/20}$ decreased seawards in the Diani Beach transects with higher levels recorded at the beach end of the transects during all sampling times apart from the month of August. The highest $BOD_{5/20}$ content at the beach was recorded in February and November.

4.2.4.2 Dissolved oxygen and biochemical oxygen demand in Galu Beach

The DO content in the February sample was higher than that of the other sampling months (Table 44). The overall DO levels exhibited a seaward increase and so did the $BOD_{5/20}$. There were high levels of $BOD_{5/20}$ recorded in February and November at the beach end of the transects.

Table 43. Mean dissolved oxygen and biochemical oxygen demand levels (mg O_2/l ± SE)in Diani Beach during the sampling months (n = 4 at each sampling point).

DISSOLVED OXYGEN

	Sampling points				
Sampling month	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	15.06 ± 1.73	-	-	-	-
May (rainy SE monsoon)	5.99 ± 0.32	-	6.17 ± 0.57	-	5.79 ± 0.41
August (dry SE monsoon)	6.06 ± 0.57	-	7.38 ± 0.62	-	7.13 ± 0.43
November (rainy SE monsoon)	6.89 ± 0.41	-	7.07 ± 0.42	-	6.72 ± 0.24

BIOCHEMICAL OXYGEN DEMAND

	Sampling points				
Sampling month	10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	4.48 ± 1.55	-	-	-	-
May (rainy SE monsoon)	1.83 ± 0.33	-	1.24 ± 0.21	-	0.99 ± 0.18
August (dry SE monsoon)	0.76 ± 0.17	-	0.88 ± 0.39	-	0.47 ± 0.19
November (rainy SE monsoon)	2.62 ± 0.33	-	1.04 ± 0.20	-	0.32 ± 0.06

Table 44. Mean dissolved oxygen and biochemical oxygen demand levels (mg $O_2/l \pm SE$) in Galu Beach during the sampling months (n = 4 at each sampling point).

DISSOLVED OXYGEN

Sampling month	Sampling points 10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	11.30 ± 1.19	-	-	-	-
May (rainy SE monsoon)	5.69 ± 0.96	-	6.87 ± 1.14	-	7.25 ± 0.82
August (dry SE monsoon)	6.33 ± 0.61	-	6.95 ± 0.56	-	7.76 ± 0.74
November (rainy SE monsoon)	7.46 ± 0.99	-	8.25 ± 0.84	-	8.89 ± 0.72

BIOCHEMICAL OXYGEN DEMAND

Sampling month	Sampling points 10 m	30 m	50 m	70 m	90 m
February (dry NE monsoon)	3.89 ± 1.01	-	-	-	-
May (rainy SE monsoon)	1.09 ± 0.14	-	1.48 ± 0.45	-	1.77 ± 0.26
August (dry SE monsoon)	2.29 ± 0.13	-	0.93 ± 0.19	-	2.00 ± 0.16
November (rainy SE monsoon)	3.55 ± 0.59	-	2.83 ± 0.49	-	2.48 ± 0.41

4.2.4.3 Overall levels of dissolved oxygen and biochemical oxygen demand in Diani and Galu Beaches

There were similar levels of dissolved oxygen (DO) in Diani and Galu Beaches with the highest levels recorded in February (The dry NE monsoon) (Fig. 30). In Galu Beach the $BOD_{5/20}$ was slightly higher than that recorded in Diani Beach (Fig. 31) though it was statistically insignificant. However, the seasonal variation was found to be significant ($H = 11.35$, $p \leq 0.05$).

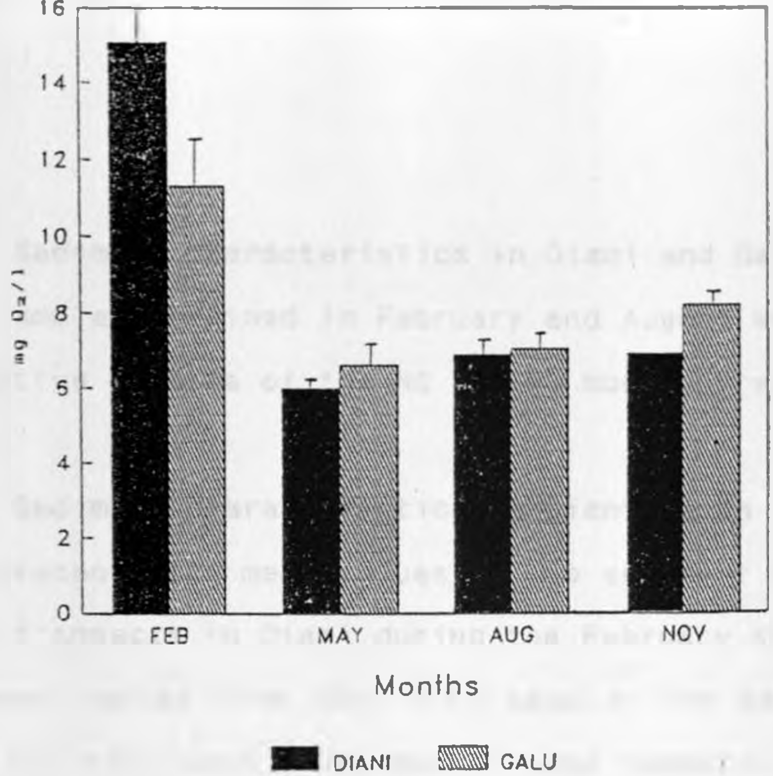


Fig. 30. Levels of dissolved oxygen in Diani and Galu Beaches (n = 20 in each month).

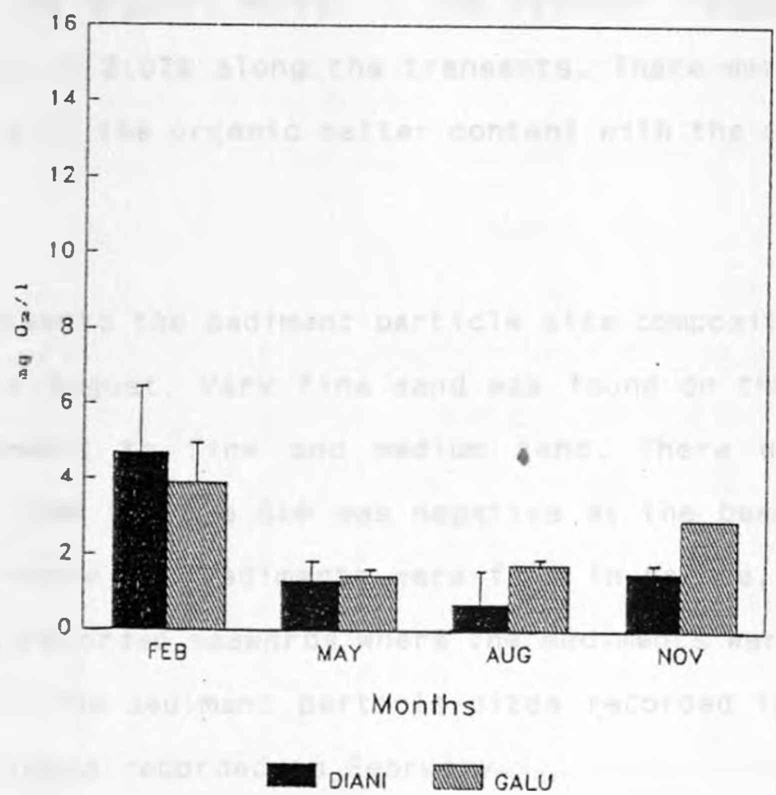


Fig. 31. Biochemical oxygen demand in Diani and Galu Beaches (n = 20 in each month).

4.2.5 Sediment characteristics in Diani and Galu Beaches

Sediment samples obtained in February and August were analyzed as representative samples of the NE and SE monsoon respectively.

4.2.5.1 Sediment characteristics in Diani Beach

Table 45 presents the mean values of the sediment characteristics along the transects in Diani during the February sampling period. The sediment varied from very fine sand at the beach end of the transects to fine sand and medium sand seawards. There was an increase in sediment dispersion (QDΦ) from the beach end of the transects towards the sea. Skewness (SkΦ) was negative in the upper beach areas in Diani and it became positive in the seaward sediments. The organic matter in the sediment ranged from 8.01 ± 2.4% to 10.71 ± 2.07% along the transects. There were no distinct fluctuations in the organic matter content with the different soil types.

Table 46 presents the sediment particle size composition along the transects in August. Very fine sand was found on the beach. This changed seaward to fine and medium sand. There was a seaward increase in QDΦ and the SkΦ was negative at the beach end of the transects, where the sediments were fine in nature, but positive values were recorded seawards where the sediments were composed of medium sand. The sediment particle sizes recorded in August were similar to those recorded in February.

Table 45. Sediment characteristics (± SE) along the transects in Diani Beach in February.

	Sampling points				
	10 m	30 m	50 m	70 m	90 m
Median particle size (MdP)	3.05 ± 0.22	2.95 ± 0.14	2.16 ± 0.29	1.96 ± 0.22	1.83 ± 0.41
Median particle size (mm)	0.105 - 0.125	0.125 - 0.149	0.21 - 0.25	0.25 - 0.295	0.25 - 0.295
Texture	very fine sand	fine sand	fine sand	medium sand	medium sand
Quartile deviation (QdP)	0.83 ± 0.12	1.03 ± 0.08	1.17 ± 0.13	1.18 ± 0.09	0.75 ± 0.01
Skewness (SkP)	- 0.23 ± 0.05	- 0.30 ± 0.07	+ 0.09 ± 0.19	+ 0.01 ± 0.09	+ 0.06 ± 0.11
Organic matter content (%)	8.12 ± 0.85	10.01 ± 1.87	8.95 ± 0.61	10.71 ± 0.78	8.01 ± 1.74
Sample size (n)	8	8	7	7	8

Table 46. Sediment characteristics (± SE) along the transects in Diani Beach in August.

	Sampling points				
	10 m	30 m	50 m	70 m	90 m
Median particle size (MdP)	3.01 ± 0.10	2.66 ± 0.12	2.13 ± 0.31	1.43 ± 0.25	1.48 ± 0.31
Median particle size (mm)	0.105 - 0.125	0.149 - 0.177	0.21 - 0.25	0.35 - 0.42	0.35 - 0.4
Texture	very fine sand	fine sand	fine sand	medium sand	medium sand
Quartile deviation (QdP)	0.57 ± 0.08	0.82 ± 0.12	1.27 ± 0.39	0.97 ± 0.05	0.85 ± 0.09
Skewness (SkP)	- 0.18 ± 0.06	- 0.19 ± 0.03	- 0.24 ± 0.13	+ 0.08 ± 0.01	+ 0.15 ± 0.04
Organic matter content (%)	10.51 ± 1.20	9.90 ± 1.89	8.99 ± 1.86	13.11 ± 0.92	22.40 ± 8.33
Sample size (n)	8	8	5	5	5

There was a seaward increase in organic matter from 10.51 ± 1.17% at the beach to 22.39 ± 7.07% at the seaward end of the transects. The organic matter was higher particularly at the end of the transects.

4.2.5.2 Sediment characteristics in Galu Beach

In February, very fine sand was found at the beach end of the Galu Beach transects (Table 47). This changed to fine sand at the end of the transects. The sediment dispersion (QDΦ) decreased seawards while the skewness (SkΦ) changed from being positive at the beach end of the transects to negative values at the seaward end. The organic matter content of the sediment ranged from 10.84 ± 0.99 % to 13.14 ± 1.94 %.

Table 48 presents the sediment characteristics in Galu Beach in August. The sediment was composed of very fine sand at the first three sampling points. This changed to fine sand then to very fine sand at the seaward end of the transects. The sediment dispersion (QDΦ) increased seawards while the sediment was negatively skewed at all the sampling points confirming the fine nature of the sediments. The change in sediment characteristics from February to August indicates the shifting nature of the Galu substrate.

Table 47. Sediment characteristics (± SE) along the transects in Galu Beach in February.

	Sampling points				
	10 m	30 m	50 m	70 m	90 m
Median particle size (MdΦ)	3.65 ± 0.11	3.26 ± 0.22	2.88 ± 0.39	2.96 ± 0.17	2.99 ± 0.28
Median particle size (mm)	0.074 - 0.088	0.105 - 0.125	0.125 - 0.149	0.125 - 0.149	0.125 - 0.140
Texture	very fine sand	very fine sand	fine sand	fine sand	fine sand
Quartile deviation (QdΦ)	1.52 ± 0.59	1.43 ± 0.18	1.25 ± 0.14	0.99 ± 0.14	0.79 ± 0.08
Skewness (SkΦ)	+ 0.86 ± 0.70	+ 0.39 ± 0.22	+ 0.01 ± 0.28	- 0.62 ± 0.16	- 0.28 ± 0.18
Organic matter content (%)	11.61 ± 1.45	13.14 ± 1.94	10.84 ± 0.99	11.69 ± 0.03	11.05 ± 1.69
Sample size (n)	4	8	8	7	8

Table 48. Sediment characteristics (± SE) along the transects in Galu Beach in August.

	Sampling points				
	10 m	30 m	50 m	70 m	90 m
Median particle size (MdΦ)	3.53 ± 0.09	3.27 ± 0.22	3.30 ± 0.01	2.63 ± 0.15	3.15 ± 0.02
Median particle size (mm)	0.074 - 0.088	0.088 - 0.105	0.088 - 0.105	0.149 - 0.174	0.105 - 0.125
Texture	very fine sand	very fine sand	very fine sand	fine sand	fine sand
Quartile deviation (QdΦ)	0.81 ± 0.17	0.88 ± 0.17	1.40 ± 0.04	1.23 ± 0.07	1.33 ± 0.03
Skewness (SkΦ)	- 0.26 ± 0.12	- 0.24 ± 0.10	- 0.90 ± 0.21	- 0.38 ± 0.09	- 0.33 ± 0.07
Organic matter content (%)	13.29 ± 1.61	16.09 ± 1.82	13.79 ± 1.79	16.28 ± 1.07	11.34 ± 1.80
Sample size (n)	7	7	6	7	8

The organic matter content of the sediment was 13.29 ± 1.51 % at the start of the transects. There was an increase in the mid sections of the transects then a decrease at the end of the transects.

4.2.6 Hotel bed occupancy

The hotel data of monthly bed occupancy was not forthcoming. However the trend compiled from two hotels in the Diani area can be assumed to be the trend in the other hotels. The high season is from December to March and the sampling month of February is in this period. The mean number of visitors in Diani and Galu Beach hotels (estimated from the data of 2 hotels in Diani) and extrapolated to 18 hotels in Diani Beach and 4 hotels in Galu Beach is shown in table 43.

Table 49. Estimated visitors in Diani and Galu Beaches during the 1993 sampling period.

MONTH	DIANI	GALU
FEB (dry NE monsoon)	1226.70	272.60
MAY (wet SE monsoon)	744.48	165.44
AUG (dry SE monsoon)	734.40	163.20
NOV (wet NE monsoon)	1377.90	306.20

CHAPTER FIVE

DISCUSSION AND CONCLUSIONS

5.1 Flora

5.1.1 Seagrasses

In both Diani and Galu Beach, the seaward increase in seagrass biomass observed along all the transects can be attributed to the size of the species. The smaller species like *Halophila* spp. and *Halodule* spp. contributed to the low biomass levels at the beach end of the transects. Larger and bulkier species such as *S. isoetifolium* and *T. ciliatum* contributed to the higher biomass recorded seawards.

The seagrass distribution (zonation) in both Diani and Galu Beach was similar to that described by den Hartog (1977) and Coppejans *et al.* (1992) where the finer (smaller) parvozosterids (*Halodule* spp.) and halophilids (*Halophila* spp.) inhabit the upper sections of the beach. The coarser magnozosterids (*Thalassia* sp. and *Cymodocea* spp.) and amphibolids (*Thalassodendron* sp.) were found to colonize the seaward sections of the transects.

The mixed species composition found in Diani and Galu has also been documented for Mombasa Harbour by Aleem (1984) and in the Flores Sea, Indonesia by Nienhuis *et al.* (1989). In these areas monospecific beds are rare. Instead a complex vegetation occurs where a blend of seven or eight species grow together in a mixed vegetation community (Nienhuis, *op. cit.*). The most prominent species in Diani were *T. ciliatum* and *T. hemprichii* as has been documented for several parts of the Kenyan coast (Isaac & Isaac, 1968; Njuguna, 1985). In Galu, *T. ciliatum* was replaced by *H. wrightii* in dominance.

Angiosperms (seagrasses) were found to dominate in June and July with high biomasses recorded in August by Moorjani (1977). This can be seen in Diani where there was a slight increase in biomass from May to August. However, in Galu there was an overall decline in August instead of an increase. In the assessment of seagrass communities in Tanzania, Semesi (1988) found fluctuations in seagrass production from year to year due to severe wave action, shifting sand, pollution and the balance between sedimentation and erosion. Any one of these factors or a combination of several could have been the cause of the fluctuations in the seagrass biomass estimates made during this study.

According to the categorization of nutrient responses by flora produced by Harlin and Thorne-Miller (1981) marine vascular plants (seagrasses) predominate in Diani Beach, which is the area of concern due to the high beach hotel concentration. This indicates that the nutrient levels in Diani have not reached levels that would lead to the dominance of macroscopic algae or phytoplankton.

Work done in Florida, indicated that *Thalassia testudinum* typifies an oligotrophic species while *Halodule wrightii* is found in eutrophic areas (Lapointe *et al.*, 1994). The presence of several seagrass species in Diani and the lack of dominance of *H. wrightii* indicates that Diani has not experienced the shift in seagrass species that is typical of eutrophic areas. In Galu Beach, *H. wrightii* is abundant however its association with other seagrass species indicates the influence of other physico-chemical factors such as sediment grain size rather than eutrophication.

The significant positive relationship between seagrasses and sediment size in Diani Beach can be explained by the fact that the sediment composition in Diani Beach covered a wider spectrum (ranging from very fine to fine and medium sands). The sediments in Galu Beach belonged to the very fine and fine sand categories thus making hard to discern any relationships. This seagrass-sediment relationship indicates that the seagrass zonation pattern along the transects is related to the sediment type where the fine beach sediment at the start of the transects supports small pioneer species (eg. *Halodule* spp. and *Halophila* spp.) while the coarser sediment along the transects is colonized by larger seagrass species. This was particularly evident in Diani Beach where the community climaxed with *T. ciliatum* at the end of the transects in sediment composed of medium sand. In Galu Beach, the low occurrence of *T. ciliatum* in only two of the four transects and the dominance of *H. wrightii* confirms the fine nature of the sediment in Galu Beach. This relates well with the work by Coppejans *et al.* (1992)

on the zonation of the seagrass species. *H. ovalis* and *H. wrightii* formed the pioneer vegetation on the upper intertidal zone of fine sediments. This was followed by a mixture of *T. hemprichii, C. rotundata, C. serrulata* and *S. isoetifolium*. Monospecific beds of *T. ciliatum* were evident at the end of the transects.

5.1.2 Algae

Transects D_4 and G_4 in Diani and Galu Beach respectively had a rock platform at the start of the transects from 0 to 20 m from the beach. Seagrasses were found where sand filled crevices in the rock platform. The areas that lacked a seagrass cover provided a substratum for the attachment of algae hence leading to the wider variety of algal species found in these two transects. A similar situation was reported in Shark Bay, Western Australia (Kendrick, 1988) where algae dominated in rocky outcrops not colonized by seagrasses. In Diani and Galu Beaches the remaining transects had a sandy substratum that was colonized by seagrass species.

The distribution of the algae groups along the Diani Beach transects conformed to the effect of light as documented by Wood (1987). The Chlorophyta were found on the upper beach in areas of shallow water whereas the Rhodophyta and Phaeophyta were found in deeper areas as they are able to utilize sections of the light spectrum not used by the green algae. This distribution pattern was not as distinct in Galu Beach.

The increase in the number of algal groups during the August sampling period in Diani Beach conformed to the presence of high floral diversity reported by Issac and Issac (1968) during the SE monsoon period when the low spring tides occur during the night. At night, desiccation stress is less severe and temperatures are low. These conditions are favorable for benthic algae (McClanahan, 1988). During the NE monsoon, the lowest spring tides are during the day where high air temperatures cause plant stress and reduce the diversity of benthic algae (Isaac & Isaac, 1968).

The algae group Rhodophyta (red algae) dominated in the samples as was reported by Moorjani (1977). This was followed by Chlorophyata (green algae), Phaeophyta (brown algae) and Cyanophyta (blue-green algae) respectively. Moorjani (*op. cit.*) reported Chlorophyta to be abundant at the end of the NE monsoon. During this period the aerial and water temperatures are higher and the low spring tides occur during the day. The high temperatures were found to favor the growth of Chlorophyta and Cyanophyta which were highest in February and March. Phaeophyta were abundant at the end of the SE monsoon (September to October) when the aerial and water temperatures are low and the low spring tides occur at night. Rhodophytes were found to be abundant throughout the year with a general abundance during the SE monsoon months of May to June. However, some species were found to be more abundant at the end of the NE monsoon and others at the end of the SE monsoon period.

In Diani Beach, the Chlorophyta and Cyanophyta were present during the NE and SE monsoon sampling periods while the red algae were present throughout the year with the highest biomass recorded during the SE monsoon month of August. The Phaeophyta were abundant during the SE monsoon month of May instead of at the end of the SE monsoon period. Studies in Florida Keys by Lapointe *et al.* (1994) show that macroalgal epiphytes comprising of *Laurencia* sp. and *Dictyota* sp. are abundant in seagrass beds affected by eutrophication and threaten the survival of seagrasses by light limitation. The abundance of brown algae in Diani Beach compared to Galu Beach is due to *Dictyota* sp. and could be attributed to eutrophication effects or high growth from March to May which is typical of this species.

In Galu Beach, the Chlorophyta and Cyanophyta conformed to the NE monsoon abundance pattern established by Moorjani (1977). However, the Rhodophyta were more abundant during the NE months of February and November instead of the SE monsoon period. According to Wamukoya (1987), the density of rhodophytes does not change much throughout the year as they grow in the mid tide and low tide zones. Hence, the rhodophytes are not subjected to intense temperature and salinity fluctuations. Instead, they are subjected to tidal effects in which case waves dislodge some of the species. This could be the case in Galu, where the highest biomass of red algae (Rhodophyta) was recorded during the NE monsoon sampling months which is a period of low wave action in comparison to the SE monsoon period. Similarly, during the May sampling period, the low biomass of green calcareous algae at the end of the transects in Diani Beach and Galu Beach could be indicative of the turbulence and high wave action characteristic of the SE monsoon.

As this was not a monthly study, distinct seasonality patterns of the different algal groups could not be deciphered. Excessive growth of green seaweeds (algae) in response to sewage effluents is becoming a common phenomenon (Lobban & Harrison, 1994). If eutrophication was a critical problem in Diani Beach then the biomass of green algae would have been much greater and more persistent during the seasons than what was recorded during this study.

5.1.3 Seasonal distribution of *T. ciliatum* and attached epiphytes

The epiphytic algae found in this study showed a preference for the stems of *T. ciliatum* due to the rough surface that makes stems suitable for the attachment of algal spores (Semesi, 1988). Leaves are easily shed off thus making stems the preferred site of attachment. In this study and in the study conducted by Semesi (*op. cit.*), there was a higher biomass of epiphytic algae in August than in the other months.

In studies by Kendrick *et al.* (1988) on the seagrass *Amphibolis* *antartica* (Labill.) Sonder & Aschers the epiphytic community was composed of Phaeophyta and Chlorophyta algal groups which may also occur on the substratum. However, where space on the substratum is limited the seagrasses provide a stable and suitable surface for colonization. Majority of the Rhodophytes on *A. antartica* were epiphytic and this can be seen in the species distribution on the stems of *T. ciliatum* in this study.

The biomass of *T. ciliatum* was higher in Diani hence leading to a higher epiphytic load compared to Galu Beach where few *T. ciliatum* plants meant that there was a smaller area for attachment. Thus the epiphtyic load was due to the presence of an attachment substratum rather than due to the effects of eutrophication.

5.2 Fauna

5.2.1 Epibenthic fauna

Benthic communities experience increased mortality or migrate during the rainy monsoons to escape sediment erosion and low salinities (Alongi, 1990). This explains the low abundance of epibenthic fauna recorded during the rainy SE monsoon month of May in Diani Beach. However, the higher number of animals recorded in Galu Beach during the same period could be due to the prevalence of less turbulent conditions compared to Diani Beach . Hence, the is the possibility that fewer animals were dislodged and killed in Galu Beach.

Molluscan epifauna in Diani Beach were restricted to the upper beach areas at the start of the transects whereas in Galu there was a more even spread of the molluscs throughout the transects. The molluscs seen were gastropoda while bivalves were absent among the molluscan epifauna in the two study areas. Similarly, Taylor and Lewis (1970) reported the rarity of bivalves in seagrass beds of Mahé, Seychelles. In Galu Beach, *Cyprea tigris* was seen among the seagrass leaves indicating the absence of over collection tendencies compared to Diani Beach where no *C. tigris* was encountered during the study period.

Yannik (1976) reports that few gastropods are found on flat, bare dead coral or in the presence of dense sea urchin populations. In Diani Beach, sea urchins (Echinoidea) were abundant after the first sampling site along the transects hence restricting the gastropod fauna to the upper beach areas where the sea urchins were notably absent. In Galu, the sea urchin population was not as high and the gastropods were not restricted to the beach end of the transects.

Kikuchi & Pares (1988) reported a high abundance and diversity of gastropods in *T. ciliatum* beds compared to the shallower *Cymodocea* beds along the Eastern African coast. However, in this study, gastropods were rare at the end of the transects which were areas of monospecific *T. ciliatum* beds particularly in Diani Beach. This could be due to the effects of turbulence or the presence of Echinodea in these areas that restricts the presence of gastropods.

The Echinoderm fauna was marked by the presence of the group Echinoidea (sea urchins) whose numbers were higher than the other Echinodermata. The sea urchins were more numerous in Diani Beach. McClanahan (1987) reported that in the dominance of *E. mathaei* other echinoid species such as *Diadema* spp. are rare. This was confirmed in Galu Beach where low numbers of *E. mathaei* were found along with *Diadema setosum* and *D. savignii*. Studies by Muthiga and McClanahan (1987) recorded upto 14.1 ± 1.7 individuals/m^2 of *E. mathaei* in the inner reef areas of Diani. Grey (1990) recorded 14.2 individuals/m^2 with a range of 2 - 37 individuals/m^2 in 40 - 60 % seagrass areas. These seagrass areas were similar to the areas in which the transects for this study were based. However, she found a preference for rubble where 24.5 individuals/m^2 of *E. mathaei* were found. The number of *E. mathaei* recorded in this study were not as high as those recorded by Grey (1990) and this could be attributed to the different methods of estimation used. However, the sea urchins were still aggregated in the seagrass areas possibly due to protection from wave action and predation.

The Asteroidea (starfish) were also more prevalent in Diani Beach than in Galu Beach inspite of the higher collectors pressure in Diani. The Asteroidea were found in rocky areas especially at the seaward end of the transects in Diani. Rocky areas at the last sampling point seawards were not common in Galu. Hence the lack of an adequate habitat in Galu seems to influence the abundance of the Asteroidea.

The differences in the distribution of animal communities in the Diani and Galu seagrass beds may also be due the host plants and seagrass growth forms as well as physico-chemical factors such as salinity, temperature and water movement. These factors closely interact with each other making it difficult to attribute the most of the patterns seen in the animal communities to any of them (Kikuchi & Peres, 1988).

5.2.2 Infauna

Unlike the work done in Mahé by Taylor and Lewis (1970), where bivalves were found to dominate the molluscan infauna, in this study there was a combination of gastropods and bivalves with the gastropods dominating in number in both Diani and Galu Beach areas throughout the sampling period. The molluscans enumerated were juveniles of several unidentified species.

The decline in infaunal numbers in May in both Diani and Galu Beach is due to the turbulence of the SE monsoon period. Most meiobenthic communities suffer from increased mortality during the rainy monsoons however rapid recovery is the norm due to the high level of resilience of this community (Alongi, 1990). Macrobenthos (infauna) monitored during this study showed rapid recovery. However, this does not mean the return of all the taxa to the premonsoon community structure as can be seen by the lack of reoccurrence of the sipunculids in Diani Beach after they disappeared in May.

Infaunal densities and composition have been found to vary over all time scales from day, weeks, months to years therefore what has been interpreted as a seasonal change may in fact be a daily change. Replicate plots within small locations have shown differences attributed to localized water movement, food supply, oxygen levels, pollutants and predators (Morrisey, *et al.*, 1992). All these factors act on small spatial scales and can be the cause of the large variability found in the infauna samples during the study.

There was no discernable pattern of correlation of infauna and other biotic and physico-chemical factors. As reported by Bloom (1983) some correlations were registered but the causal significance of these was questionable. This indicates that breeding patterns, recruitment and seasonal succession of species have a greater influence on the infauna than the factors analyzed during this study. Other indirect factors such as water movement, turbulence and suspended load may act together to represent the sedimentary environment thus making it difficult to attribute the infaunal densities to one or more specific factors.

5.3 Physico-chemical parameters

The high water temperatures recorded during the study period, were the result of exposure during the low spring tides thus causing water in the pools to heat up rapidly. The overall decline in air and water temperatures seawards indicates the oceanic influence. The air over the oceanic mass is cooler than the air that is in the beach area thus leading to a decline in air temperatures seawards. The low water and air temperatures recorded during the SE monsoon in both Diani and Galu Beach were characteristic of the SE monsoon where high wind speeds, increased cloud cover, fewer sunshine hours and a reduction in radiation prevails (McClanahan, 1988) and these variables were reversed during the NE monsoon.

The salinity of inshore waters is determined by the salinity of oceanic water entering the lagoons and creeks by tides, evaporation and freshwater run-off from tributary catchment areas (Norconsult, 1975). There was a seaward increase in salinity in Diani and Galu Beaches indicating the seaward mixing with oceanic waters in the area. However, the salinities recorded in both Diani and Galu Beach were lower than the normal level of 35‰ for seawater. This indicates the seepage of freshwater into these lagoon areas during the low tide periods. Ruwa and Polk (1986) reported similar underground seepage in Kanamai where the salinity is normal at high tide but drops to 24 - 25‰ during the low tide. In the study areas, springs of bubbling water were obvious along the beach ends of the transects during the low spring tide period when sampling was undertaken.

The low salinities of the SE monsoon season (May and August) compared to the NE monsoon (February and November) in Diani and

Galu Beach are the result of high rainfall discharge and run-off from the land into the sea. Although May was not a high rainfall month in Diani, as in the previous years, the low salinity can be attributed to run-off from upland areas. During the NE monsoon, a combination of high insolation, with an evaporative effect on lagoonal pools, and low rainfall discharge could be the cause of the higher salinities recorded during the NE monsoon sampling periods of February and November. The salinity recorded in August was lower than the previous months. This could be attributed to continued rainfall run-off though the highest rainfall in this area was recorded in June, a month before the August sampling period.

The pH levels recorded during the NE monsoon months especially in November were close to the normal seawater level of 8.0 reported by Norconsult (1975). The levels recorded in May and August were lower than the norm and could be attributed to the effect of run-off from rainfall.

The overall nitrate levels in the two areas did not exceed 5 µg at N/l (µM) recorded in the waters of the Indian ocean by Smith and Codisporti (1980). The level recorded in Diani Beach in May was similar to 2.75 µg at N/l (µM) recorded by Kazungu (1989) in the open waters of Tudor Creek during the rainy season. The level of ammonium recorded was less than 3 µM. Phosphate levels in Diani and Galu Beaches exceeded the normal seawater levels of 0.5 - 1.0 µg at P/l (µM) reported by Spenser (1975) for open oceanic waters in all the sampling months apart from May.

Nitrates and ammonium are the principal sources of fixed nitrogen for aquatic plants and this has been shown by the high affinities of phytoplankton, macroalgae, and vascular plants for inorganic nitrogen species in experimental setups (Ryther & Dunstan, 1971). However, tropical areas contain low phosphate levels hence it is thought that phosphates are held close within the biomass and recycled within the ecosystem (Furnas, 1992). In this study, the overall low levels of nitrates in comparison to the normal seawater levels of the Indian Ocean indicate the uptake by the seagrasses and the algae. However, phosphates were in excess of the normal levels indicating that the phosphate held within the ecosystem is adequate for its maintenance.

The spring tides and extreme spring tides during the intermonsoon times have been reported to result in periodic nutrient inputs from estuarine areas on a lunar and annual basis (McClanahan, 1988). Seasonal patterns in tidal heights correlated with groundwater nutrient concentrations in a study conducted by Lapointe *et al.* (1990) where the sea level was found to be the dominant component regulating the groundwater table height and there was tidal pumping of groundwater nutrients during the seasonal maximum ebbing tides. The decline in phosphate levels in May could indicate the effect of the low maximum spring tidal level in which case the tidal pumping of groundwater nutrients into the lagoon would be low. The comparable levels of phosphates in both Diani and Galu Beach indicate nutrient seepage in both areas especially through the groundwater as shown by the low salinity levels. Though the hotels in Galu Beach may be new their concern for sewage treatment may be low. Nevertheless, the effects of rainfall dominate during the high rainfall months as can be seen in the high concentrations of nitrate and ammonium recorded in Diani and Galu Beaches especially during the rainy monsoon period of May. The effect of visitor number is negligible as nutrient levels were high during the SE monsoon (May and August) when visitor numbers were low. Tidal flushing and rainfall seem to be the contributory factors to nutrient loading in the lagoons.

Ryther & Dunstan (1971) indicate that nitrogen compounds become depleted more rapidly and more completely than phosphate compounds in the sea. However, detectable levels of nitrates and ammonium were found in Diani and Galu Beaches. A study by Barnes (1973) in Jamaica on sewage pollution from tourist hotels revealed low phosphate levels of 0.002 - 0.0007 μg at P/1 and ammonium levels of 0.02 - 0.03 μg at N/1 in the affected areas. The levels of these nutrients recorded in this study were much higher than the levels reported in Jamaica indicating the possible effects of nutrient seepage into the seagrass areas in both Diani and Galu. However, bacterial mineralization and nitrogen fixation at the sediment level also release inorganic nutrients into the water column (Kazungu, *et al.* 1989). Bacterial processes have been known to convert organic nitrogen compounds into ammonia which is utilized and diffuses into the water column (Zieman, 1982). This could be another cause of the high inorganic nutrient levels in the water column.

Fourqurean *et al.* (1992) reported that leaf uptake of nutrients by seagrasses is of secondary importance. Seagrasses have roots which penetrate the more nutrient rich medium of the sediment hence the sediment forms the most important source of nutrients for seagrasses. Organic matter was reported to be the source of the sediment nutrients thus areas of high seagrass biomass would have greater organic matter contributions hence high pore water nutrients. This study revealed similar organic matter quantities in both Diani and Galu beaches inspite of the fact that the seagrass biomass was higher in Diani.

Johannes (1980) documented the effects of submarine groundwater discharge (SGD) where polluted interstitial groundwater may have impacts on rooted aquatics. The nutrient levels in the groundwater were not measured in this study, but this would account for the difference in the seagrass biomass in Diani and Galu beaches. This may indicate a higher nutrient load in the groundwaters of Diani Beach which is taken up by the seagrasses and reflected in the biomass. Though, physical factors such as the shifting sediments in Galu or grazing pressures could deter the accumulation of high seagrass biomass levels.

The biochemical oxygen demand ($BOD_{5/20}$) level is used to assess the organic matter content of the water and it gives a measure of the biodegradable material in the water. However, the $BOD_{5/20}$ level did not surpass the critical level of 10 mg O_2/l that is characteristic of a polluted system in Diani Beach, the area of concern. Though insignificant the slightly higher $BOD_{5/20}$ levels in Galu may be an indication of weaker circulation in Galu compared to Diani. The predominance of very fine sediments in the Galu beach area also confirms the weaker circulation patterns relative to Diani beach where fine and medium sands were found.

Dispersion values ($QD\Phi$) indicate the degree of sediment sorting. A small $QD\Phi$ value indicates a well sorted sediment (Giere, 1988). In Diani Beach, the sediments had lower dispersion values at the beach end of the transects thus making the beach sediments well sorted in comparison to the seaward sediments. In Galu Beach, the $QD\Phi$ was small in the seaward sediments in February but this changed in August with the beach sediments having smaller dispersion values thus making them better sorted.

Negative skewness indicates the fine nature of the sediments (Taylor & Lewis, 1970, Giere, 1988). In Diani Beach, the negative skewness at the beach end of the transects in February and August indicates the fine nature of the beach sediments while the positive skewness at the seaward end of the Diani transects conforms to the coarse nature of the sediments.

In Galu Beach, the negative skewness of the sediments particularly in August indicated the fine nature of the sediments at the seaward end of the transects. The predominance of medium sand in the seaward sections of the Diani transects indicates the prevalence of more turbulent conditions ând high wave action in Diani Beach compared to Galu Beach where fine sediments predominate. The soil particle size has been found to be large where the wave energy is greater (Jones, 1969) thus the presence of fine sediments in Galu confirms the fact that wave action and turbulence is not as strong as it is in Diani.

Coarse sediments are characterized by a low organic matter content while fine silts and clays have higher organic matter quantities (Nicholas, 1970). However, there was no significant difference between the organic matter in the different grain sizes in Diani and Galu Beach indicating that though the sediment was finer in Galu the organic matter content was similar to that in Diani.

5.4 Conclusions

This study revealed the predominance of mixed seagrass meadows in Diani Beach contrary to the situation that would exist if eutrophication was intense in which case monospecific beds of the seagrass *H. wrightii* would have dominated. Although, the higher seagrass biomass in Diani Beach would indicate a higher nutrient content in the area, only the nitrates proved to be significantly higher in Diani Beach. The levels of ammonium and phosphate were similar in both areas. The presence of measurable nutrient quantities in the water column when uptake by the flora was expected to lead to negligible levels indicated submarine ground waters and nitrogen fixation as possible sources of nutrients to the seagrasses.

Indicators of eutrophication, particularly the green algae, did not dominate the algal biomass indicating that eutrophication was not a problem in Diani Beach. Other physico-chemical factors influenced the algal biomass such as the seasonal turbulence of the SE monsoon months. Epiphtyic algae which would have been also used as pollution indicators in Diani Beach indicated attachment based on substratum availability.

Epibenthic faunal taxa were similar in the two areas with localized abundances of groups such as the Asteroidea in Diani Beach based on the substratum type rather than pollution effects. The infaunal diversities may have been different if the species level of identification was used. However, seasonal differences in the individual taxa were significant which was not the case with the epibenthos. The lack of seasonality in the individual epibenthic taxa indicates that the surface dwelling organisms (epibenthos) were more resilient to the seasonal fluctuations. The infauna may have been affected by the changing sedimentary conditions particularly distinct in Galu Beach where the sedimentary characteristics recorded in February had changed by August. The changing substrate may be the cause of the low infaunal densities recorded in Galu Beach while other studies reveal an abundance of high infaunal densities in fine sediments.

The establishment of a nutrient baseline level is difficult as the concentration of phosphates and nitrogen based compounds fluctuate with the tides, fresh water run-off, plankton concentration and the effect of dilution on the sewage. These factors mean that the levels of nutrients measured in this study are prone to wide variability.

The biochemical oxygen demand ($BOD_{5/20}$) test used as an organic pollution indicator showed values that were not typical of eutrophic areas for Diani Beach, thus indicating good circulation in this lagoon. Water-borne nutrients did not reside in the lagoon for long due to the tidal flushing hence avoiding excessive growth of macroalgae particularly the green algae. If this was not the case, over the 20 years that the hotels have been in existence, more evidence of eutrophication relating to macroalgal and phytoplankton blooms as well as high $BOD_{5/20}$ levels would have been apparent in the Diani ecosystem.

Galu Beach, however, presents an area of concern due to the similar nutrient levels recorded in comparison to Diani Beach. The finer sediments and slightly higher $BOD_{5/20}$ indicate weaker circulation patterns in the lagoon. Galu Beach would be prone to the effects of eutrophication if the concentration of hotels increased.

The following aspects are recommended for future research work:

- Monthly monitoring of nutrients should be undertaken for more informative data over a period of several years. This would help to investigate the tidal effect on the seepage of nutrient rich waters into the lagoons.

- Seagrass productivity studies to obtain estimates of the growth of different seagrass species should be carried out. This could be used to estimate the growth rates in terms of nutrient enrichment rather than the use of biomass estimates which are prone to the presence of stunted and fully grown seagrass varieties.

- Studies on algal production and biomass should be undertaken.

- The study of tidal circulation patterns would reveal their effectiveness in the protection of coastal lagoons from eutrophication.

- Twenty four hour sampling regimes should be formulated to cover the effects of the tidal cycles on the rate and flow of underground seepage. The identification of the main seepage locations and assessment of the sediment nutrient levels would help to confirm the sediments as the source of eutrophication rather than the surface water.

This study only covered a fraction of the lagoons in Diani and Galu hence the inclusion of a wider study area may produce a more comprehensive picture of the dynamics of this ecosystem. Considering the outcome of this study, eutrophication could become a problem in Galu Beach, thus it is an area where sewage treatment plants should be a part of the hotel construction.

REFERENCES

Aleem, A. A. 1984. Distribution and Ecology of Seagrass communities in the Western Indian Ocean. **Deep Sea Research** 31 (6-8): 919 - 933.

Alongi, D. M. 1990. The ecology of tropical soft bottom benthic ecosystems. **Oceanogr. Mar. Bio. Ann. Rev.** 28: 381 - 496.

Bandeira, S. O. (1995) Marine Botanical communities in southern Mozambique with special reference to seagrass diversity and conservation. **Ambio 24** (7-8): 506 - 509.

Barnes, E. S. 1973. Sewage pollution from Tourist hotels in Jamaica. **Mar. Pollut. Bull.** 4: 102 - 105.

Barnes, R. D. 1980. **Invertebrate Zoology**. Fourth Edition. Holt-Saunder. Tokyo. 1089 pp.

Bloom, S. A. 1983. Seasonality and structure of a macrobenthic seagrass community on the Florida Gulf Coast. **Int. Revue ges. Hydrobiol.** 68: 539 - 564.

Brakel, W. H. 1982. Tidal patterns on the East African Coast and their implications for littoral biota. In Symposium on the Coastal and Marine environment of the Red Sea, Gulf of Aden and Tropical Western Indian Ocean. UNESCO/ ALESCO. The Red

Sea and Gulf of Aden Environmental Program, Jeddah, 2: 403 - 418.

Bryceson, I. 1982. Pollution of Dar-es-Salaam coastal environment by industrial and domestic effluents. Workshop on current state and development of marine sciences in Tanzania, April 1982.

Buchanan, J. B. and J. M. Kain. 1971. Measurement of the Physical and Chemical Environment. In Holme, N. A. & A. D. McIntyre (eds). **Methods for the study of marine benthos.** I. B. P. Handbook No. 16. Blackwell Scientific Publi., Oxford. 30 - 58.

Byers, S. C., E. L. Mills and P. L. Stewart. 1978. A comparison of methods of determining organic carbon in marine sediments with suggestions for a standard method. **Hydrobiologia** 58 (1): 43 - 47.

Chapman, V. J. 1950. **Seaweeds and their uses.** Methuen and Co. Ltd., London. 304 pp.

Clark, A. M. and F. W. E. Rowe. 1971. **Monograph of shallow water Indo-West Pacific Echinoderms.** Trustees of the British Museum (Natural History), London. 238 pp.

Coppejans, E., H. Beeckman and M. De Witt. 1992. The seagrass and associated macroalgal vegetation of Gazi Bay (Kenya). **Hydrobiologia 247**: 59 - 75.

Day, J. H. 1974. **A guide to marine life of South African shores.** Second Edition. Balkema, Capetown. 300 pp.

Eagle R. A. and E. I. S. Rees. 1973. Indicator species: a case for caution. **Mar. Poll. Bull.** 2: 25

Ferraro, S. P. and F. A. Cole. 1990. Taxonomic level and sample size sufficient for assessing pollution impacts on the Southern Californian Bight macrobenthos. **Mar. Ecol. Prog. Ser.** 67: 251 - 262.

Ferraro, S. P. and F. A. Cole. 1992. Taxonomic level sufficient for assessing a moderate impact on macrobenthic communities in Puget Sound, Washington, U. S. A. **Can. J. Fish. Aquat. Sci.** 49: 1184 - 1188.

Fortes, M. D. 1990. **Seagrasses: A resource unknown in the ASEAN region.** Ass. of South East Asian Nations / United States Coastal resources management project, Education series 6. 46 pp.

Fourqurean, J. W., J. C. Zieman and G. V. N. Powell. 1992. Relationships between porewater nutrients and seagrasses in a subtropical carbonate environment. **Mar. Bio. 114**: 7 - 65.

Furnas, M. J. 1992. The behaviour of nutrients in tropical aquatic ecosystems. In D. W. Connell & D. W. Hawker (eds). **Pollution in Tropical Aquatic Ecosystems.** CRC press. Florida. 29 - 65.

Giere, O., A. Eleftheriou and D. J. Murison. 1988. Abiotic Factors. In R. P. Higgins & H. Thiel (eds). **Introduction to the study of meiofauna.** Smithsonian Institution, Washington, D. C. 61 - 78.

Gray, M. C. 1990. Population densities of the sea urchin *Echinometra matheii* in relation to defined habitat types in Diani Lagoon, Kenya. 3.2.1. Project report. Exeter University. 25 pp.

Griffiths, J. C. 1967. **Scientific method in analysis of sediments.** McGraw - Hill Inc. 508 pp.

Harlin, M. M. and B. Thorne-Miller. 1981. Nutrient enrichment of seagrass beds in a Rhode Island Coastal Island. **Mar. Bio.** 65: 221 - 229.

Hartog, C. den 1977. Structure, function and classification in seagrass communities. In McRoy & Helfferich (eds) **Seagrass ecosystems: A scientific perspective.** Marcel Dekker Inc. New York. 89 - 121.

Hayes, L. 1994. The three coast regional statistics for room percentage occupancy for three years of 1993, 1992 and 1991. Kenya Association of Hotel Keepers and Caterers. (Coast Branch).

Holme, N. A. and A. D. McIntyre (eds). 1971. **Methods for the study of marine benthos** I. B. P. Handbook No. 16. Blackwell Scientific Publi., Oxford. 334 pp.

Isaac, W. E. and F. Isaac. 1968. Marine botany of the Kenya coast. 3. General account of the environment, flora and vegetation. **J. E. Afr. Nat. Hist. Soc.** 27 (116): 7 - 27.

Isaac, F. M. 1969. Marine Botany of the Kenya coast. 4: Angiosperms. **J. E. Afr. Nat. Hist. Soc.** 27 (116): 29 - 47.

Jassund, E. 1976. **Intertidal seaweeds in Tanzania. A field guide.** First Edition. University of Troms. 160 pp.

Jones, D. A. (ed). 1969. Bangor - Watamu expedition. University of North Wales. Preliminary Report. 66 pp.

Johannes R. E. and S. B. Betzer. 1975. Introduction. In E. J. Ferguson Wood & R. E. Johannes (eds). **Tropical marine pollution.** Oceanography Series 12. Elsevier Scientific Publishing Company. Amsterdam. 1 - 12.

Johannes, R. E. 1980. The ecological significance of submarine discharge of groundwater. **Mar. Ecol. Prog. Ser.** 3: 365 - 373.

Kazungu, J. M., F. Dehairs and L. Goeyens. 1989. Nutrient distribution patterns in Tudor Estuary (Mombasa, Kenya) during the rainy season. **Kenya J. Sci. Tech. Ser. B** 10 (1-2): 47 - 61.

Kendall, B. 1985. The shell trade. **Swara** 8 (1): 8 - 11.

Kendrick, G. A., D. I. Walker and A. J. McComb. 1988. Changes in distribution of microalgal epiphytes on the stems of the seagrass *Amphibolis antartica* along a salinity gradient in Shark Bay, Western Australia. **Phycologica** 27 (2): 201 - 208.

Kikuchi, T. and J. M. Peres. 1977. Consumer ecology of seagrass beds. In C. P. McRoy & C. Helfferich (eds.). **Seagrass ecosystems: A scientific perspective.** Vol.4. Marine Science. Marcel Dekker Inc., New York. 147 - 193.

Kwale District Environmental Assessment Report. 1985. National Environmental Secretariat. Ministry of Environment and Natural Resources. No. 67839. Nairobi.

Lakshaman K. K. 1983. Ecological importance of seagrasses. Paper presented at the all-India Symposium on marine plants, their biology, chemistry and utilization. Dona Paula, Goa. Oct 30 - Nov 1. 17 pp.

Lapointe, B. E., J. D. O'Connell and G. S. Garrett. 1990. Effects of on site sewage disposal systems on nutrient relations of groundwaters and nearshore surface waters of the Florida Keys. Biogeochemistry 10 : 289 - 307.

Lapointe, B. E. and M. W. Clark. 1992. Nutrient input from the watershed and coastal eutrophication in the Florida Keys. Estuaries 15 (4): 465 - 476.

Lapointe, B. E., D. A. Tomasko and W. R. Matzie. 1994. Eutrophication and Trophic state classification of seagrass communities in the Florida Keys. Bull. Mar. Sci. 54 (3): 696 - 717.

Lobban, C. S. and P. J. Harrison. 1994. Seaweed ecology and Physiology. Cambridge University Press. 366 pp.

Magurran, A. C. 1988. **Ecological diversity and its measurement.** Princeton University Press, New Jersey. 179 pp.

Martens, E. E. 1992. Coastal wetland utilization. In S. A. Crafter, S. G. Njuguna and G. W. Howard (eds) Proc. of the Kenya wetlands working group seminar on wetlands of Kenya. National Museums of Kenya. IUCN Publication. 3 - 5 July, 1991. viii + 183 pp.

Martens, E.E. 1994. Marine wetlands in Kenya: Ecology, threats, conservation. In Wildlife Clubs of Kenya. Workshop on Wetlands conservation. Internal report, Nairobi.

McClanahan, T. 1987. Overfishing and coral reef degradation: A preliminary report from East Africa. **Conservation Biology** 1 (2): 97 - 99.

McClanahan, T. 1988. Seasonality in East Africa's coastal waters. **Mar. Ecol. Prog. Ser. 44**: 191 - 199.

McClanahan, T. (in review). Community structure of coral reef associated gastropod assemblages: Distributin, diversity patterns and ecological relations.

McComb, A. J. and R.J. Lukatelich. 1986. Nutrients and plant biomass in Australian estuaries with particular reference to south-western Australia. Limnology in Australia Monogr. Biol. 61: 433 - 455.

McRoy, C. P. and R. J. Barsdate. 1970. Phosphate absorption in eelgrass. Limnol. Oceanogr. 15 (1) : 14 - 20.

McRoy, C. P. and C. Helfferich. 1980. Applied aspects of seagrasses In Phillips, R. C. and C. P. McRoy (eds) 1980. Handbook of Seagrass Biology: An ecosystem perspective. Garland STMP Press. New York. 297 - 343.

Mollison, S. 1971. Kenya's coast: An illustrated guide. East African Publishing House, Nairobi. 158 pp.

Moorjani, S. A. 1977. Ecology of marine algae of the Kenya coast. Phd. Thesis. University of Nairobi. 285 pp.

Moorjani, S. and B. Simpson. 1988. Seaweeds of the Kenya coast. Oxford Univ. Press, Nairobi. 134 pp.

Morrisey, D. J., A. J. Underwood, L. Howitt and J. S. Stark. 1992. Temporal variation in soft-sediment benthos. J. Exp. Mar. Biol. Ecol. 164: 233 - 245.

Moser, C. A. 1958. Survey methods in social investigation. Heinmenn Educational Books Ltd. London. 549 pp.

Munga, D., A. C. Yobe, M. Owili and S. M. Mwaguni. 1993. Assessment of land based resources of marine pollution along the Kenyan Coast. Report presented to WHO regional office, Brazaville. 60 pp.

Muthiga, N. and T. McClanahan. 1987. Population changes in the sea urchin (*Echinometra matheii*) on an exploited fringing reef. **Afr. J. Ecol. 25**: 1 - 8.

Ngoile, M. A. K. 1988. Marine pollution in Tanzania: Sources, dispersion and effects. In J. R. Mainoya (ed.). Proc. of workshop on ecology and bioproductivity of the marine coastal waters of Eastern Africa. 18 - 20 Jan, 1988. Univ. of Dar-es-Salaam. 133 - 143.

Nicholas, F. H. 1970. Benthic polychaete assemblages and their relationship to the sediment in Port Madison, Washington. **Mar. Biol. 6**: 48 - 57.

Nienhuis, P. H., J. Coosen and W. Kiswara. 1989. Community structure and biomass distribution of seagrasses and macrofauna in the Flores Sea, Indonesia. **Netherlands J. of Sea research. 23 (2)**: 197 - 214.

Nixon, S. W. 1993. Nutrients and Coastal Waters. **Oceanus 36 (2)**: 38 - 47.

Njuguna, S. G. 1985. Seagrasses. **Swara 8 (1)**: 8 - 11.

Norconsult, A. S. 1975. Mombasa water pollution and waste water disposal study. Ministry of Local govt. on behalf of Mombasa Municipal Council. 34 pp + Appendices.

Parsons, T. R., Y. Maita and C. M. Lalli. 1984. **A manual of chemical and biological methods for seawater analysis.** Pergamon Press Ltd., Oxford. 173 pp.

Pearson, T. H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. **Mar. Biol. Ann. Rev. 16**: 229 - 311.

Phillips, R. C. and E. G. Meñez. 1988. **Seagrasses.** Smithsonian contributions to the Marine Sciences. No. 24. Washington D. C. 104 pp.

Raman, A. V. and P. N. Ganapati. 1987. Benthic polychaete macrofauna and pollution in Visakhapatnam Harbour, India. In Thompson, M. F., R. Sarojini & R. Nagabhushaban (eds). **Biology of Benthic Marine Organisms (Indian Ocean) Techniques and methods as applied to the Indian Ocean.** A. A. Balkema, Rotterdam. 463 - 484.

Reish, D. J. 1972. The use of marine invertebrates as indicators of varying degrees of marine pollution. In M. Ruivo (ed). **Marine pollution and sealife.** Fishing newsbook. 203 - 207.

Ruwa, R. K. and P. Polk. 1986. Additional information on mangrove distribution in Kenya. **Kenya J. Sci. Tech. Ser. B 7 (2):** 41 - 45.

Ruwa, R. K. 1991. Kenya's marine ecosystems: An introduction. In Abungu, L. L & G. H. O. Abungu (eds) Proc. of the 1991 workshop on Marine Environment Education, Kanamai, Mombasa. 11 - 21, August, 1991.

Ryther, J. H., J. R. Hall, A. K. Peace, A. Bakun and M. M. Jones. 1966. Primary organic production in relation to the chemistry and hydrography of the Western Indian Ocean. **Limnol. Oceanogr. 3:** 371 - 380.

Ryther, J. H. and W. M. Dunstan. 1971. Nitrogen, Phosphorous and eutrophication in the coastal marine environment. **Science 171:** 1008 - 1013.

Samoilys, M. 1988. Abundance and species richness of coral reed fish on the Kenyan coast: The effects of protective management and fishing. Proc. of the 6th Intern. coral reef Symp., Australia. 2: 261 - 266.

Semesi, A. K. 1988. Seasonal changes of macro-epiphytes on seagrass, *Thalassodendron ciliatum* (Forssk.) den Hartog at Oyster Bay, Dar-es-Salaam, Tanzania. In J. R. Mainoya (ed.). Proc. of workshop on ecology and bioproductivity of the marine coastal waters of Eastern Africa. 18 - 20 Jan, 1988. Univ. of Dar-es-Salaam. 51 - 58.

Semesi, A. K. 1990. Seagrass beds from selected sites along the coast of Tanzania. Paper presented at the Symposium on " The ecology of mangroves and related ecosystems." Sept, 1990. Mombasa. 15 pp.

Semesi, A. K. 1991. Research trends and application of results: seaweeds, mangroves and seagrasses in Tanzania, East Africa. In SAREC Documentation workshop on Tropical coastal lagoon ecosystems. Inhaca Island, Mozambique. Dec 3 - 5. 1995. Conference reports.

Smith S. L. and L. A. Codispoti. 1980. South West monsoon of 1979: Chemical and Biological response of the Somali Coastal waters. Science 209: 597 - 599.

Sokal, R. R and F. J. Rohlf. 1969. Biometry: The principals and practice of statistics in biological research. W. H. Freeman & Co., San Fransisco. 776 pp.

Spenser, C. P. 1975. The macronutrient elements. In J. P. Riley and G. Skirrow (eds). **Chemical oceanography.** Academic Press. London. 2: 245 - 300.

Taylor, J. D. and M. S. Lewis. 1970. The flora, fauna and sediments of the marine grass beds of Mahé, Seychelles. **J. Nat. Hist.** 4: 199 - 220.

Tomasko, D. A. and B. E. Lapointe. 1991. Productivity and biomass of *Thalassia testudinum* as related to water column nutrient availability and epiphyte levels: Field observations and experimental studies. **Mar. Ecol. Prog. Ser.** 67: 251 - 262.

UNEP. 1982. Conservation of coastal and marine ecosystems and living resources of the East African Region. UNEP Regional Seas Reports and Studies. No. 11. 73 pp.

Virnstein, R. W. 1987. Seagrass associated invertebrate communities of the southeastern U.S.A. In J. Durako, R. C. Phillips & R. R. Lewis III (eds.). A review in Florida marine research publications. Proc. of the symposium on subtropical-tropical seagrasses of the southeast U.S.A. Florida Dept. of Nat. Res. Bureau of marine research. 89 - 116.

Wakibia, J. G. 1995. The potential human induced impacts on the Kenyan seagrasses. UNESCO reports in Marine Science. No. 66. Coastal systems and sustainable development in Africa. 176 - 187.

Wamukoya, G. 1987 Seasonal changes in marine fauna along the Kenyan coast. Kenya Belgium Project in Marine Sciences. Second Quarterly Report. April to June 1987. 96 - 102.

Warwick, R. M. 1988. Analysis of community attributes of the macrobenthos of Frierfjord/Langesundfjord at taxonomic levels higher than species. **Mar. Ecol. Prog. Ser. 46**: 167 - 170.

Wood, E. 1987. **Subtidal Ecology**. Edward Arnold. London. 125 pp.

Yaninek, J. S. 1976. Survey of gastropod populations at Diani and at Malindi Marine National Park, Kenya. **J. East Afr. Nat. Hist. Soc. 31** (159): 1 - 10.

Zar, J. H. 1984. **Biostatistical Analysis**. Second edition. Prentice - Hall, Inc. New Jersey 718 pp.

Zieman, J. C. 1975. Tropical marine pollution. In E. J. Ferguson Wood & R. E. Johannes. **Tropical marine pollution**. Oceanography Series 12. Elsevier Scientific Publishing

Company. Amsterdam. 63 - 74.

Zieman, J. C. and R. G. Wetzel. 1980. Productivity in Seagrasses: methods and rates. In Phillips, R. C. & C. P. McRoy (eds) 1980. **Handbook of Seagrass Biology: An ecosystem perspective.** Garland STMP Press. New York. 87 - 116.

Zieman, J. C. and K. Adams. 1982. The ecology of seagrasses of south Florida: A community profile. U. S. Fish. and Wildlife Services, Office of Biological Services. Washington. D. C. FWS/OBS - 82/25. 158 pp.

APPENDIX I

QUESTIONNAIRE

Name of hotel: _______________________

Name of respondent (optional): _______________________

Position occupied by the respondent: _____________________

Duration of time the respondent has worked at the hotel: ______

Q1. When was this hotel established?

A1. ______________________

Q2. What is the bed capacity of this hotel?

A2. ____________________

Q3. Looking at the current trends in the tourism industry, how has this affected your hotel in terms of tourist bookings for the years 1992/93? (Tick the appropriate answer)

A3. There has been a decrease _____________
There has been an increase _____________
There has been no difference ____________

Q4. In your opinion what type of tourists visit your hotel? (Tick the appropriate answer)

A4. Business types attending conferences ______________
Environmentally conscious types ___________
Not environmentally conscious types ___________
Combination of the above _________________

Q5. What is the origin of the tourists that visit your hotel? (Tick the appropriate answer)

A5. United Kingdom ______________
United States of America _________________
France _________________
Germany __________________
Italy ________________
Other countries (specify) _________________

Q6. What time of the year do most tourists from the different countries visit your hotel ? (If there is no specific time period for the different groups, please state so)

A6.

COUNTRY	VISITING TIME (months)
United Kingdom	
United States of America	
France	
Germany	
Italy	
Others:	

Q7. Does your hotel offer any of the following water based activities to its guests? (Tick all if appropriate)

A7. Wind surfing ___________
Diving ___________
Glass bottom boat tours ___________
Other (specify) ___________

Q8. Are the above activities offered by: (Tick the appropriate response)

A8. the hotel management? ___________
private companies? ___________

Q9. Have you heard about eco-tourism?

A9. Yes ___________
No ___________

Q10. How did you hear about eco-tourism?

A10. At a workshop ___________
In magazines ___________
On television ___________
Other (specify)___________

Q11. Eco-tourism involves water recycling and electricity conservation, use of local building materials and proper waste disposal. Is the management of your hotel undertaking any of these activities ?(If yes, indicate which ones even if they have not been mentioned. If no, go to Q 14).

A11.

Q12. What methods are you using to make your guests more environmentally conscious?

A12. Video shows ______________
Lectures ____________________
Brochures _______________
Others (specify) _________________

Q13. What problems do you face trying to promote eco-tourism?

A13.

Q14. If you have not, do you intend to start on an eco-tourism program in the near future?

A14. Yes ____________
No _____________(If No, go to Q15.)

Q15. What is (or has been) the reason for your reluctance? (Tick those applicable)

A15. It involves too much work _______________
It involves too much money _____________
Lack of experienced personnel_______________
Bureaucratic reasons ______________
It is not worth consideration ______________
It is not the responsibility of the hotel management_____

Q16. What is (are) the source(s) of your waste material? (Tick all if appropriate)

A16. Kitchen wastes ____________
Paper wastes _____________
Plastic wastes __________

Metallic wastes eg. tins etc. ____________
Sanitary wastes ______________
Swimming pool water ___________
Other (specify) ___________

Q17. What method is used to dispose of each of the above waste material? (Use the following categories: recycling, treatment, compost pit, septic tanks. If there is another method used, specify)

A17.

WASTE	DISPOSAL METHOD
Kitchen wastes	
Paper wastes	
Plastic wastes	
Metallic wastes	
Sanitary wastes	
Swimming pool water	
Others:	

Q18. What type of sewage disposal system is used in your hotel?

A18. Septic tanks ___________
Soakage pits ___________
Treatment plant ___________
Others (specify) ______________

Q19. How far inland, in distance, from the beach, are the treatment plant or the septic tanks located? (Tick the appropriate category).

A19.

DISTANCE	TREATMENT PLANT	SEPTIC TANK
50 meters		
100 meters		
300 meters		
500 meters		
more than 500 meters		

NOTE: If your hotel has a treatment plant, answer Q20 to Q25.
If your hotel uses septic tanks and soakage pits, answer Q26 to Q28.

Q20. If your hotel has a treatment plant, what type of treatment is undertaken?

A20.

Q21. What is done with the treated water? (Tick those that apply)

A21. It is placed in soakage pits __________
It is used to water the hotel compound __________
It is recycled back into the hotel sewage system _________
It is disposed of into the ocean ___________
Other (specify)________________________

Q22. If the treated water is discharged into the ocean, how far, seaward, is it discharged?

A22.

Q23. How often is it disposed into the ocean?

A23. Daily ____________
Once a week ___________
Once a month _______________
Other (specify)____________

Q24. When is it disposed into the ocean?

A24. During the day __________
At night _____________

Q25. Are any of the sewage waste materials disposed of into the ocean without treatment?

A25. Yes ______________
No ______________ (If no, go to Q29)

If Yes, specify which ones ________________________________

Q26. How long does it take for the septic tank and soakage pits to fill up?

A25.

Q27. When the septic tank and soakage pits are full do you: (Tick the appropriate response)

A27. (a) hire a private firm to empty it? __________
(b) dispose of the sewage in an alternative way?
(specify) _______________________

Q28. Is any of the sewage waste material disposed into the ocean?

A28. Yes _____________
No _________ (If no, go to 29)

If Yes, specify which ones ______________________

Q29. Do you clean the beach area infront of your hotel to remove washed up seagrasses and other debris?

A29. Yes ______________
No _____________

Q30. What is done with the seagrass? (Tick the appropriate response)
A30. It is buried in pits along the beach _______________
It is thrown back into the sea ____________
It is used as compost _____________
Other (specify) ______________

Q31. Have you noticed any changes in the beach condition over the past 5 years?

A31. Yes ___________
No ______________ (If no, go to Q 34)

Q32. Has this change been seen as: (Tick the appropriate answer)

A32. An increase in animal numbers ____________
An increase in seagrass densities in the lagoon _______

An increase in beach usage by tourists ________
A decrease in animal numbers ____________
A decrease in seagrass densities ___________
A decrease in beach usage by tourists___________
Presence of drainage channels on the beach_________
Presence of large amounts of green algae along the beach___
More seagrass being swept onto the beach _________
A change in sea water color__________
Tourist complaints (specify) ______________

Q33. If animal numbers have shown changes please indicate which ones in particular:(Tick the appropriate category)

A33.

ANIMAL	INCREASE	DECREASE
Sea urchins		
Sea cucumbers		
Starfish		
Porcupine fish		
Crabs		
Others (specify)		

Q34. In your opinion, do you think that you are doing a good job in promoting eco-tourism?

A34. Yes ___________
No __________

Q35. Do your neighboring hotels carry out similar efforts or is it lacking? (If there is no hotel next to you, state).

A35

Please fill in this table showing bed occupancy for the years 1991, 1992 and 1993.

MONTH	1991	1992	1993
JAN			
FEB			
MAR			
APR			
MAY			
JUN			
JUL			
AUG			
SEP			
OCT			
NOV			
DEC			

APPENDIX II

SEDIMENT PARTICLE SIZE DETERMINATION

(Source: Griffiths, 1967; Buchanan & Kain, 1971).

Cumulative frequency curves were drawn using the phi (Φ) notation as an expression of the sediment particle size grades. Large phi values represent small particle sizes (silts and clays) whereas small phi values represent large sediment sizes (coarse sands).

The median diameter (MdΦ) was estimated as the measure of central tendency by reading the phi value which corresponded to the point where the 50% line crossed the cumulative curve.

The quartile deviation (QDΦ) measures the spread of the sediment. This was calculated as the number of phi units lying between the 1st (Q1Φ) and 3rd (Q3Φ) quartiles (ie) between 25% and 75% on the cumulative curve. The following equation used:

$$QD\Phi = (Q3\Phi - Q1\Phi)/2$$

A sediment with a small spread between the quartiles is considered to be well sorted.

The skewness of the spread on either side of the median average was estimated as:

$$Sk\Phi = [(Q1\Phi + Q3\Phi)/2] - Md\Phi$$

A positive SkΦ value indicates that the grain size fractions are larger than the median diameter (MdΦ) while a negative value indicates the predominance of finer fractions (Giere *et al.*, 1988).