A COMPARATIVE STUDY OF MACROFAUNA IN A HIGHLY EXPLOITED AND A LESS EXPLOITED MANGROVE SWAMP AT GAZI AREA, KENYA

BY

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DECLARATION

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

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This thesis has been submitted for examination with my approval as Supervisor.

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DEDICATION

I dedicate this thesis to Jacqui, who made the call that changed my life.

Sis, the triple "P" has just began ....for, "He who states his case seems right until another comes to examine him" and, "Even as it is not good to be ignorant, so he who hurries his feet misses the mark" (Proverbs 18:17; 19:2).

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

1. INTRODUCTION AND LITERATURE REVIEW

1.1 INTRODUCTION

Mangroves are ecosystems that are comprised of salt tolerant evergreen plants that grow in sheltered tropical and subtropical coastlines. Several species have characteristic aerial roots and show a zonation pattern that is determined by abiotic factors.

Mangroves are of immense ecological importance to coastal communities and habitats and presently there has been much concern that mangroves are being degraded at an alarming rate. In the Kenyan coast, mangrove forests are scattered in the creeks and cover an area of approximately 53,000 hectares, which, however, is being reduced particularly through deforestation. Being transitional between purely terrestrial and purely oceanic ecosystems, mangrove swamps are known to support a diversity of characteristic flora and fauna, several of which are of commercial importance.

Many general and descriptive studies have been made of various aspects of the mangrove ecosystem in different areas of the world. Although work has been done on the distribution of mangrove macroflora and macrofauna in Kenya, nothing exists in the literature on the effects of mangrove depletion on the biodiversity or even a comparative study of deforested and natural mangrove swamps.

The concern that deforestation of mangroves will lead to a loss of this diversity led to the design of this project, focusing on how significant the loss of biodiversity is, due to deforestation. This study specifically targeted the macrofauna which play an important role in this ecosystem.

1.2 LITERATURE REVIEW

1.2.1 Mangrove macroflora distribution and zonation

Mangrove swamps (mangal) are restricted to tropical and subtropical shores (Chapman, 1977). They usually grow around the mouths of rivers and creeks where there is a gradual slope of the land to the sea, plus a large tidal range resulting in a broad inter-tidal zone consisting of a mixture of sand and silt. Mangroves only develop in places free of strong waves and tidal action, behind islands, in creeks, in estuaries and in lagoons protected by coral reefs. Where strong waves and tidal actions are prevalent the soft sandy substratum is eroded and mangrove seedlings are unable to root (Van Speybroeck, 1990).

In Eastern Africa, mangroves have been described by Graham (1922), where the author also describes the species present along the Kenyan coast with some notes on their ecology. MacNae and Kalk (1962) gave a full account of the mangal on Inhaca Island (Mozambique). MacNae (1968) reviewed the literature on mangroves of the East African region and briefly described the geographic distribution of mangrove forests of the Rufiji Delta (Tanzania). Based on the information given by the above authors, Table 1 shows the orders and genera that have been recorded in the East African coast.

Family	Genus	Species
1. Rhizophoraceae	1. *Rhizophora*	1. *R. mucronata**
Rhizophoraceae	2. *Ceriops*	2. *C. tagal**
Rhizophoraceae	3. *Bruguiera*	3. *B. gymnorrhiza**
2. Verbenaceae	4. *Avicennia*	4. *A. marina**
3. Sonneratia	5. *Sonneratia*	5. *S. alba**
4. Sterculiaceae	6. *Heritiera*	6. *H. littoralis**
5. Meliaceae	7. *Xylocarpus*	7. *X. granatum**
Meliaceae	Xylocarpus	8. *X. moluccensis*
6. Lumnitzera	8. *Lumnitzera*	9. *L. racemosa**

Table 1: The orders and genera of mangrove species recorded along the East African coast ;*, species recorded along the Kenyan coast. (Source: Banyikwa, 1986)

The distribution of mangroves along the Kenya coast has been studied by Isaac and Isaac (1968), Moorjani (1977), Kokwaro (1986) and Ruwa and Polk (1986). There are 7 common species of mangrove trees occurring in Kenya. These are *Rhizophora mucronata* Lam., *Bruguiera gymnorrhiza* (L.) Lam., *Ceriops tagal* (Perrottet) C.B. Robinson, *Avicennia marina* (Forsk.) Vierh., *Sonneratia alba* J. Smith, *Xylocarpus granatum* Koenig, *Lumnitzera racemosa* Willd. The mangrove swamps on the Kenyan coast cover approximately 53,000 ha (Gang and Agatsiva, 1992). The most outstanding stands occur in Lamu area in the northern coast of Kenya, including the islands of Manda and Pate, and also along the Vanga Funzi area in the southern coast of Kenya. Other areas with less extensive stands are Mtwapa, Kilifi, Mida creek and Ngomeni - Fundi Isa area and the Mombasa - Port Reitz area and Gazi to the south of Mombasa (Fig. 1).

The composition and establishment of mangrove vegetation is associated with a number of factors such as soil salinity gradients, water table depths, pH and oxygen content of the soil (Chapman, 1977). According to Thom (1967), salinity is simply an eliminator of competition and not the determining factor in zonation. He suggests that substratum and water effects are the important factors controlling zonation and each species has a given set of tolerance. Johnstone and Flodin (1982) have proposed 6 types of likely factors influencing the zonation pattern: 1) inundation and depth of water, 2) wave action, 3) drainage, 4) salinity and fresh water regime, 5) substrate, 6) biota and biotic interactions.

Studies on the zonation pattern of mangrove species along the Kenyan coast have been concentrated recently at Gazi Bay (Coppejans and Gallin, 1989; Gallin *et al* 1989; Beeckman *et al* , 1990; Ruwa, 1990; Van Speybroeck, 1992), and at Mida creek (Van Speybroeck, 1992; Gang and Agatsiva, 1992). The studies revealed a topography and water level - determined zonation pattern, with *S. alba* growing closest to the low water line, followed by *R. mucronata*, *B. gymnorrhiza*, *C. tagal*, *A. marina*, *L. racemosa* and *X. granatum*.

Seagrasses and associated algae occur in patches on the submerged mangal bottom (Martens, 1992). Other plants found growing near the mangrove habitat are rounded shrubs of *Sueda monoica* J. F. Gmel, a succulent herb forming mats of

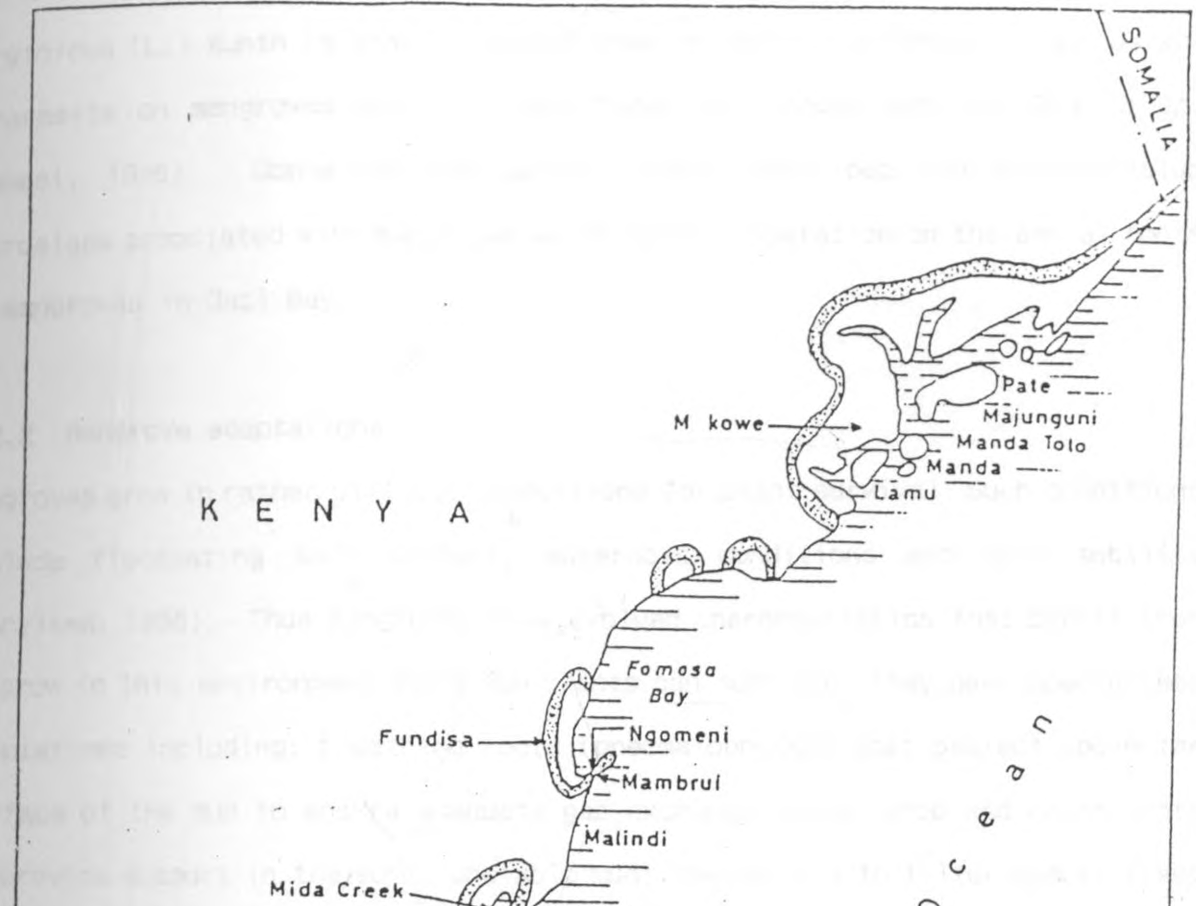


Fig 1. Distribution of Mangrove forests along the Kenya Coastline (Source: Kokwaro, 1986)

Arthrocnemum indicum (Willd.) Moq., *Sesuvium portulacastrum* (L.) L., *Sporobolus virginicus* (L.) Kunth (a grass), *Acrostichum aureum* L. (a fern), *Loranthus sp.* a parasite on mangroves and different types of lichens such as *Roceila sp.* (Semesi. 1986). Coppejans and Gallin (1989) described the Bostrychietum macroalgae associated with mangroves which form a vegetation on the aerial roots of mangroves in Gazi Bay.

1.2.2 Mangrove adaptations

Mangroves grow in rather difficult conditions for plant survival. Such conditions include fluctuating salt content, anaerobic conditions and soil mobility (Banyikwa, 1986). Thus mangroves have evolved characteristics that permit them to grow in this environment where few plants can survive. They have specialised adaptations including: breathing roots (pneumatophores) that project above the surface of the mud to ensure adequate gas exchange; prop, drop and cable roots to provide support in the soft, unstable mud; the ability to filter almost fresh water from salt water by means of strongly negative hydrostatic pressure in the system, in turn produced by very high osmotic pressure of leaf cells; and glands in the leaves to excrete excess salt and viviparity i.e. seeds (propagules) that germinate before they fall from the parent tree, so that they can become established more quickly in the soft and unstable substratum (Chapman, 1976; Saenger *et al*, 1983; Rützler and Feller, 1988; Van Speybroeck, 1990).

It must be noted however, that not all mangrove species show the same morphological or physiological adaptations because they come from different families and genera. Their differences in adaptations allow the mangrove species to be competitively superior in different niches (Ruwa, 1992).

1.2.3 Physico-chemical factors

1.2.3.1 Temperature

The basic climatic factor governing the geographical distribution of species is probably air temperature (Blasco, 1984). Extensive mangrove development occurs only when the average air temperature of the coldest month is higher than 20 ^{0}C and where the seasonal range does not exceed 10 ^{0}C. The presence of mangroves seems to correlate with those areas where the water temperature of the warmest month exceeds 24 ^{0}C. *A. marina var resinifera* appears to be the most cold resistant species occurring near Auckland (mean temperature 19.5 ^{0}C) at about 37 ^{0}S (Blasco, 1984). The temperature ranges along the Kenyan coast during the South - east monsoon and North - east monsoon are 20 to 31 ^{0}C and 23 to 32 ^{0}C, respectively (Ruwa, 1993).

1.2.3.2 pH

The pH values in mangrove areas fall within a range of 5 to 8 (Pinto, 1984; Frith *et al.* 1976). In mangrove areas, soil pH is one of the important parameters that control the chemical status and mobility of many important elements, e.g. at any given redox potential, many metals exhibit greater solubilities at a low pH. The pH can have an effect on phosphate binding in the soil. If a soil has a pH greater than about 7, it is possible that NH_4 volatization occurs, with resulting loss of nitrogen. In some instances, however, flooding may have the effect of increasing the pH of acid soils and decreasing the pH of alkaline soils so that most flooded soils converge to about pH 7. The flooded soils are buffered by iron, manganese and aluminium oxides/hydroxides and carbonates (Boto, 1984).

1.2.3.3 Salinity

A salinity of 34.5 p.p.t has been recorded in the coast of Kenya and Tanzania (Semesi, 1992). In estuaries and creeks values as low as 19 p.p.t may be recorded and values exceeding 40 p.p.t have also been recorded (Chapman, 1977). Salinity is an important factor determining the distribution of plants and animals in mangrove swamps.

1.2.3.4 Nutrients

The water in the continental shelves of Kenya and Tanzania is poor in nutrients (Semesi, 1992). Alongi (1988) listed low interstitial concentration of dissolved inorganic nutrients as one of the major environmental characteristics dominant in tropical oceans.

In investigating the diurnal variation in physico-chemical properties of a mangrove biotope in Kakinanda coast, Andhra Pradesh, India, Selvam *et al* (1992) recorded dissolved inorganic phosphate in mangal ranging from 0.73 to 1.11 µg at/l. This was low during the day and showed no relationships with tides whereas during the night hours phosphate concentration increased at the time of high tide and decreased during the low tide regime. Nitrite concentrations ranged from 0.06 to 0.28 µg at/l, and were lower during the day time but rose significantly at night, but this did not correlate with the tide. Nitrate concentration ranged from 1.60 to 7.10 µg at/l. The concentration was independent of the oscillation in tides during day time. However, during night hours nitrate concentration increased during the high tide period and decreased during the low tide regime. Ammonia concentration was high, and the maximum values, 23.65 and 8.85 µg at/l, did not show any relationship with tides even during night hours. The increased phosphate, nitrate and nitrite concentrations during the high tide period in the mangrove water indicates that some amounts of nutrients are imported to the mangrove environment through the tidal movement which was apparent during the night hours only. These reported levels of nutrients are not indicated to be potentially or actually limiting for mangrove production, but generally nutrient levels in mangrove ecosystem are usually limiting. This is supported by Boto (1991) who suggested that particulate and dissolved organic and inorganic N and P concentrations in tropical mangrove areas are extremely low. He adds that this appears to be especially so for mangrove systems which are influenced almost entirely by tidal movements and which have virtually no freshwater input from terrestrial riverine or groundwater sources.

Boto and Wellington (1988) showed that mangrove waters have high concentrations of ammonia resulting from continuous decomposition of mangrove litter. The highest ammonia concentration they recorded in the coral creek off Australia was 1.6 µM/l with most samples less than 0.5 µM/l. Nitrate (+nitrite) concentrations were also generally very low, rarely exceeding 0.3 µM/l.

Kazungu *et al.* (1986), observed that the nitrate concentrations in the water samples from Tudor creek, Kenya, ranged between 0.2 to 22.6 µg at-N/l and suggested that the high levels were probably due to pollution from the nearby hospital. Similar studies showed comparatively narrow ranges of nitrate concentrations (0.05 to 0.3 µg at/l) at Gazi Bay within a distance of only 50 km south of Tudor Creek (Kazungu *et al.*,1993). Boga (1993) recorded the highest nitrate + nitrite concentration (69.54 - 113.93 µg at N/l) in December, in Gazi Bay, in the *Rhizophora* zone.

1.2.3.5 Soil organic matter and particle size

A negative correlation exists between organic carbon and the grain size of the sediment (Alongi, 1988). Organic matter such as humic acids and organic acids from root exudates are thought to play an important role in the buffering capacities of mangrove soils (Boto, 1984). However, Boto states that major changes in soil properties may perhaps occur only during severe storms or exceptional spring tides.

Boga (1993) recorded highest levels of organic matter in the *Rhizophora* zone (25.34 to 37.17%) and lowest levels in the *Ceriops* zone (3.53 to 8.6%) in Gazi Bay, Kenya. He showed a relationship between bacteria numbers and organic matter.

Organic rich muds and fine sands are usually associated with the stilt roots and pneumatophores of *Avicennia* spp. and *Rhizophora* spp., with coarser sand being dominant in the high intertidal zone (Boto and Wellington, 1988). Icely and Jones (1978) recorded median diameter for sediment in Mida creek ranging from 0.140 mm to 0.380 mm and mean organic content of 13.03 to 0.41%.

1.3 Ecological Importance of Mangroves

Bossi and Cintron (1990) suggested 4 major ecological functions of mangrove ecosystems. First, mangroves play a role in shoreline stabilisation and protection. The tangle of mangrove roots traps sediments, hence stabilising mud and preventing siltation in adjacent seagrasses and coral reefs. The root mass also breaks the force of waves protecting the shoreline from erosion. Second, their root system acts as a buffer for water pollution by trapping pollutants from runoff waters an important role in water quality control. Third, mangroves provide aquatic nurseries and wildlife habitat with many species of commercially important marine/estuarine organisms depending at least for a part or whole of their life-cycles on mangroves. Last, the falling leaves form the base of important detritus food chains and food webs in the mangrove ecosystem and also contributes to offshore productivity.

1.4 Mangrove macrofauna diversity, distribution and zonation

1.4.1 The mangrove macrofauna

Crabs and molluscs dominate the mangal fauna. According to Jones (1984), crabs occurring in association with the mangal, fall into 6 families: Mictyridae, Grapsidae, Gecarcinidae, Portunidae, Ocypodidae and Xanthidae. The majority of crab species live on the substratum of the mangroves and fall into three categories : burrowing forms, forms living in burrows constructed by other animals or predatory forms wandering across the surface (Jones, 1984). Studies on the distribution and abundance of crabs have been dealt with by Warner (1969); Sasekumar (1974); Frith and Brunenmeister (1980) and Macintosh (1984). The mangal molluscs represent a transition between sea and land fauna.

Schrijvers (1991), in an ecological study of mangrove macrobenthos at Gazi bay, distinguished a total of 18 macrobenthic taxa and diversity values (Shannon - Wiener diversity indices) ranging from 1.65 to 3.35. Chakrabarti (1988), in a study of plant and animal dynamics in Sundarban, India, showed that mangrove zones situated below the mean tide level was observed to be comparatively richer in genetic and species diversity than other zones which are either frequently inundated or situated above the mean tidal level. Shokita (1989) gave an account of macrofaunal community structure and food chain in the mangal of Indo-West

Pacific Ocean.

Although Sanders and Hessler (1969) noted that benthic fauna are highly diverse in the tropical environments and dominant species rarely occur, the current view of species composition of benthic fauna is that various types of associations exist, from associated groups to loosely integrated aggregations due to co-occurrence. In addition, epibenthic predators are important in limiting numbers of macrofauna in soft bottom intertidal sediments, and biological interactions may occur between benthic species sharing a common resource of food and space.

1.4.2 Zonation patterns of the mangrove macrofauna

Many authors agree that the mangal crab fauna exhibit zonation. There is a distinct zonation of Brachyura crab genera and species reflecting adaptation to different degrees of terrestriality (Icely and Jones, 1978; Mall *et al*, 1982; Macintosh, 1984). The mangal crabs of different regions of the world are grouped into the following categories based on the horizontal zonation: First, those inhabiting the levels of high water spring tides which correspond to the landward fringe mangal on terrestrial margin; second, those inhabiting the zone between high water spring tide and mean high water neap tide which corresponds to the *Bruguiera* forest and *Ceriops* thicket, *Avicennia* and *Rhizophora* transition, terrestrial fringe and *Rhizophora* overlap with *Ceriops* zone; third, those inhabiting the zone between mean high water neap tide and mean sea level which corresponds to the *Rhizophora* forests, true mangrove forest, and *Rhizophora* mosaic with *Ceriops*; fourth, those inhabiting the zone between mean sea level and low water which corresponds to the seaward fringe *Rhizophora* and *Sonneratia* mixed zone to creek edge; and finally, those inhabiting sub-littoral zone and standing water in creeks.

There are many different patterns of zonation of mangal molluscs. Based on Berry's (1963) scheme for both vertical and horizontal distribution of Malayan mangal fauna, Plaziat (1984) proposed a more general zonation of mangal molluscs in which four zones are recognised. These include the littorina zone, the bivalve zone, the mud creeper and crevice dweller zone, and last, the low climber zone. Wells (1986) in a study of distribution of molluscs across a pneumatophore boundary in Australia, showed that the pneumatophore fringe has a greater density and biomass.

On the ecology and physiology of the decapods of mangrove swamps, Macintosh (1988) states that mangrove crabs are distributed principally in relation to sediment texture and shore level. It follows that, on suitable substrata, individual species are zoned according to their tolerance to high temperatures, salinity extremes and desiccation, parameters that increase in severity towards the landward mangrove limit. Sasekumar (1974) in his research on the Malaysian mangal fauna, concluded that tidal exposure time largely determines the vertical range of inter-tidal species. He found that grapsid crabs are more successful in colonising higher levels than ocypodid crabs, some of the former occurring in areas with 90% exposure to air.

1.4.3 Causal factors for zonation

To understand why there are horizontal zonation patterns in the macrofauna, the influence of tidal exposure time, substratum particle size, organic content and texture, water content and salinity and interference among species are the factors that should be taken into consideration (Shokita, 1989).

In the study of distribution and abundance of *Uca lactea* de Haan in the Kunduchi mangrove creeks, Dar es Salaam, Tanzania, Muhando (1990) found that there was a strong correlation between crab density and percentage pore water and organic matter content of sediments. Alongi (1989) stated that macrofaunal densities vary with season and sediment type and that in mangroves tannins may play a role in controlling densities of macrofauna.

In a study of macrofaunal distribution in mangrove ecosystems in Kenya, Ruwa (1988) described the factors influencing mangrove macrofauna as sediment texture, shade, shore-level, ground water table and biological interactions. Species diversity was found to be higher under shade conditions while species diversity increased with the following order of changes in sediment textures: sandy, sandy mud, muddy sand and muddy substrate. On the upper shore areas *Uca inversa* (Hoffmann) were abundant and in muddy sand habitats with predominantly *C. tagal* numerous *Sesarma guttata* Milne Edwards and few *U. lactea* and *Uca gaimardi* (Milne Edwards) were found. Where mangroves were heavily cut and the substratum is sandy mud, *U. lactea* were present and *S. guttata* were scanty.

Ocypodid mouth parts are highly specialised for extracting food in the forms of organic material and micro-organisms from certain substrate particle sizes. Hence the types and degrees of mouth part specialisation exhibited by species of fiddler crabs and the heterogeneity of substrates within an area will partly determine species composition and/or distribution (Frith and Brunenmeister, 1980). Indeed, examination of mouthparts of mangrove *Uca* species in South East

Asia has confirmed the apparent relationship between sediment grade inhabited and the configuration of setae on the 2nd maxillipeds e.g. inhabitants of sandy mangrove areas such as *U. lactea annulipes* and *Uca vocans* (Latreille) have some plumose setae on the 2nd maxillipeds but it is the stout spoon tipped form that dominates (Miller, 1961; Macintosh, 1984).

The lack of clear zonation of some crabs within the mangal may be attributed in part to the limited vertical range of the mangal itself, but even more so to the way in which the mangroves modify the effects of total exposure (Jones, 1984).

Ristich *et al* (1977) in the study of benthic and epibenthic macroinvertebrates of Hudson river (USA), found salinity as one of the important measurable factors controlling species range and community boundaries. The number of species was highest in the polymesohaline zones and lowest in freshwater.

Studies by Hagrave and Thiel (1983) of benthic macrofaunal species successions at one location and more detailed sampling show that benthic species associations usually existed as a continuum along a gradient of environmental variables such as salinity or bottom texture. These studies also showed that a dominant species characteristic of an assemblage often did not exist in shallow water areas and that certain species altered their environment to affect species composition over time.

1.4.4 Importance of mangrove macrofauna in the ecosystem

Crab populations are important in converting mangrove leaf litter into detritus, a principle energy source for heterotrophs of the adjoining inshore community.

By grazing from the mud surface crabs are also believed to have an important effect on sediment meiofaunal and microbial activity. In addition, the burrowing activities of the crabs can modify considerably the topography and vegetation of mangrove swamp (Macintosh, 1988). Apart from accelerating oxidation in the soil, seawater penetration through the burrows must also accelerate soil to water nutrient exchanges.

The effect of crabs on topography and soil chemistry have also been investigated by several authors (Katz, 1980; Jones, 1984). A rough estimate of the soil mixed up by the burrowing activities of 2 mangrove crabs *Sesarma meinerti* De Man and *Cardisoma carnifex* (Herbst) at Mida Creek, Kenya, indicate that they play a role of primary importance in the ecology of mangroves (Micheli *et al*, 1991).

Demonstrating the impact of sesarmid crabs on soil ammonium and sulphide levels, and on forest productivity and reproductive output, Smith III, *et al*. (1991) suggested that crabs occupy a keystone position in the overall ecology of Australian mangrove forests.

Grazing on fresh mangrove litter is typical of most sesarmid and gecarcinidae crabs. In Queensland mangroves (Australia), sesarmid crabs remove up to 80% of the annual leaf fall (Robertson and Daniel, 1989) and 75% of the propagules (Smith, 1987) from the forest floor while in Florida and Panama, crabs have been indicated as minor consumers of the forest primary production especially the leaves (Odum and Heald, 1975) and propagules (Smith *et al*, 1989). Micheli *et al*. (1991) recorded an exceptionally high leaf removal by crabs ($14 g/m^2/d$) in Mida Creek, Kenya.

A study of *Metaplax, Uca* and *Sesarma* populations on the Selangor coast of Malaysia indicated that the total annual production by mangrove crabs is 0.9 to 17 g/m^2 (2.5 to 30 Kcal/m^2). It is known that mangrove crabs concentrate carbon and nitrogen in their faeces so that these represent a rich food material for other consumers (Macintosh, 1984).

Although there are several studies that have shown that the mangrove crabs play a significant role in the consumption of forest primary production in some mangrove areas, studies on the contribution of the mangrove crabs to the total secondary production and annual production is scarce. However, it seems that the contribution of crabs to the secondary production and annual production is not significant. Jones (1984) postulates that although the crab fauna may represent as much as 75% of the mangal faunal biomass, the production estimate for instance, of 0.9 to 17 g/m^2/yr (2.5 to 30 kcal/m^2) for Malaysian mangal crabs is relatively insignificant in comparison with the total gross production of the mangal (*circa* 6000 g organic matter/m^2/yr).

Molluscs which are deposit feeders are also important in the recycling of nutrients. The majority of the molluscan fauna occurs on or as burrowing forms in the mud substrate. Some species live epiphitically on the roots, trunks, and / or leaves of the mangrove vegetation and may make diurnally, tidally or seasonally influenced vertical movements on the plants. A few species of Teredinidae (ship - worms), are endophytic, boring into mangrove tissues. These may be very abundant in frequently inundated sites and appear to be of importance not only as decomposers of mangrove wood but also as makers of tunnels and cavities for occupation by other organisms.

Both molluscs and crustaceans in the mangroves living in the tree zones and on the seaward mudflat, are largely dependant on detrital breakdown of the mangroves for their nutrition. They may play a key role in converting primary production by the trees into animal tissue available to higher trophic levels (Wells, 1984). Figure 2 shows a food web in a mangrove ecosystem.

Studies have shown that benthic infauna are important mediators of nutrient recycling through the following mechanisms: the ingestion of pellets (coprophagy) which have been reconstituted by bacteria, the vertical transport of organic detritus from below the redox potential discontinuity to the sediment-water interface and the resuspension of nutrient rich bottom muds into the water column providing a potential food source of suspension feeders (Bilyard, 1987).

1.5 Mangrove Utilisation and Exploitation

Mangrove forests provide fuel-wood, charcoal, timber and wood for building, poles for fish traps and building houses, fishing floats and tannin for fish nets and leather industries. Mangrove plants are also used as raw materials for paper pulp, sugar, alcohol, honey, cooking oil, vinegar, tea-substitute, fermented drink, vegetable propagules, medicine and green manure (Walsh, 1974; Saenger *et al* 1983; Mainoya, 1986; Semesi,1991; Martens, 1992).

Like the tropical rainforests, mangroves are being degraded and destroyed globally through conversion to single use options e.g. agriculture, mariculture ponds, salt evaporation ponds and by traditional uses exceeding the sustainable yield of direct products (Hamilton and Snedaker, 1984). The mangrove areas have

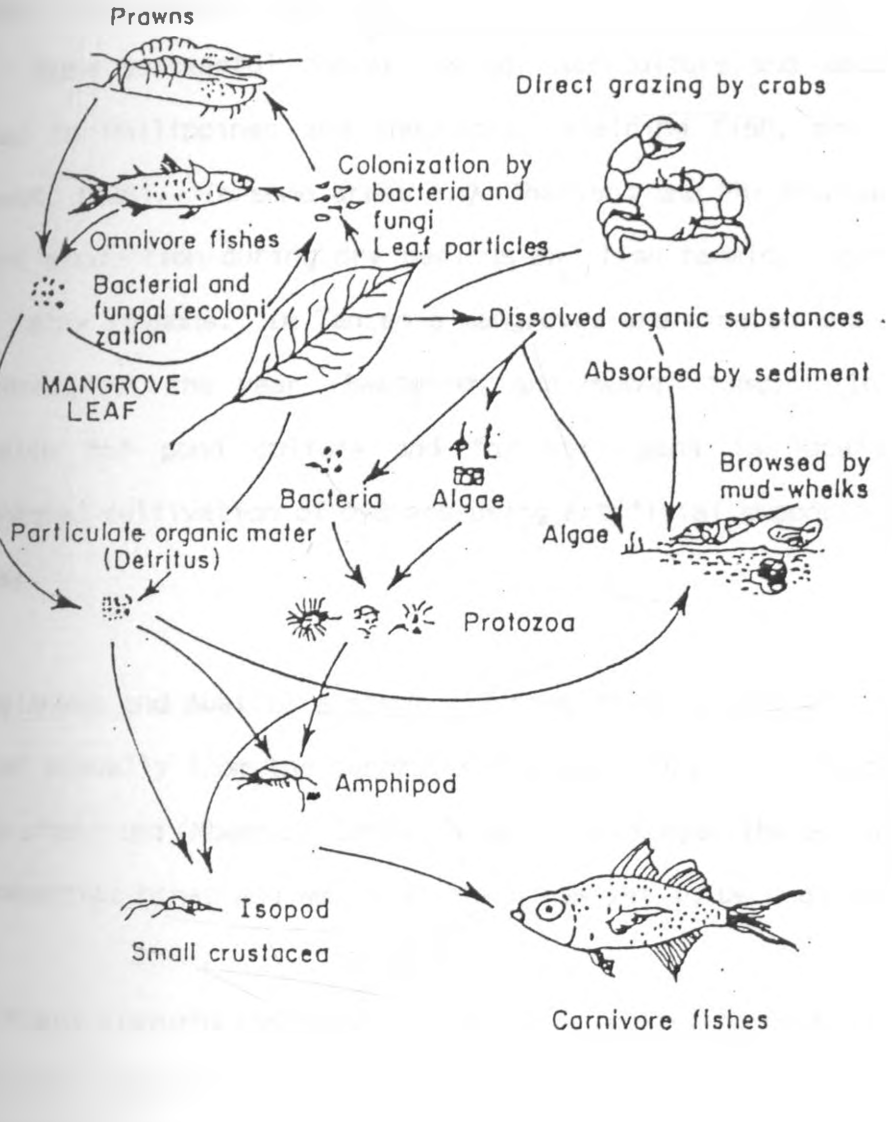


Fig 2. Mangrove food web
(Source: Aksornkoae, 1993)

also proven valuable for other uses. Agriculture, aquaculture, housing and transportation have all encroached on mangrove systems. Agricultural use of mangal is directed mostly to its conversion and salt resistant rice varieties have successfully been cultivated for example in Sierra Leone (Walsh, 1977). However, such an agricultural conversion is short term because the previously anaerobic soils when oxygenated become highly acidic (Hamilton and Snedaker, 1984). More successful conversion for mariculture and aquaculture has been achieved in Philippines and Indonesia, yielding fish, shrimp and shellfish (Tomlison, 1986). In some areas e.g. Thailand and Philippines, ponds are used for salt production during dry periods and fish farming (shrimp and milkfish) during rainy seasons. In Tanzania mangroves are cleared and land used as salt pans throughout the year (Bwathondi and Mwaya, 1986). In Kenya, mangrove conversion for pond culture and for salt pans is localised in Ngomeni. Experimental cultivation of oysters using artificial supports is in progress at Gazi Bay.

In Bangladesh and Australia about 177 tons of honey and 49 tons of beeswax are produced annually from the mangroves (MacNae, 1974). In Tanzania, bee keeping is also practised (Mbwana, 1986). However, in Kenya, the potential of mangroves for commercial honey and wax production has yet to be realised.

Human impact disturbs the mangrove ecosystem to varying degrees, ranging from the trivial to complete destruction. Land use of mangroves results in the destruction of the mangrove ecosystem in most cases. Overexploitation of mangroves by traditional users is closely linked to the general problems of rapidly expanding populations and associated decreases in economic standards

(Hamilton and Snedaker, 1984).

In Kenya, the most important item produced in the swamps is poles and exportation of the poles has been a practice since settlement of Arabs in the coast. For instance, mangrove poles has been one of the commodities that have been exported from Lamu for over 500 years and one of the major commodities exported from Malindi to various foreign ports during 1918 to 1948. Records from the fifteenth to the turn of the twentieth century showed that the Arabs of Malindi obtained their mangrove poles from either the Mida creek area (16 km south of Malindi) or at Ngomeni (29 km north of Malindi). Since about 1925 these forests have been overcut, so the mangroves had to be obtained from Mto Kilifi region, 56 km north of Malindi. In 1957, 711 scores (1 score = 20 mangrove poles) were cut at Ngomeni; two years later this figure increased to 1,227. By 1967, 2,879 scores were cut, and in 1968, 4,422 were cut almost all of which was exported (Martin, 1973).

In 1922 Graham estimated 180 sq. miles (46,619.82 ha) covered by mangroves, but this may be an underestimate as at present 53,000 ha have been estimated (Gang and Agatsiva, 1992) by more modern methods, and deforested areas are usually seen in mangrove areas. In 1922, about 470,000 poles were sold and about 40,000 issued free to the coastal communities for house building. Of these poles nearly 300,000 were exported to Arabia and India. By 1950's areas like Ngomeni and Lamu were overcut and the Forestry Department officials believed that on account of the increased wealth from petroleum in the Persian Gulf, there would be considerable decrease in the demand for poles. This did not turn out to be the case. In spite of a rapid increase in income, the people of Arabia and the

Persian Gulf still wanted mangrove poles: the wealthy for scaffolding and the poor people to use them to build their houses (Martin, 1973). Presently timber is used in the building industry and mangrove poles are exported to Arabia (Rainbow and Campbell, 1990). However, overexploitation greatly depleted the availability of mangrove poles leading to a ban on their export by the government in 1982.

1.6 Management and Conservation

An inadequate knowledge of the mangrove ecosystem, together with the intense pressure on the resource is the cause of the high rate of depletion of the mangroves (Saenger *et al*, 1983). In addition, lack of up-to-date and accurate data poses planning problems on conservation and management of mangroves (Gang and Agatsiva, 1992).

In most countries there is already some awareness to save the mangroves. Diverse management approaches designed to meet location specific situations, priorities and needs have been tried. For instance in Sierra Leone, the main thrust is to restore the biodiversity and productivity of overcut mangroves, afforestate degraded mud - flats and rehabilitate other human impacted coastal areas (FAO, 1994).

In the first step to achieve the management and conservation of mangroves, Tanzania has done an inventory of all the mangroves of mainland Tanzania with the assistance of NORAD. Aerial photography and ground checks were used to assess the state of all the mangrove reserves in the country (Semesi, 1991). Semesi stresses that the participation of the coastal people is of paramount importance for the success of the management of the mangrove resource and that they should be involved actively in conservation, utilisation and management. Such is the case in Gazi Bay where the community was involved in reafforestation of mangroves in the rehabilitation programme currently going on (Kairo, pers comm). Semesi also listed some of the limitations and constraints encountered in management planning which also seem to apply to Kenya, in addition to lack of co-ordination between the many different government institutions directly or indirectly involved in issues concerning mangroves.

In Kenya, the Forest Department is responsible of controlling the cutting by issuing licenses and ensuring that poles are cut according to the quantity specified, and suspends further cutting in some areas until regeneration is restored. Martens (1992, 1994) and Gang and Agatsiva (1992) have recommended a multidisciplinary management plan to be developed in order to conserve and manage the mangroves of Kenya on a sustainable basis.

1.7 Effects of mangrove removal and exploitation

The depletion and exploitation of mangroves is thought to lead to a decreased productivity of the swamps and causes loss in the biodiversity.

A documentation of mangrove forest community recovery in America following the removal of a major part of the upper, above ground, structure and foliage showed distinct patterns of recovery and canopy reclosure (Snedaker *et al.*, 1992). Two species (*L. racemosa* and *Avicennia germinans* (L)) with reserve or secondary meristems quickly produced new leaves and shoots in response to elevated light levels.

In contrast, recovery of *Rhizophora mangle* L. was limited by the slow production of new branch structures because this species is unable to regenerate on larger or older cut branches. An increase in seedling establishment following canopy removal was observed and canopy reclosure was shown to be the result of the growth of new foliage on the damaged but surviving mature trees.

At Ngomeni prawn farm (Kenya), the changes in height of the shore due to excavations altered the horizontal sequence of crab distribution along the surface profile across the shore in the disturbed mangrove forest. However, it was noted that the various species of crabs still occurred in their preferred levels. It was observed that recolonisation by mangrove was prolific and the trees were robust along the lower sides near the bottom of the excavated channels that brought seawater into the ponds, but extremely poor at higher shore levels where the vegetation had been clear cut about a decade ago and left unused (Ruwa, 1990).

1.8 Consequences of mangrove forests degradation

Loss of biodiversity in degraded mangroves is only one of the consequences of mangrove exploitation. Others include: decreased production of firewood, poles and timber; decrease of fish and prawn catches; less revenue paid to government in terms of royalties, tourist fee etc.; increase of coastal erosion increase of siltation and eventual reduction of seagrasses and coral reefs (Martens, 1992; Semesi, 1992).

CHAPTER 2

2. OBJECTIVES AND STUDY AREA

2.1 OBJECTIVES

The following were the objectives of this study.

1. To determine and compare the abundance and diversity of macrofauna of a heavily exploited and a less exploited mangrove swamp.

2. To determine the macrofauna that may be affected by the mangrove depletion.

2.2 STUDY AREA

2.2.1 Location

This study was conducted in Gazi (Muftana) Bay, located southcoast of Kenya (50 km from Mombasa) in Kwale district (4^0 25'S and 39^0 50'E) (Fig. 3). Gazi Bay is sheltered from strong waves by the presence of the Chale peninsula to the east and a fringing coral reef to the south. Two rivers, R. Kidogoweni (located to the north of the Bay) and R. Mkurumuji (located to the south of the Bay), create brackish conditions that favour mangrove growth.

2.2.2 Vegetation and Zonation

The mangrove forest in Gazi covers an area of approximately 615 ha. The mangrove species commonly found in this area are: *Avicennia marina* (Forsks) Viern., *Bruguiera gymnorrhiza* (L) Lam., *Ceriops tagal* (Perr) C. B.

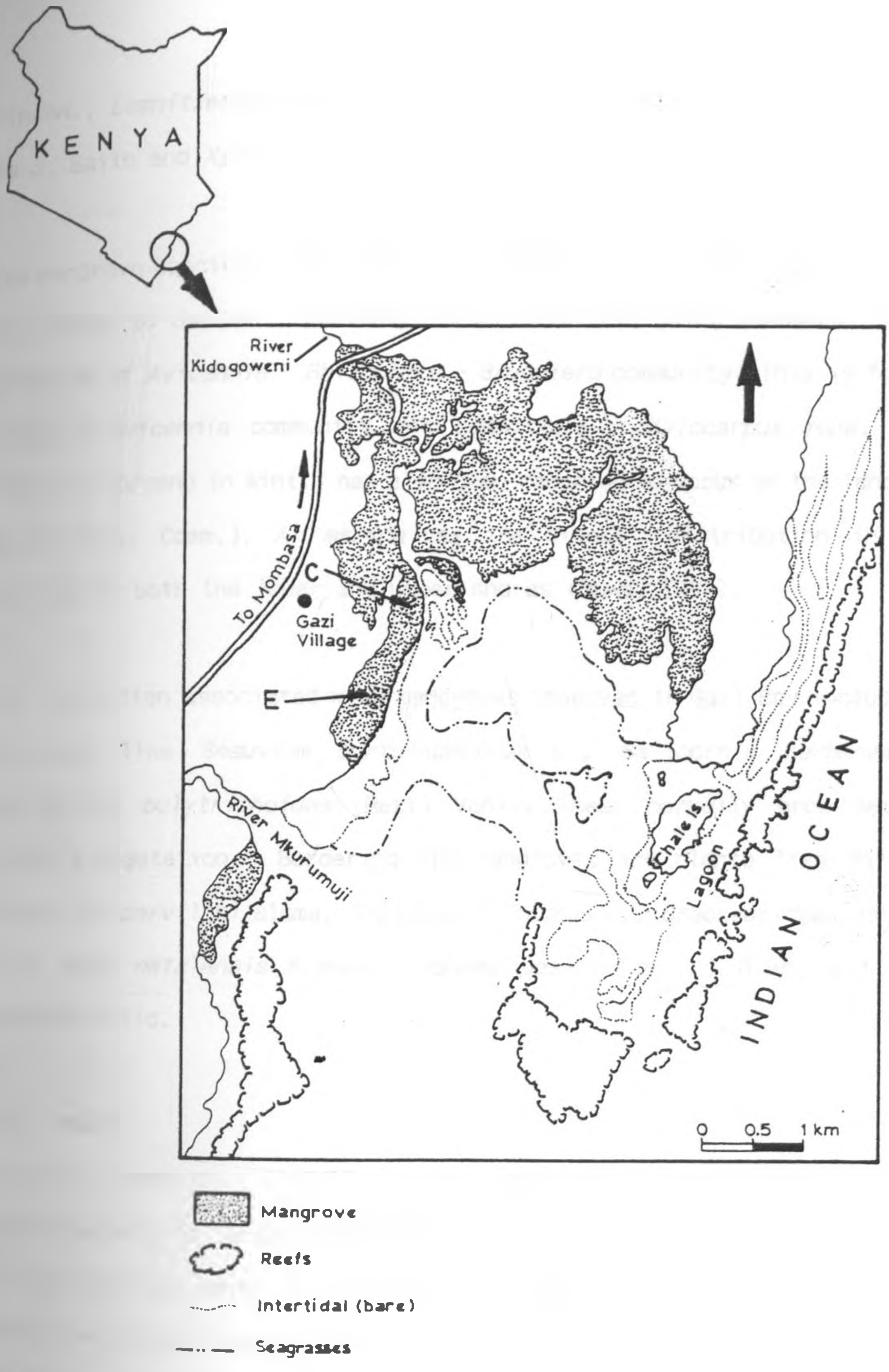


Fig. 3: Map of Gazi area and the study sites shown as C (less exploited area) and E (highly exploited area) (Source: KMFRI)

Robinson., *Lumnitzera racemosa* (Willd), *Rhizophora mucronata* Lam., *Sonneratia alba* J. Smith and *Xylocarpus granatum* (Koen).

These mangrove species show a zonation pattern, with *S. alba* occupying the lowest zone closest to the sea. Following the *S. alba* zone, going landwards, is a mixed vegetation of *Avicennia - Rhizophora - Bruguiera* community. This is followed by *Ceriops - Avicennia* community and *Lumnitzera - Xylocarpus* zone. *Heritiera littoralis* (Dryand in Aint.) has also been reported to occur on the landward side (Kairo, Pers. Comm.). *A. marina* has the widest distribution in Gazi Bay occurring at both the lower and upper shores (Ruwa, 1992).

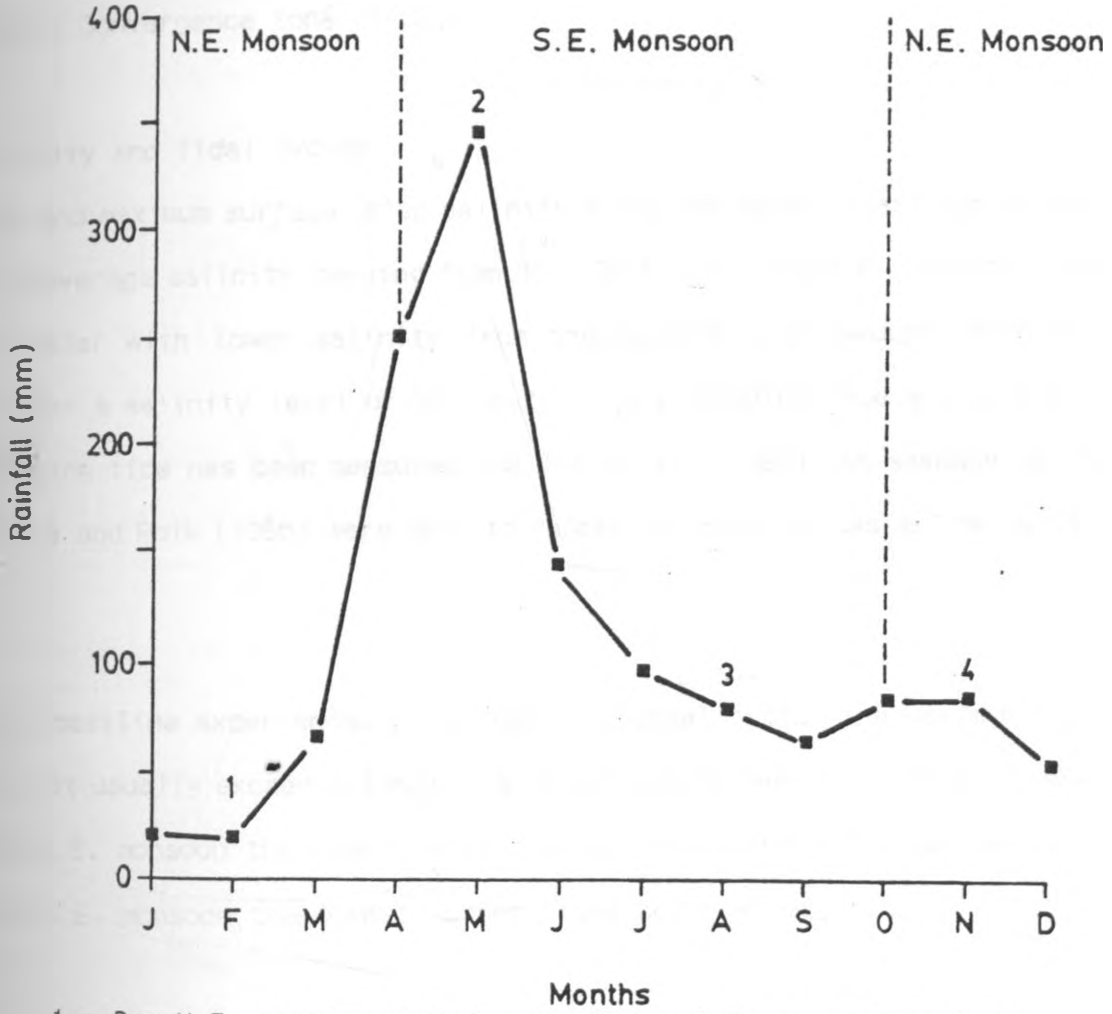
Other vegetation associated with mangroves observed in Gazi Bay include several halophytes like *Sesuvium portulacastrum* L., *Salicornia herbacea* L. and *Fimbristylis polytrichoides* (Rezt) Vahl.. These normally grow between the *Avicennia* vegetation. Bordering the mangroves are plants like *Salacia* sp., *Allophyllus pervillei* Blume, *Hibiscus tiliaceus* L., *Brackeuridges sanguebarica* Oliv., *Rhus natalensis* Krauss, *Ipomoea pes-caprae* (L) R.Br. and *Asparagus racemosus* Willd.

2.2.3 Fauna

The faunal community in Gazi is very diverse consisting of various groups from the microscopic to large ones like mammals. Some of these animals are visitors and some are residents in the mangrove swamp. Conspicuous fauna include the genera *Uca* (fiddler crabs), *Sesarma* (grapsid crabs), *Dernardus* (Hermit crabs) and *Ocypodidae* (ghost crabs). Gastropods common on the forest floor are horn shells (*Terebralia palustris* (Linne)) and on the tree trunks and pneumatophores the periwinkles (*Littorina scabra* (Linne)) and mangrove whelks (*Cerithidea decollata* (Linne)). Oysters (*Crassostrea cucullata* (Born)) and barnacles (*Balanus* spp. and *Chthalamus* spp.) are found attached on the surface of the most seaward mangrove species, *S. alba* and *R. mucronata*. Spectacular in the muddy areas are the mud skippers (*Periophthalmus* spp.) that hop around. Spiders (*Gasteracantha* spp.) construct their webs within the mangrove vegetation while ants (*Oecophylla longinoda* spp.) are common on the trees, constructing nests within the mangrove leaves. Mosquitoes and their larvae are common on the pools of water close to the landward limit of the mangroves. Different types of avifauna (e.g. whimbrels (*Numenius sp.*), common sandpipers (*Tringa sp.*), mangrove kingfisher (*Halycyon sp.*), olive sunbirds (*Nectarinia sp.*), white throated bee-eaters (*Merops sp.*), sombre greenbuls (*Andropadus sp.*)) are also found in mangroves and on the shore. Mammals such as bats, bushpigs, vervet monkeys and baboons can also be observed in this Bay.

2.2.4 Climate

The climate in Gazi Bay is one that prevails along the Kenyan coast, normally hot and humid with little variation in temperature. The average annual temperature is around 28 ^{0}C. The temperature in Gazi ranges between 20 ^{0}C and 30 ^{0}C (Ruwa, 1992) and the humidity is around 95 % due to the close proximity of Gazi area to the sea. The total annual precipitation varies from 800 to 1800 mm, showing a bimodal pattern of rainfall. The average monthly rainfall graph for Gazi area showed highest rainfall in May (long rains) and November (short rains) and the drier months being January - February and September (Kwale District Environ. Impact Assess., 1985). Figure 4 shows the average rainfall for the period 1922 - 1987 (65 years) for a station near Gazi (Gazi Associate Sugar works: Station



1 - Dry N.E. monsoon period 2 - Rainy S.E. monsoon period

3 - Dry S.E. monsoon period 4 - Rainy N.E. monsoon period

Fig. 4: The average monthly rainfall (mm) for Gazi Associate Sugar Works Station (1962 - 1987) (Source: Meteorological Dept. Headquarters)

9439004; Source: Meteorological department Headquarters, Nairobi).

The rains are brought by the two Monsoon winds prevailing along the Kenyan coast: The North East (N.E.) monsoon (November to March) and South East (S.E.) monsoon (April to October) which are influenced by the annual migration of the Intertropical Convergence Zone (ITCZ).

2.2.5 Salinity and Tidal Cycles

The minimum and maximum surface water salinity along the Kenyan coast varies very little, the average salinity ranging from 35 - 36 p.p.t. The N.E. monsoon winds bring sea water with lower salinity from the Malayan archipelago (Moorjani, 1977). At Gazi a salinity level of 35 p.p.t. at the incoming tide and 32 p.p.t. at the outgoing tide has been measured (Gallin *et al.*, 1989). At seepage points of Gazi, Ruwa and Polk (1986) were able to record salinity values as low as 16 - 20 p.p.t..

The Kenyan coastline experiences mixed semi - diurnal tides. The maximum tidal range does not usually exceed 3.8 m but may sometimes be over 4 m (Brakel, 1982). During the N.E. monsoon the lowest spring tides occur during the day while during the S.E. monsoon the lowest spring tides occur at night.

2.2.6 Geology and Soils

The rocks are mainly of sedimentary origin. The river deposits of alluvium of the recent geological period are found in the mangrove swamps.

The soils vary with the topography and geology of the area. Gazi, being in the coastal plains has sand, clay, loam and alluvium deposits. The soils of the mangrove swamps are very poorly drained, very deep, excessively saline, olive to greenish grey, loam to clay and often with sulfidic material (Kwale District Environ. Assess. Report, 1985).

2.2.7 Human Activities

Gazi village is a small village with about 100 homesteads and a human population of about 720. The people of Gazi depend on the sea for a living. Gazi Bay presents an important area for both commercial and subsistence fishing activities. Recent small scale aquaculture ventures involve the artificial raising of oysters by the Kenya Marine and Fisheries Research Institute (KMFRI). Apart from fishing, cutting of mangroves for building poles and fuel wood is among the common occupations for the people of Gazi. Cutting is done at low tide and poles are transported to the harbour in canoes at high tide. Very little commercial agriculture goes on at Gazi. The area around Gazi Bay is a coconut plantation owned by the Msambweni Development Farm.

For many years there has been extensive exploitation of Gazi mangroves for various purposes. The mangrove forest has been affected most noticeably by wood extraction for industrial fuel and building poles. Wood extraction for fuel has declined following the depletion of the big mangrove trees and inaccessibility of the resource in the remaining parts (Kairo, 1993).

2.2.8 Reasons for choice of this study site

1. Gazi area is accessible and different areas are easy to reach compared to

other mangrove swamps.

2. Both highly exploited and less exploited areas are present in this area.
3. A lot of research has been carried out in Gazi and this provided background information.

2.2.9 Description of Transects and sampling stations

In Gazi, 2 sites were selected (Fig.3) and transects established in the highly exploited (E) and the less exploited (C) areas, with several stations (see Figs. 5 & 6)

2.2.9.1 Highly Exploited area (Transect E)

Consists of a few trees of *A. marina*, *L. racemosa* and *B. gymnorrhiza* towards the landward edge. Approaching the shore, is a bare sand dune with few *Casuarina* trees and old tree stumps. Close to the shore are *S.alba* trees.
This area was deforested approximately two decades ago.

Description of the 4 stations in transect E where sampling of macrofauna and other factors was done is as follows.

Station E1 - Deforested mixed *A. marina* and *C. tagal*, with sandy substratum.

Station E2 - Deforested mixed *B. gymnorrhiza* and *C. tagal*, having coarse sand.

Station E3 - Deforested *R. mucronata*, near a sand dune, with muddy, dark substratum.

Station E4 - Deforested *S. alba*, with muddy, dark substratum.

2.2.9.2 Less Exploited area (Transect C)

In this transect *C.tagal* trees occur towards the landward side followed by a mixed forest of *B. gymnorrhiza* and *R. mucronata*.

A sand dune occurs midway towards the shore where *Pandanus kurkii* Rendle (walking palm) are present and towards the shore *A. marina* and *S. alba* occur.

Description of the 4 stations in transect C where sampling of macrofauna and other factors was done is as follows.

Station C1 - Mixed *A. marina* and *C. tagal*, with a sandy substratum.

Station C2 - Mixed *B. gymnorrhiza* and *C. tagal*, with sandy substratum

Station C3 - *R. mucronata*, with a dark muddy substratum.

Station C4 - *S. alba*, with dark, muddy substratum.

CHAPTER 3

3. MATERIALS AND METHODS

3.1 SAMPLING MACROFLORA

Line transects of 10 m width were established in the selected sites. The transects ranging from 200 m to 240 m in length, covered the different mangrove vegetation zones (from the landward edge towards the water edge). Quadrats of 10 m x 10 m were made along the transects at 10 m intervals. In each quadrat, plant species encountered were recorded and the mangrove trees seedlings and / or tree stumps present in the quadrats were counted. Circumference of mature trees was recorded for computation of diameter at breast height (dbh). The dbh was used to calculate the basal area, $g = \pi/ 4(dbh)^2$. The frequency of occurrence of plant species was also recorded. The relative density (Rde), relative dominance (Rdo) and the relative frequency (Rfr) were calculated as follows (Cintron & Novelli, 1984):

Rde = (# of individuals of a spp/ total #of individuals) x 100
Rdo = (total basal area of a spp/ basal area of all spp) x 100
Rfr = (frequency of a spp/ sum frequency of all spp) x 100

The Rde, Rdo and Rfr are used to interpret the importance of the contribution of each component species to the stand in terms of density, contribution to basal area (dominance) and the probability of occurence through out an area (frequency).

The Importance Value (IV) was calculated as IV = Relative frequency + Relative dominance + Relative density. The Importance Value gives the overall dominance of a species in a community. This was done only once during the study period, in November 1992.

3.2 SAMPLING MACROFAUNA

Quantitative sampling of macrofauna was done along the transects at 4 stations, in the different vegetation zones. Epifauna were sampled using an aluminium drop trap (Oluoch pers. comm.) of 0.5 m x 0.5 m (three drops per station). The epifauna were counted, recorded and collected where possible. Crabs were collected by excavating the burrows into which they retreated when disturbed. Identification of crabs was done following identification keys by Crane (1976). The epifauna collected were preserved in formalin and later in the laboratory, their biomass was estimated by weighing them in different groups of taxa in each station before and after drying them in an oven at a temperature of 60 ^{0}C.

Macroinfauna were collected over an area of 0.1 m x 0.1 m to a depth of 15 cm by scooping the sediment using a hand spade (the area was marked out using a small 0.1 m x 0.1 m quadrat). This was repeated three times per station in each of the vegetation zones. The sediment collected was placed in polythene bags, fixed with neutralised 5% formalin containing Rose Bengal stain. In the laboratory, the sediment was sieved through a 1.0 mm and 0.5 mm sieve to obtain the macroinfauna. Material trapped in the 1.0 mm sieve was sorted out by hand. The material that passed through the 1.0 mm sieve but was retained in the 0.5 mm sieve was placed in a jar with a spout and subjected to a jet of water, and the floating matter which also contained the macroinfauna was passed from the spout and trapped again in the 0.5 mm sieve as the heavier sediment settled to the bottom of the jar (i.e. the decanting method). The macroinfauna were then picked out using a binocular microscope, and identified. There was lack of adequate identification keys but where possible identification was done to the genus level following identification keys by Day (1978) and Barnes (1982), and counted. The samples were preserved in 5% neutralised formalin.

From the pit created by digging the sediment for infauna, the water that immediately seeped in was collected using 100 ml capacity cleaned plastic bottles. The samples were preserved with 2 drops of chloroform (except for pH and salinity) and frozen to avoid metabolism by micro-organisms. This interstitial water was analysed for some of the physico - chemical factors as described below in section 3.3.

3.3 PHYSICO - CHEMICAL FACTORS

3.3.1 Elevation

Elevation in cm above MLWS was taken along the transects after every 10 m using a T - piece water level. Heights above MLWS were computed using a tide table (1993) for Kilindini harbour (Mombasa).

3.3.2 Salinity

The salinity of interstitial water collected was measured using an Aanderaa Instruments salinometer. Units were recorded in parts per thousand.

3.3.3 pH

The pH of interstitial water collected was measured using a CG 840 (Schott) pH meter.

3.3.4 Temperature

The air, interstitial water and sediment temperatures were recorded using a simple mercury glass thermometer, with a precision of 0.5 ^{0}C.

3.3.5 Nutrients

Inorganic nitrate, inorganic phosphate and ammonium content of the interstitial water collected was determined using a Technicon auto - analyser.

3.3.5.1 Determination of nitrate + nitrite (here after referred to simply as nitrate)

Nitrate in the collected water was reduced quantitatively to nitrite when a sample was run through a column containing cadmium fillings coated with metallic copper. The nitrite produced was determined by diazotizing with sulphanilamide to form a highly coloured azo dye whose absorbance was measured using a spectrophotometre 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 were prepared from a stock solution of potassium nitrate, KNO_3 (concentration = 20 µg - at N/l) for calibration.

3.3.5.2 Determination of Inorganic Phosphate

The water samples were allowed to react with a composite reagent containing molybdic acid, ascorbic acid and trivalent antimony. The resulting complex was reduced to give a blue solution whose absorbance was measured using a spectrophotometre at a wavelength of 885 nm. Standard solutions of 0.2, 1.0, 2.0, 3.0, 4.0 and 5.0 µg - at P/l were prepared from a stock solution of potassium dihydrogen phosphate, KH_2PO_4 for calibration.

3.3.5.3 Determination of Ammonium

The samples were treated in an alkaline citrate medium with sodium hypochlorite and phenol in the presence of sodium nitroprusside which acts as a catalyst. The blue indophenol colour formed with ammonia present in the sample was measured using a spectrophotometre at a wavelength of 640 nm. Standard solutions of 0.2, 2.0, 4.0, 6.0, 8.0 and 10.0 µg - at N/1 were prepared from a stock solution of ammonium sulphate solution for calibration.

3.3.6 Determination of soil organic matter

Soil samples were collected using a core of 3.6 cm in diameter. The soil was oven dried at 60 ^{0}C and divided for organic matter and particle size analysis (see section 3.3.7).

An estimate of organic matter present in the soil samples was obtained by the loss of weight on ignition at 600 ^{0}C in a furnace for a period of 6 hours and was expressed as a percentage of the dry weight.

3.3.7 Particle size analysis

A graded series of standard sieves (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), were used to separate a known weight of sediment to the different categories of particle size, using an electric sieve shaker. The weights of soil particles retained in each sieve was measured and the percentage compostion of the mean grain size (in mm) determined.

3.4 Sampling time

Salinity, temperatures, nutrients and soil samples were taken together with the macrofauna, during the daylight low spring tides (usually between 9:00 a.m. and 1:00 p.m.) in four seasons during the study period (1993): February representing the dry N.E. monsoon period, May representing the rainy season of the S.E. monsoon, August representing the dry season S.E. monsoon and November representing the rainy season of the N.E. monsoon period.

3.4 Statistical analyses

For the different variables recorded, 2-factor ANOVA was done for the two areas and seasons, and the relationship between the physico-chemical factors were tested using Pearsons correlation coefficients on the SPSS programme. A χ^2 test was performed for the proportions of different groups of macrofauna occurring in the two areas. Diversity indices (Shannon - Wiener diversity (H')) were calculated and a t-test was used to test their significance. The diversity index was calculated as follows (Zar, 1984):

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

where pi is the proportion of i^{th} species

To test the difference between two diversity indices the following t - test was used:

$$t = \frac{H'_1 - H'_2}{s_{H'1 - H'2}}$$

$$s_{H'1 - H'2} = \sqrt{s^2_{H'1} + s^2_{H'2}}$$

The evenness, E, which measures how the individuals are distributed within the species, was calculated as follows:

$E = H'/\ln S$

where S is the number of species

The Margalef's diversity index (Magurran, 1988) was used to calculate the species richness.

$D_{Mg} = (S - 1)/\ln N$

where S is the number of species and N is the number of individuals.

CHAPTER 4

4. RESULTS

4.1 MACROFLORA

4.1.1 Highly exploited site (i.e. site E)

In this transect (Table 2), four mangrove species were present (*L. racemosa, A. marina, B. gymnorrhiza* and *S. alba*) but tree stumps were dominant. Seedlings (mainly of *R. mucronata* and *C. tagal*) were also abundant. Other non-mangrove species also occurring in the transect were *Casuarina equisetifolia* L. and *S. spicatus*. *S.alba* ranked 1st in Importance Value. Tree stumps had the highest relative density (Rde). Of the mature trees, *S. alba* had the highest Rde as well as the highest relative dominance (Rdo), while the highest relative frequency (Rfr) was given by the stumps and seedlings. Figure 5 shows the profile diagram of this transect.

Area E

Species	Rde	Rdo	Rfr	IV
L. racemosa	50.00	.04	6.25	11.29
A. marina	22.85	.80	12.50	36.15
C. tagal	0	0	0	0
B. gymnorhiza	22.50	.23	12.50	35.23
R. mucronata	0	0	0	0
S. alba	60.40	1.10	12.50	74.00
C. equisitifolia	20.00	.50	6.25	26.75
P. kurkii	0	0	0	0
S. spicatus	50.00	0	12.50	62.50
seedlings	59.70	0	18.75	78.45
Stumps	81.10	0	18.75	99.85

Table 2: Relative density (Rde), relative dominance (Rdo), relative frequency (Rfr) and Importance Value (IV) of macroflora in area E.

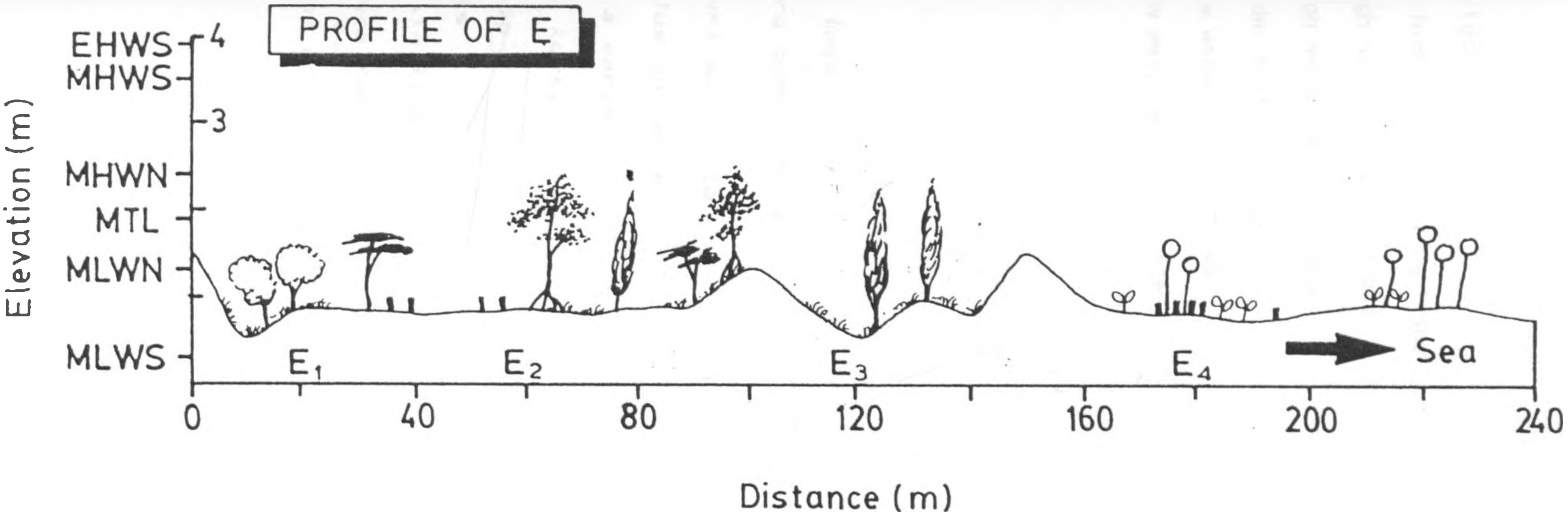


Fig. 5: Profile diagram of transect E, see legend next page

NB: Tree heights have been exaggerated

Legend for Figs. 5 & 6

EHWS - extreme high water at spring tides

MHWS - mean high water at spring tides

MHWN - mean high water at neap tides

MTL - mean tide level

MLWN - mean low water at neap tides

MLWS - mean low water at spring tides

Ceriops tagal

Bruguiera gymnorrhiza

Rhizophora mucronata

Sporobolus spicatus

Avicennia marina

Pandanus kurkii

Tree stump

Seedlings

Sonneratia alba

Lumnitzera racemosa

Casuarina equisetifolia

4.1.2 Less exploited site (i.e site C)

This transect was represented by 5 mangrove species (*A. marina, C.tagal, B. gymnorrhiza, R. mucronata* and *S. alba*) with *C. tagal* having the 1st Importance Value rank (Table 3). *S. alba* recorded the highest Rde while *B. gymnorrhiza* had the lowest. *C. tagal* had the highest Rdo as well as the highest Rfr. The non-mangrove species encountered in this transect were *S. spicatus* and *P. kurkii*. Figure 6 shows the profile diagram of this transect.

Area C Species	Rde	Rdo	Rfr	IV
L. racemosa	0	0	0	0
A. marina	26.64	6.67	16.10	49.41
C. tagal	58.73	46.11	29.03	133.87
B. gymnorhiza	22.20	15.56	6.45	44.21
R. mucronata	25.75	28.89	25.81	80.45
S. alba	100.00	2.78	3.23	106.01
C. equisitifolia	0	0	0	0
P. kurkii	75.00	0	6.45	81.45
S. spicatus	50.00	0	3.23	53.23
seedlings	29.26	0	9.68	38.94
Stumps	0	0	0	0

Table 3: Relative density (Rde), relative dominance (Rdo), relative frequency (Rfr) and Importance Value (IV) of macroflora in area C.

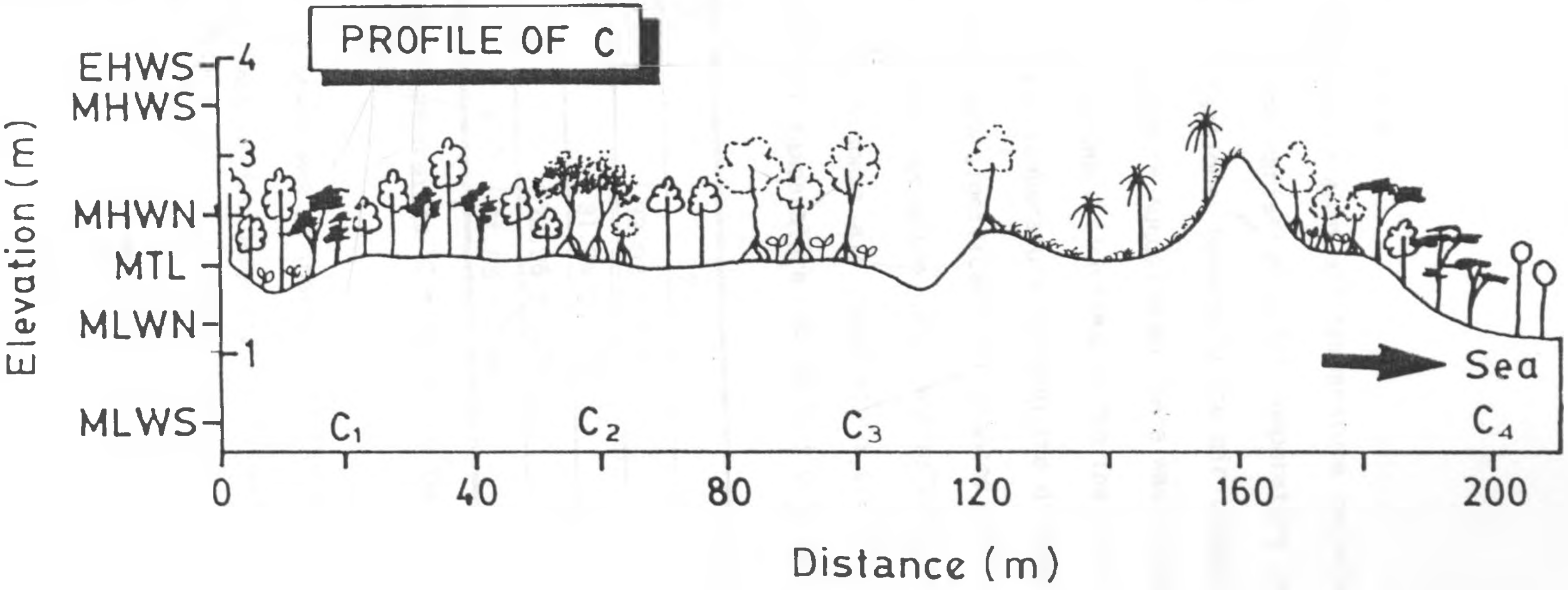


Fig. 6: Profile diagram of transect C, see legend on pg 43

NB: Tree heights have been exaggerated

4.2 PHYSICO - CHEMICAL FACTORS

4.2.1 Temperature

4.2.1.1 Air temperature

Table 4 shows the monthly mean air temperature recorded at each transect and figures 7a & 7b show the variation in air temperature recorded in the two areas during the sampling sessions. Generally the air temperature along the transect E varied randomly except in August when there was a gradual increase of the air temperature from the landward side towards the the sea. There were no significant differences in the air temperature between the different stations ($F_{(3,9)}$= 3.13, $p > 0.05$), but there were significant differences between the months ($F_{(3,9)}$= 7.5, $p < 0.05$). The source of variation in the months was between February and August. February having the highest air temperature (32.02 ^{0}C ± 0.45 SE) and August having the lowest air temperature (28.96 ^{0}C ± 0.54 SE).

Month/Site	E	C
February	32.02 ± 0.45	31.00 ± 0.33
May	31.04 ± 1.73	33.15 ± 0.68
August	28.96 ± 0.54	27.42 ± 0.65
November	31.96 ± 0.65	32.13 ± 0.52

Table 4: Mean air temperature ^{0}C ± SE in the two areas during the sampling sessions (n = 12)

Along transect C, there was an increase in the air temperature from the landward side towards the sea in February and August while there was a decrease towards the sea in May. There was no significant difference between the stations ($F_{(3,9)}$ = 0.54, $p > 0.05$), but there were significant differences between the

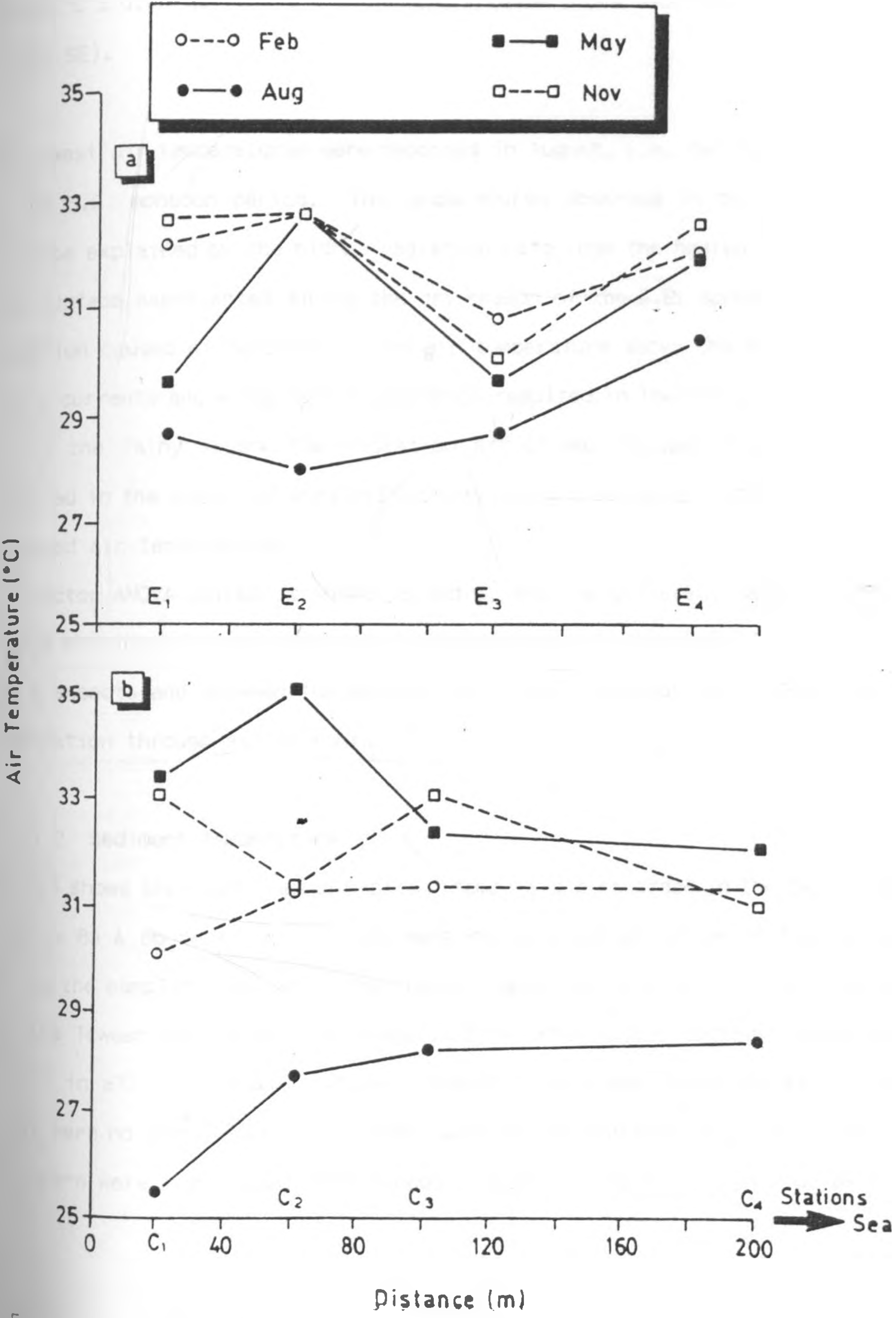


Fig. 7: Variation of air temperature along transect E (a) and transect C (b)

months ($F_{(3,9)}$= 17.56, $p< 0.05$) with the lowest air temperature recorded in August (27.42 ^{0}C ± 0.65 SE) and the highest air temperature recorded in May (33.15 ^{0}C ± 0.68 SE).

The lowest air temperatures were recorded in August, i.e. during the dry season of the S.E. monsoon period. The temperatures observed in the exploited area could be explained by the higher radiation rate from the heated from the heated bare surface experienced during the dry season of the S.E. monsoon period. The radiation caused differences in the air temperature above the surface, leading to air currents and windy conditions which resulted in lowered air temperatures. During the rainy season the radiation effect was reduced and more heat was retained in the vegetated area rather than being dissipated faster, resulting in elevated air temperatures.

A 2-factor ANOVA between transect E and C, and the different sampling periods, showed that the air temperature was not significantly different for both between the transects and between the months ($p> 0.05$). This may be as result of heat dissipation through air currents.

4.2.1.2 Sediment temperature

Table 5 shows the monthly mean sediment temperature recorded in the two areas and figures 8a & 8b represent the sediment temperature variation in the two areas during the sampling sessions. The highest temperatures were recorded in November and the lowest temperatures in August. E recorded higher sediment temperatures than C in all the seasons. Along transect E, no clear trend was exhibited and there were no significant differences between the stations ($F_{(3,9)}$= 0.74, $p> 0.05$) but there were significant differences between the months ($F_{(3,9)}$= 7.3, $p< 0.05$), especially between August when the lowest temperature was recorded (29.88 ^{0}C ± 1.13 SE) and November when the highest temperature (35.00 ^{0}C ± 0.41 SE) was recorded. Along transect C there was a gradual increase of the sediment temperature from the landward side towards the sea in February, May and August. There was no significant difference between the stations ($F_{(3,9)}$= 3.06, $p > 0.05$) but there was a significant difference between the months ($F_{(3,9)}$= 23.40, $p < 0.05$).

Month/Site	E	C
February	33.58 ± 0.89	29.80 ± 0.46
May	31.80 ± 0.53	30.83 ± 0.74
August	29.88 ± 1.13	27.08 ± 0.72
November	35.00 ± 0.41	33.38 ± 0.69

Table 5: Mean sediment temperature ^{0}C ± SE in the two areas during the sampling sessions (n = 12)

A 2-factor ANOVA of the sediment temperature between two areas and months showed that there were significant differences between the transects ($F_{(1,3)}$= 13.49; $p < 0.05$) and the months ($F_{(3,3)}$= 14.01; $p < 0.05$). This may be due to the differences in the vegetation cover between the two areas, the exploited area recorded higher sediment temperatures than the less exploited area due to the absence of vegetation cover which provides shading and therefore lowers the sediment temperature.

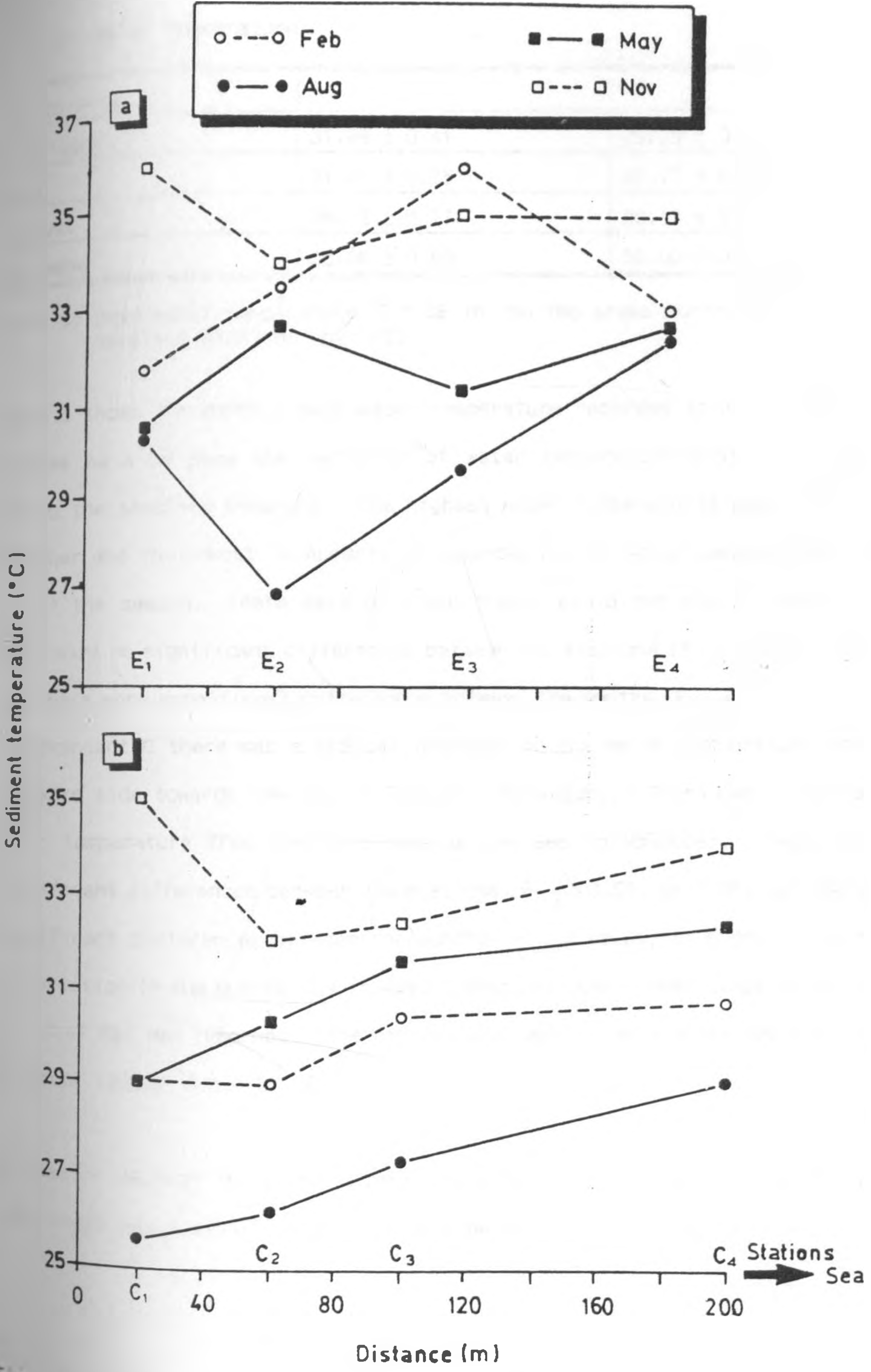


Fig. 8: Variation of sediment temperature along transect E (a) and transect C (b)

4.2.1.3 Water temperature

Month/Site	E	C
February	31.98 ± 0.41	29.33 ± 0.36
May	31.25 ± 0.75	30.17 ± 0.69
August	28.13 ± 0.77	26.17 ± 0.47
November	33.08 ± 0.60	32.00 ± 0.91

Table 6: Mean water temperature ^{0}C ± SE in the two areas during the two sampling sessions (n = 12)

Table 6 shows the monthly mean water temperature recorded at each transect and figures 9a & 9b show the variation of water temperature along the transects during the sampling sessions. The highest water temperatures were recorded in November and the lowest in August. E recorded higher water temperatures than C in all the season. There were no clear trends exhibited along transect E and there were no significant differences between the stations ($F_{(3,3)}$= 0.46, $p > 0.05$), but there were significant differences between the months ($F_{(3,3)}$= 9.30, $p < 0.05$). In transect C there was a gradual increase in the water temperature from the landward side towards the sea in February and August. There was a decrease of water temperature from the land towards the sea in November. There were no significant differences between the stations ($F_{(3,3)}$= 0.59, $p > 0.05$) but there were significant differences between the months ($F_{(3,3)}$= 12.91, $p < 0.05$). The source of variation in the months was in August when the lowest mean temperature (26.17 ^{0}C ± 0.47 SE) was recorded. The highest mean water temperature was recorded in November (32.00 ^{0}C ± 0.91 SE).

A 2-factor ANOVA of the water temperature between the two areas and months showed that there was a significant difference between the transects ($F_{(3,3)}$= 19.76, p<

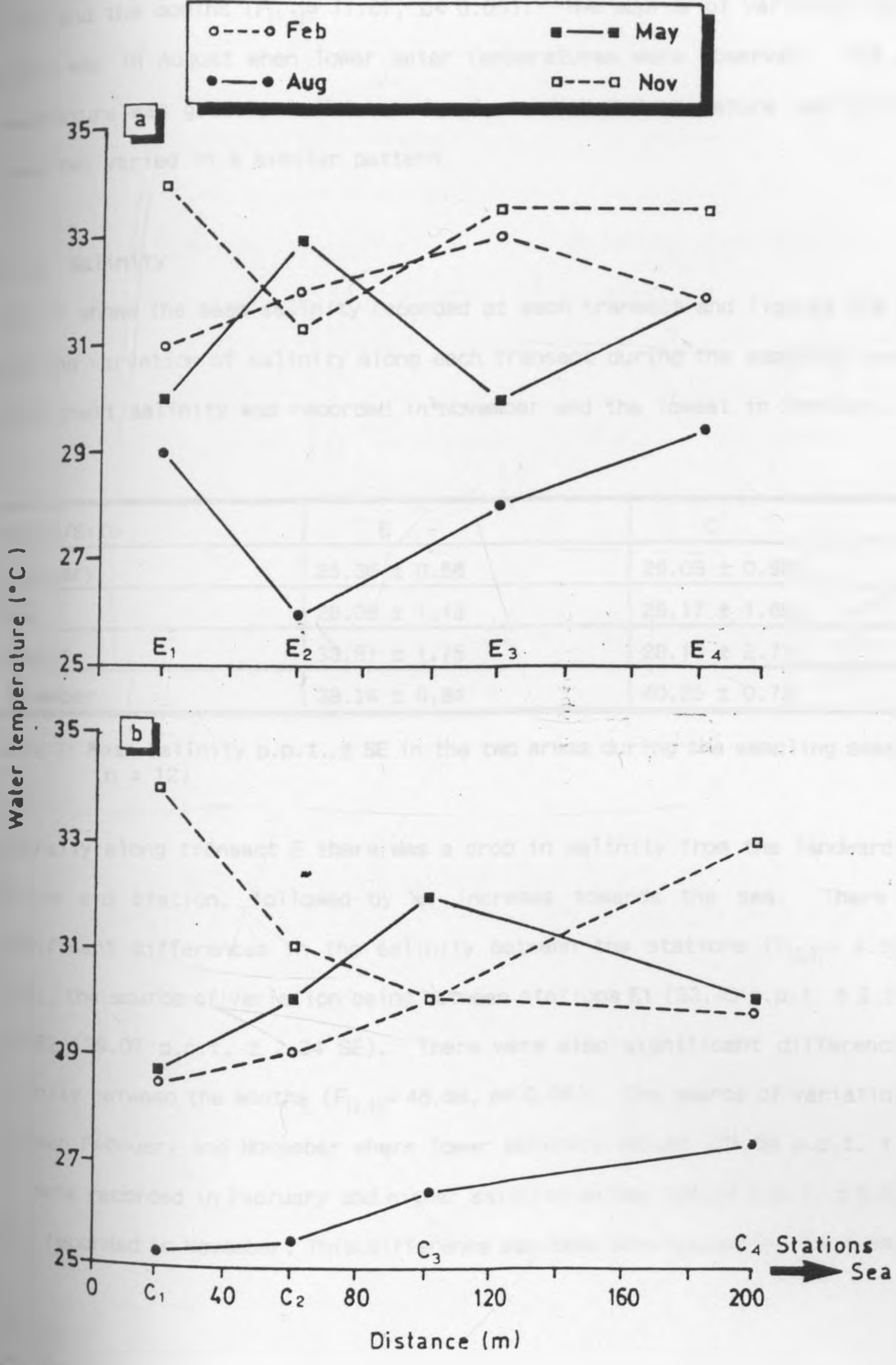


Fig. 9: Variation of water temperature along transect E (a) and transect C (b)

0.05) and the months ($F_{(1,3)}$= 11.67, $p< 0.05$). The source of variation for the months was in August when lower water temperatures were observed. The water temperature was greatly influenced by the sediment temperature and therefore these two varied in a similar pattern.

4.2.2 Salinity

Table 7 shows the mean salinity recorded at each transect and figures 10a & 10b show the variation of salinity along each transect during the sampling periods. The highest salinity was recorded in November and the lowest in February.

Month/Site	E	C
February	25.36 ± 0.56	26.09 ± 0.98
May	28.09 ± 1.13	26.17 ± 1.69
August	33.91 ± 1.75	28.10 ± 2.71
November	38.14 ± 0.84	40.25 ± 0.72

Table 7: Mean salinity p.p.t. ± SE in the two areas during the sampling sessions (n = 12)

Generally along transect E there was a drop in salinity from the landward side to the mid station, followed by an increase towards the sea. There were significant differences in the salinity between the stations ($F_{(3,9)}$= 4.55, $p< 0.05$), the source of variation being between stations E1 (33.45 p.p.t. ± 2.27 SE) and E2 (29.07 p.p.t. ± 2.34 SE). There were also significant differences in salinity between the months ($F_{(3,3)}$= 46.68, $p< 0.05$). The source of variation was between February and November where lower salinity values (25.36 p.p.t. ± 0.56 SE) were recorded in February and higher salinity values (38.14 p.p.t. ± 0.84 SE) were recorded in November. This difference may have been caused by the submarine groundwater discharges which are common during low tide. Along transect C, no clear trends were exhibited and there were no significant differences in salinity between the stations ($F_{(3,9)}= 1.22$, $p> 0.05$), but there were significant differences in the months ($F_{(3,9)}= 16.69$, $p< 0.05$). The source of variation in the months was in November when a higher salinity (40.25 p.p.t. ± 0.72 SE) was recorded. The lowest salinity (26.09 p.p.t. ± 0.98 SE) was recorded in February. A 2-factor ANOVA of the salinity between the two areas and months showed that there was no significant difference between the two transect but there was a significant difference ($F_{(3,3)}= 12.04$, $p< 0.05$) between the months. The source of variation for the months was in November and February. In November higher salinity levels were recorded while in February lower salinity levels were recorded.

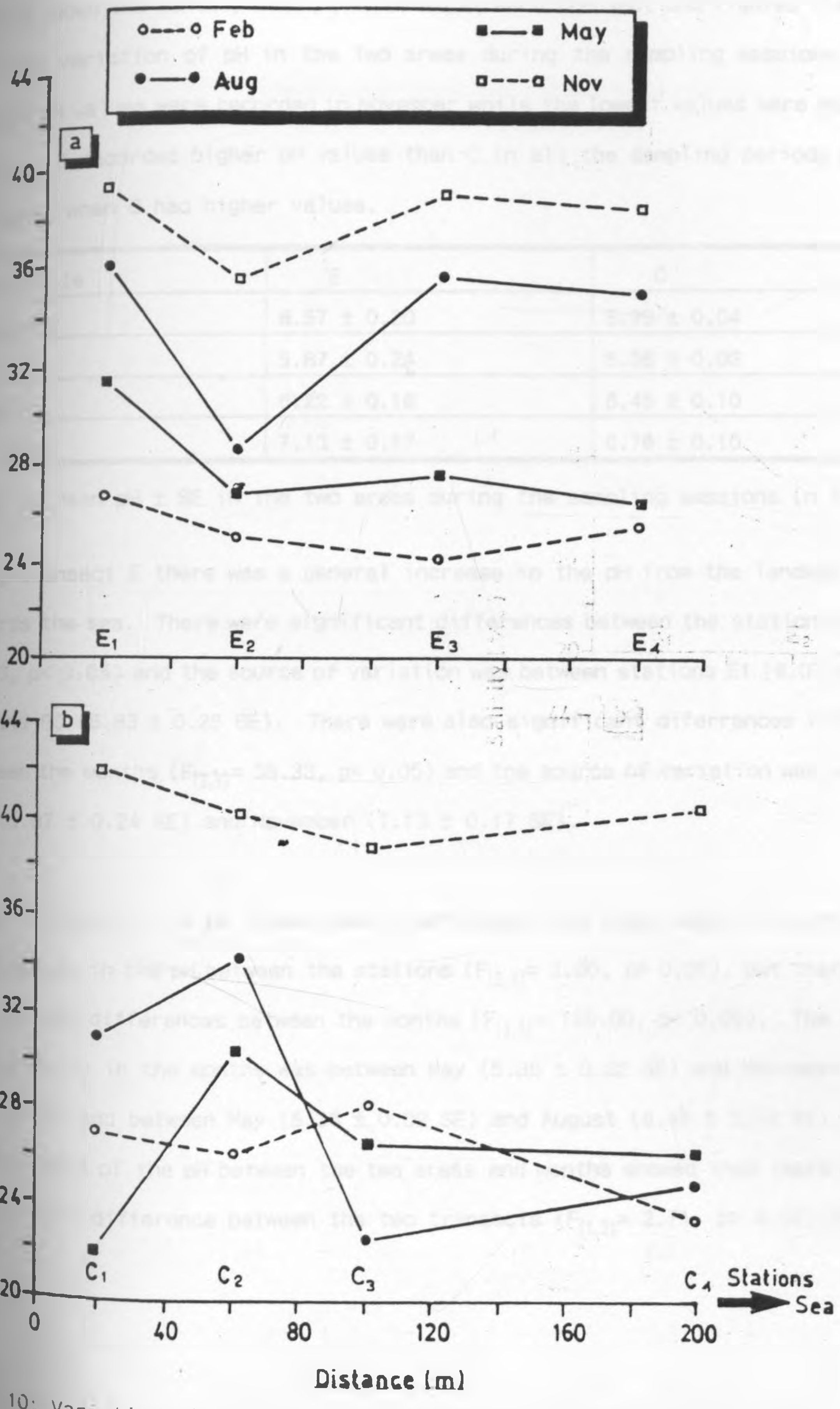


Fig. 10: Variation of salinity along transect E (a) and transect C (b)

4.2.3 pH

Table 8 shows the monthly mean pH recorded at each transect and figures 11a & 11b show the variation of pH in the two areas during the sampling sessions. The highest pH values were recorded in November while the lowest values were recorded in May. E recorded higher pH values than C in all the sampling periods except in August when C had higher values.

Month/Site	E	C
February	6.57 ± 0.20	5.99 ± 0.04
May	5.87 ± 0.24	5.36 ± 0.02
August	6.22 ± 0.16	6.45 ± 0.10
November	7.13 ± 0.17	6.76 ± 0.10

Table 8: Mean pH ± SE in the two areas during the sampling sessions (n = 12)

Along transect E there was a general increase in the pH from the landward side towards the sea. There were significant differences between the stations ($F_{(3,3)}$= 18.00, $p < 0.05$) and the source of variation was between stations E1 (6.07 ± 0.31 SE) and E3 (6.83 ± 0.25 SE). There were also significant diferrences in the pH between the months ($F_{(3,3)}$= 38.33, $p < 0.05$) and the source of variation was between May (5.87 ± 0.24 SE) and November (7.13 ± 0.17 SE).

Along transect C the pH showed small variations and there were no significant differences in the pH between the stations ($F_{(3,3)}$= 3.00, $p > 0.05$), but there were significant differences between the months ($F_{(3,3)}$= 149.00, $p < 0.05$). The source of variation in the months was between May (5.36 ± 0.02 SE) and November (6.76 ± 0.10 SE) and between May (5.36 ± 0.02 SE) and August (6.45 ± 0.10 SE). A 2-factor ANOVA of the pH between the two areas and months showed that there was no significant difference between the two transects ($F_{(1,3)}$= 2.71, $p > 0.05$) and

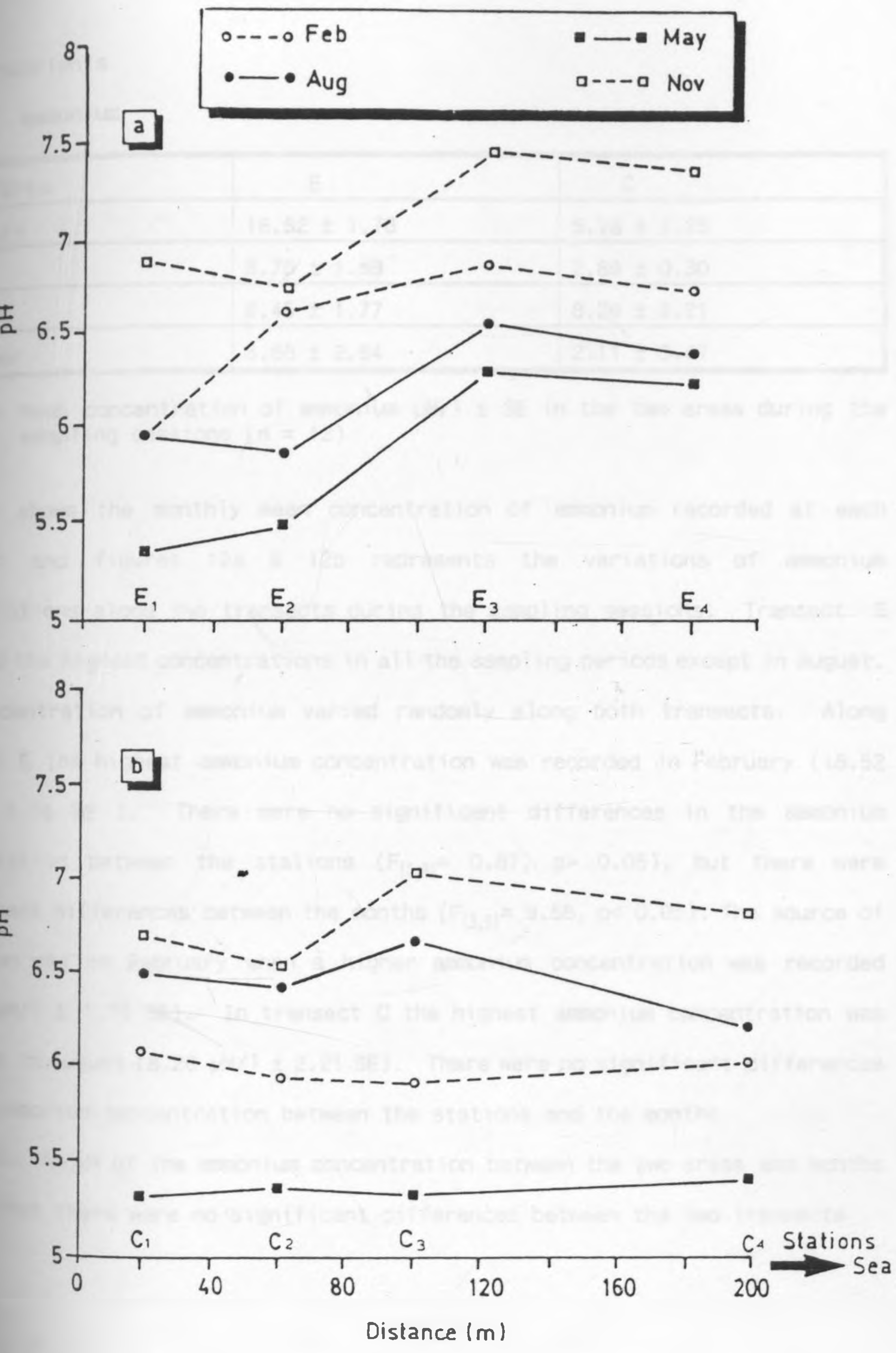


Fig. 11: Variation of pH along transect E (a) and transect C (b)

between the months ($F_{(3,3)}$= 8.43, p> 0.05).

4.2.4 Nutrients

4.2.4.1 Ammonium

Month/Site	E	C
February	18.52 ± 1.76	6.18 ± 2.25
May	5.75 ± 1.69	2.89 ± 0.30
August	6.45 ± 1.77	8.26 ± 2.21
November	5.66 ± 2.64	2.11 ± 0.67

Table 9: Mean concentration of ammonium µM/l ± SE in the two areas during the sampling sessions (n = 12)

Table 9 shows the monthly mean concentration of ammonium recorded at each transect and figures 12a & 12b represents the variations of ammonium concentrations along the transects during the sampling sessions. Transect E recorded the highest concentrations in all the sampling periods except in August. The concentration of ammonium varied randomly along both transects. Along transect E the highest ammonium concentration was recorded in February (18.52 µM/l ± 1.76 SE). There were no significant differences in the ammonium concentration between the stations ($F_{(3,9)}$= 0.87, p> 0.05), but there were significant differences between the months ($F_{(3,9)}$= 9.58, p< 0.05). The source of variation was in February when a higher ammonium concentration was recorded (18.52 µM/l ± 1.76 SE). In transect C the highest ammonium concentration was recorded in August (8.26 µM/l ± 2.21 SE). There were no significant differences in the ammonium concentration between the stations and the months.

A 2-factor ANOVA of the ammonium concentration between the two areas and months showed that there were no significant differences between the two transects

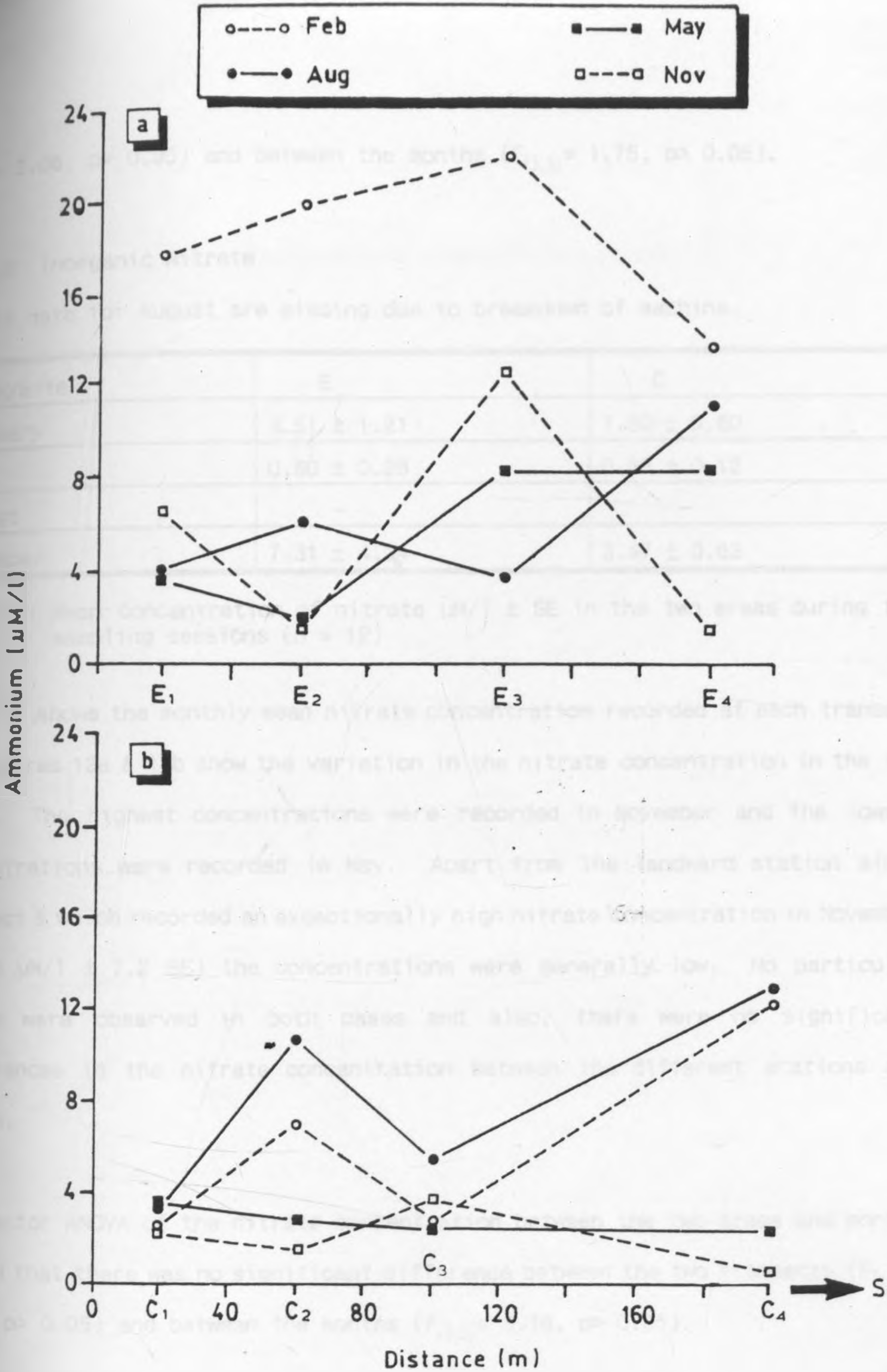


Fig. 12: Variation of the concentration of ammonium along transect E (a) and transect C (b)

($F_{(1,3)}$= 2.06, p> 0.05) and between the months ($F_{(3,3)}$= 1.75, p> 0.05).

4.2.4.2 Inorganic Nitrate

Nitrate data for August are missing due to breakdown of machine.

Month/Site	E	C
February	3.51 ± 1.21	1.80 ± 0.60
May	0.60 ± 0.26	0.88 ± 0.12
August	-	-
November	7.31 ± 4.24	3.47 ± 0.63

Table 10: Mean concentration of nitrate µM/l ± SE in the two areas during the sampling sessions (n = 12)

Table 10 shows the monthly mean nitrate concentration recorded at each transect and figures 13a & 13b show the variation in the nitrate concentration in the two areas. The highest concentrations were recorded in November and the lowest concentrations were recorded in May. Apart from the landward station along transect E which recorded an exceptionally high nitrate concentration in November (19.80 µM/l ± 7.2 SE) the concentrations were generally low. No particular trends were observed in both cases and also, there were no significant differences in the nitrate concentration between the different stations and months.

A 2-factor ANOVA of the nitrate concentration between the two areas and months showed that there was no significant difference between the two transects ($F_{(1,3)}$= 2.18, p> 0.05) and between the months ($F_{(3,3)}$= 5.16, p> 0.05).

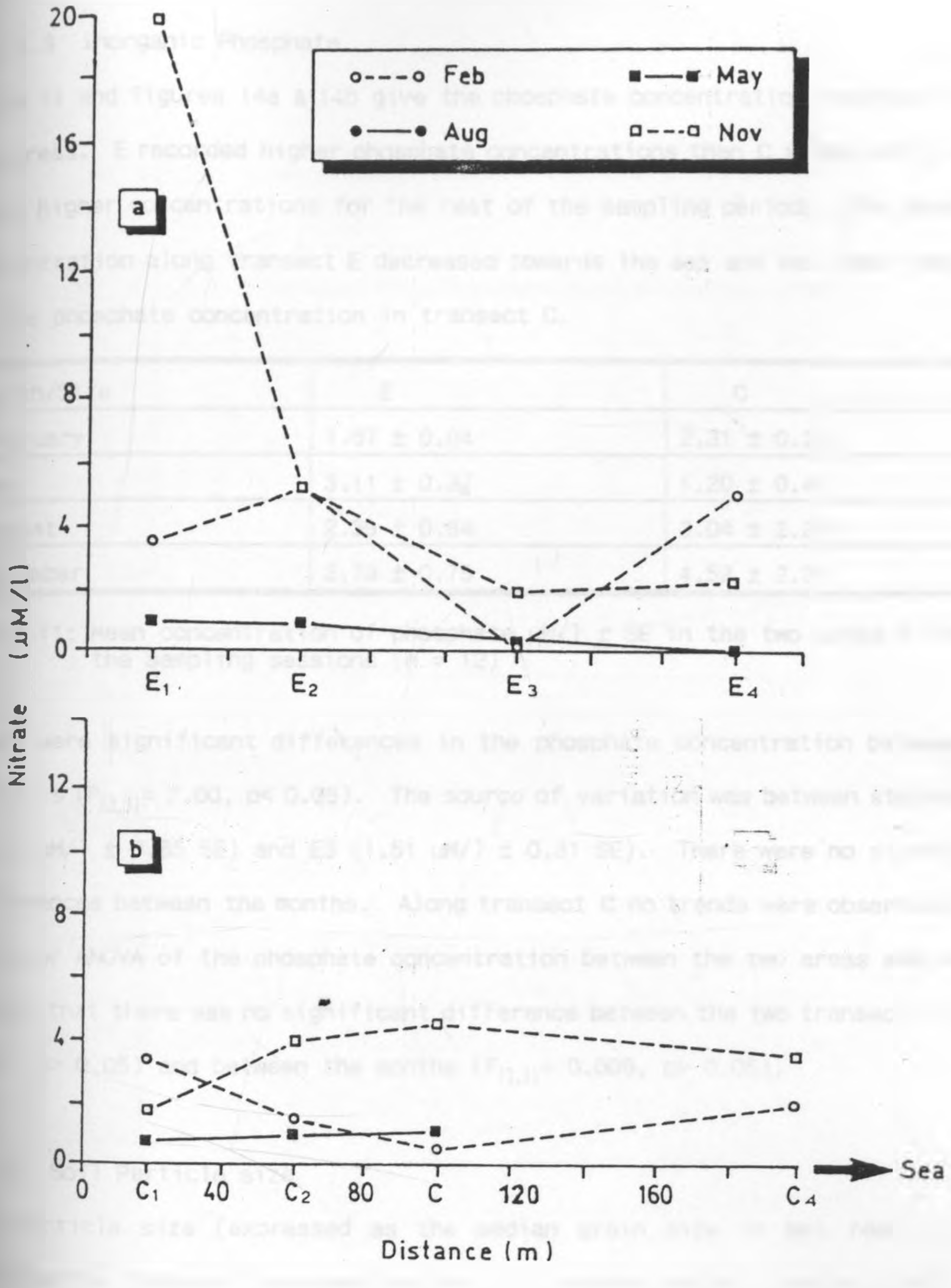


Fig. 13: Variation of the concentration of nitrate along transect E (a) and transect C (b)

4.2.4.3 Inorganic Phosphate

Table 11 and figures 14a & 14b give the phosphate concentration recorded in the two areas. E recorded higher phosphate concentrations than C in May only, while C had higher concentrations for the rest of the sampling periods. The phosphate concentration along transect E decreased towards the sea and was lower compared to the phosphate concentration in transect C.

Month/Site	E	C
February	1.67 ± 0.04	2.31 ± 0.23
May	3.11 ± 0.37	1.20 ± 0.45
August	2.39 ± 0.84	3.04 ± 2.24
November	3.79 ± 0.75	4.52 ± 2.21

Table 11: Mean concentration of phosphate µM/l ± SE in the two areas during the sampling sessions (n = 12)

There were significant differences in the phosphate concentration between the stations ($F_{(3,3)}$= 7.00, $p < 0.05$). The source of variation was between stations E1 (3.91 µM/l ± 0.85 SE) and E3 (1.51 µM/l ± 0.31 SE). There were no significant differences between the months. Along transect C no trends were observed and a 2-factor ANOVA of the phosphate concentration between the two areas and months showed that there was no significant difference between the two transects ($F_{(1,3)}$= 2.31, $p > 0.05$) and between the months ($F_{(3,3)}$= 0.006, $p > 0.05$).

4.2.5 Soil Particle size

The particle size (expressed as the median grain size in mm) results were recorded for February representing the N.E. monsoon period (February and

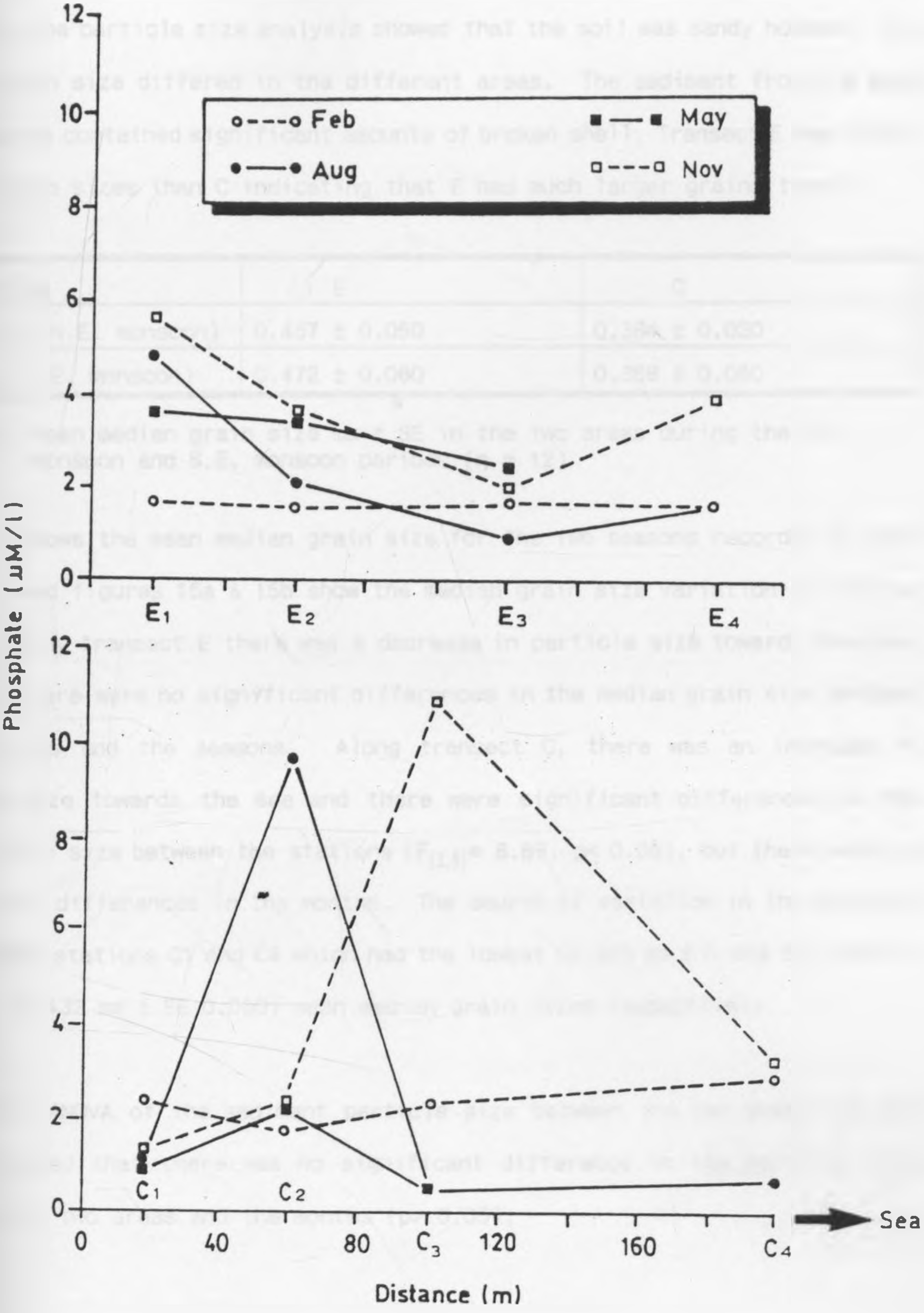


Fig. 14: variation of the phosphate concentration along transect E (a) and transect C (b)

November), and for August representing the S.E. monsoon period (August and May). Generally the particle size analysis showed that the soil was sandy however, the median grain size differed in the different areas. The sediment from the more exposed site contained significant amounts of broken shell. Transect E had higher median grain sizes than C indicating that E had much larger grains than C.

Month/Site	E	C
February (N.E. monsoon)	0.467 ± 0.050	0.384 ± 0.030
August (S.E. monsoon)	0.472 ± 0.060	0.359 ± 0.050

Table 12: Mean median grain size mm ± SE in the two areas during the N.E. monsoon and S.E. monsoon periods (n = 12)

Table 12 shows the mean median grain size for the two seasons recorded at each transect and figures 15a & 15b show the median grain size variation in the two areas. Along transect E there was a decrease in particle size towards the sea. However, there were no significant differences in the median grain size between the stations and the seasons. Along transect C, there was an increase in particle size towards the sea and there were significant differences in the median grain size between the stations ($F_{(3,9)} = 8.89$, $p < 0.05$), but there were no significant differences in the months. The source of variation in the stations was between stations C1 and C4 which had the lowest (0.323 mm ± 0.003 SE) and the highest (0.432 mm ± SE 0.000) mean median grain sizes respectively.

A 2-factor ANOVA of the sediment particle size between the two areas and the months showed that there was no significant difference in the particle size between the two areas and the months ($p > 0.05$).

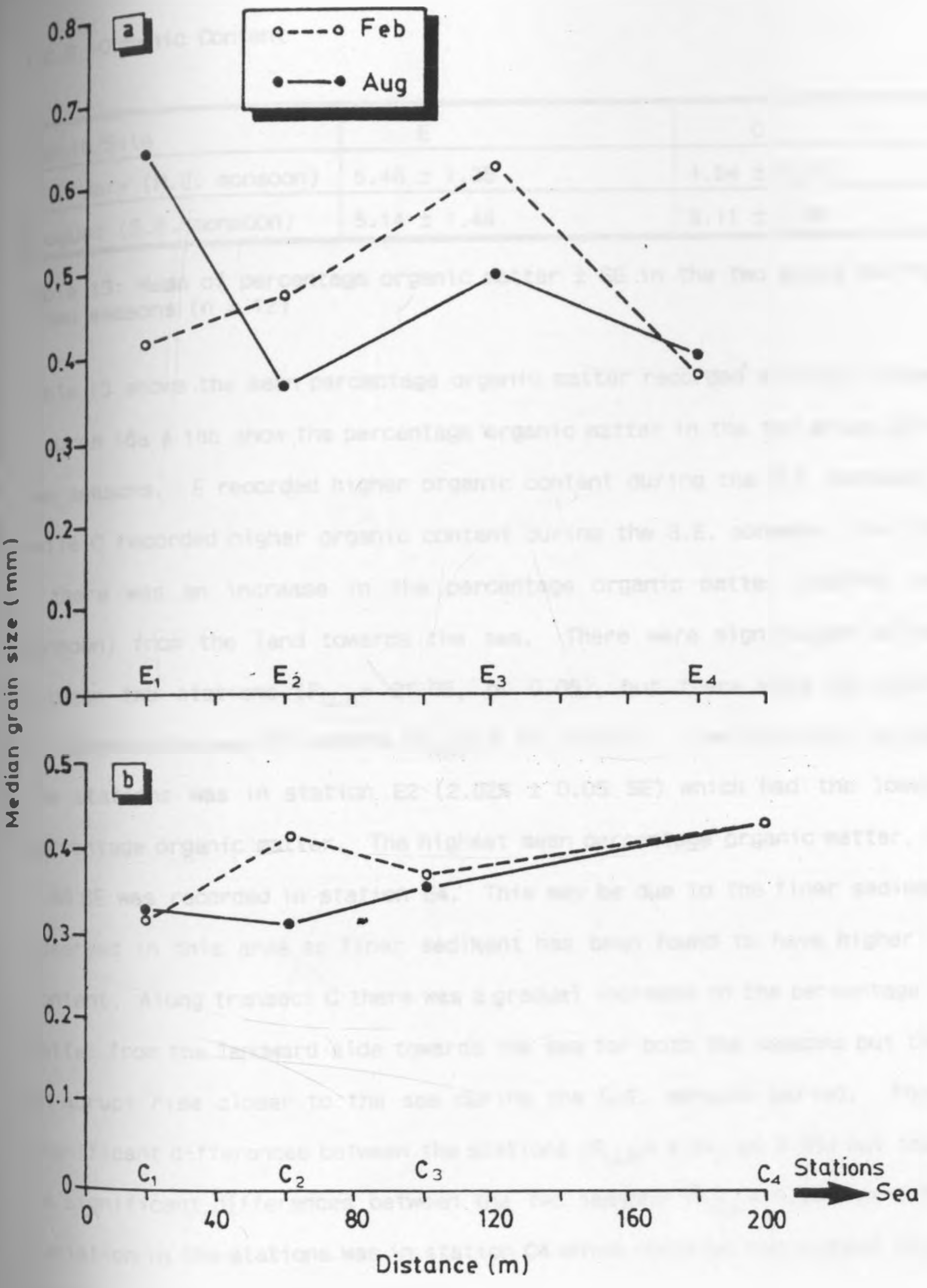


Fig. 15: Variation of median grain size along transect E (a) and transect C (b)

4.2.6 Organic Content

Month/Site	E	C
February (N.E. monsoon)	5.48 ± 1.35	4.54 ± 0.82
August (S.E. monsoon)	5.14 ± 1.44	8.11 ± 2.66

Table 13: Mean of percentage organic matter ± SE in the two areas during the two seasons (n = 12)

Table 13 shows the mean percentage organic matter recorded at each transect and figures 16a & 16b show the percentage organic matter in the two areas during the two seasons. E recorded higher organic content during the N.E. monsoon period while C recorded higher organic content during the S.E. monsoon. For transect E there was an increase in the percentage organic matter (during the N.E. monsoon) from the land towards the sea. There were significant differences between the stations ($F_{(3,3)}$= 21.05, $p < 0.05$), but there were no significant differences between the months ($F_{(3,9)}$= 0.12, $p > 0.05$). The source of variation in the stations was in station E2 (2.02% ± 0.05 SE) which had the lowest mean percentage organic matter. The highest mean percentage organic matter, 7.84% ± 0.68 SE was recorded in station E4. This may be due to the finer sediment size observed in this area as finer sediment has been found to have higher organic content. Along transect C there was a gradual increase in the percentage organic matter from the landward side towards the sea for both the seasons but there was an abrupt rise closer to the sea during the S.E. monsoon period. There were significant differences between the stations ($F_{(3,3)}$= 4.64, $p < 0.05$) but there were no significant differences between the two seasons ($F_{(3,3)}$= 0.56, $p > 0.05$). The variation in the stations was in station C4 which recorded the highest percentage organic matter (15.07% ± 5.13 SE).

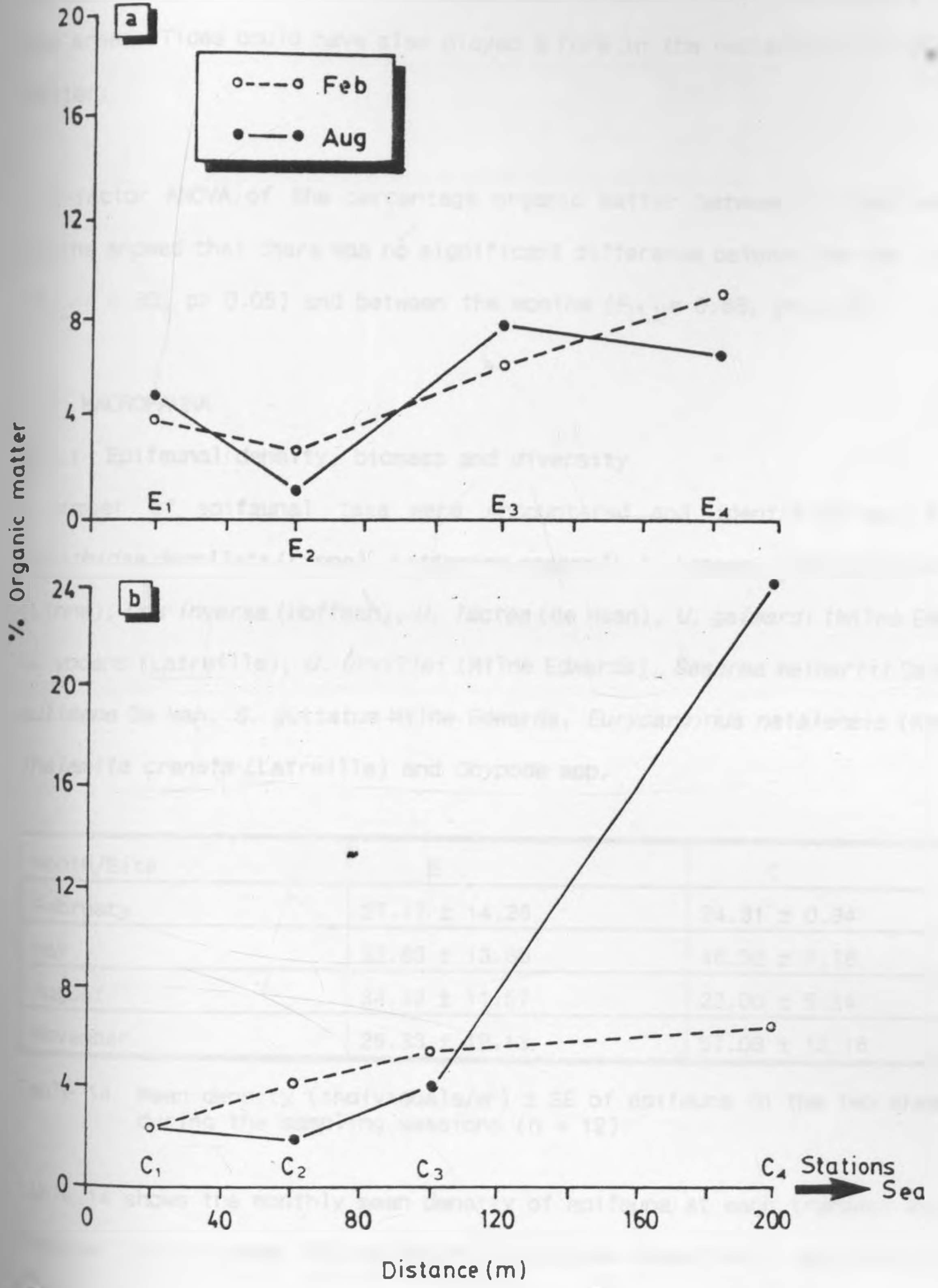


Fig. 16: Variation of percentage organic matter along transect E (a) and transect C (b)

Though this station did not have the finest sediment the observed high organic matter may be a result of the accumulation of detritus by the mangrove trees in the area. Tides could have also played a role in the redistribution of organic matter.

A 2-factor ANOVA of the percentage organic matter between the two areas and months showed that there was no significant difference between the two transects ($F_{(1,3)}$= 0.80, p> 0.05) and between the months ($F_{(3,3)}$= 0.68, p> 0.05).

4.3 MACROFAUNA

4.3.1 Epifaunal density, biomass and diversity

A number of epifaunal taxa were encountered and identified as: Anomura, *Cerithidea decollata* (Linne), *Littorina scabra* (L.), Aranae, *Terebralia palustris* (Linne), *Uca inversa* (Hoffman), *U. lactea* (de Haan), *U. gaimardi* (Milne Edwards), *U. vocans* (Latreille), *U. urvillei* (Milne Edwards), *Sesarma meinertii* De Man, *S. eulimene* De Man, *S. guttatum* Milne Edwards, *Eurycarcinus natalensis* (Krauss) *Thalamita crenata* (Latreille) and *Ocypode* spp.

Month/Site	E	C
February	27.17 ± 14.26	34.91 ± 0.94
May	32.83 ± 13.60	46.92 ± 7.78
August	34.42 ± 11.57	22.00 ± 5.24
November	26.33 ± 12.13	57.08 ± 12.16

Table 14: Mean density (individuals/m^2) ± SE of epifauna in the two areas during the sampling sessions (n = 12)

Table 14 shows the monthly mean density of epifauna at each transect and Figures 17a & 17b show the variation in the mean densities of epifauna recorded

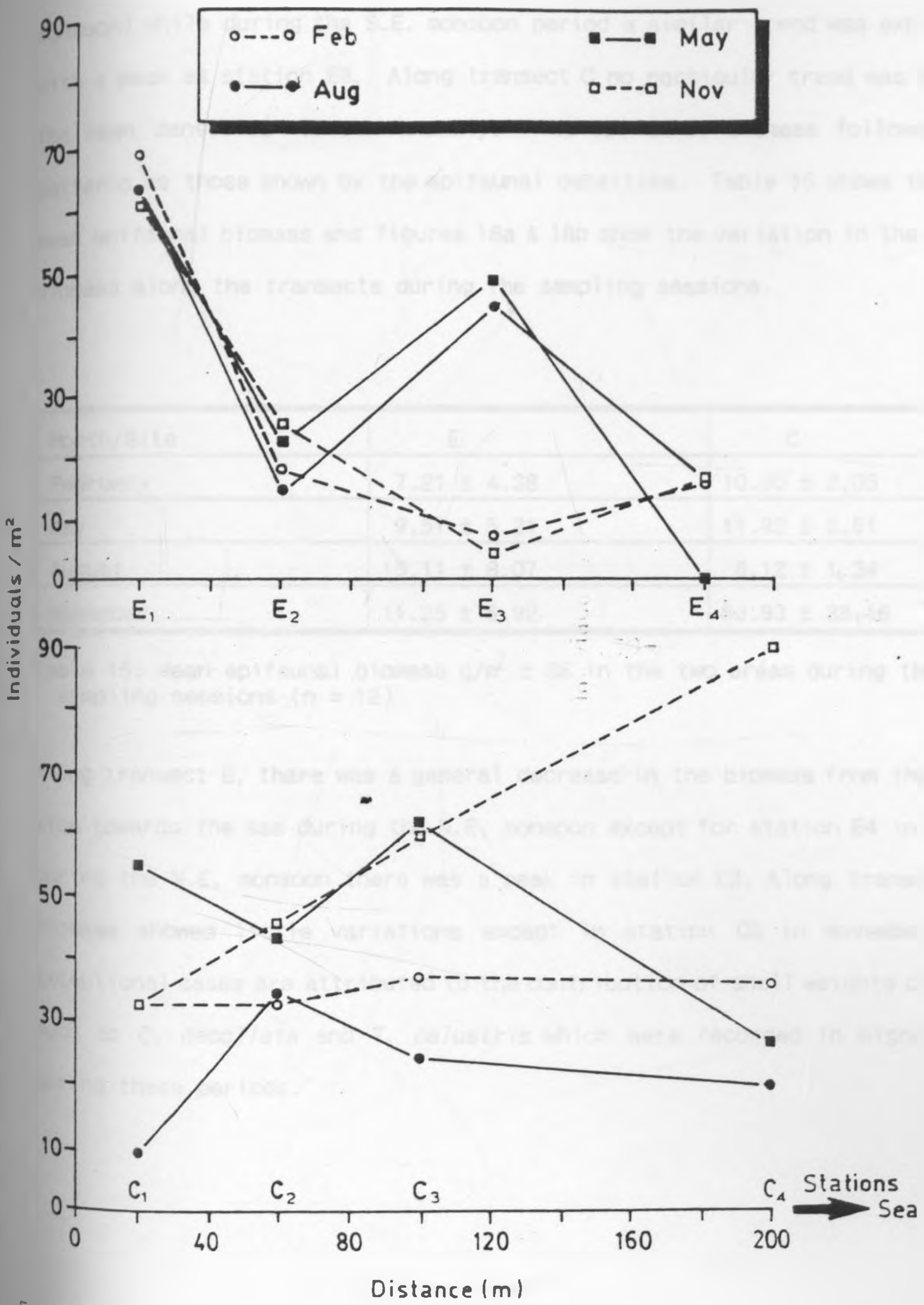


Fig. 17: Variations of epifaunal densities along transect E (a) and transect C (b)

in the two areas. Along transect E there was a general decrease in the density from the landward side towards the sea during February and November (N.E. monsoon) while during the S.E. monsoon period a similar trend was exhibited but with a peak at station E3. Along transect C no particular trend was exhibited. The mean densities varied randomly. The epifaunal biomass followed similar patterns as those shown by the epifaunal densities. Table 15 shows the monthly mean epifaunal biomass and figures 18a & 18b show the variation in the epifaunal biomass along the transects during the sampling sessions.

Month/Site	E	C
February	7.21 ± 4.38	10.90 ± 2.05
May	9.57 ± 5.21	11.93 ± 3.51
August	15.11 ± 8.07	6.12 ± 1.34
November	11.25 ± 5.92	53.93 ± 38.18

Table 15: Mean epifaunal biomass g/m^2 ± SE in the two areas during the sampling sessions (n = 12)

Along transect E, there was a general decrease in the biomass from the landward side towards the sea during the N.E. monsoon except for station E4 in November. During the S.E. monsoon there was a peak in station E3. Along transect C, the biomass showed little variations except in station C3 in November. These exceptional cases are attributed to the contribution of shell weights of molluscs such as *C. decollata* and *T. palustris* which were recorded in higher numbers during these periods.

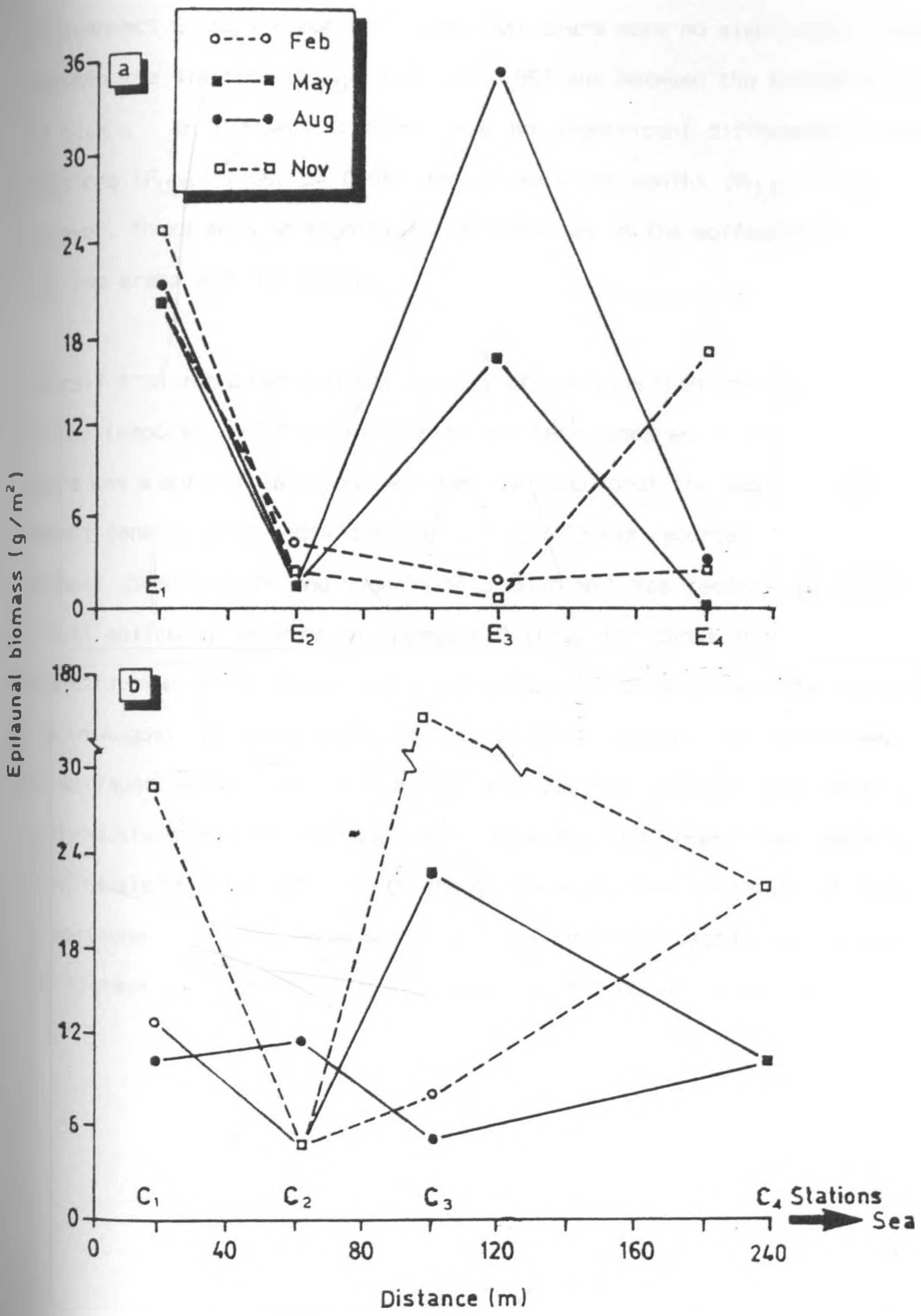


Fig. 18: Variations of epifaunal biomass along transect E (a) and transect C (b)

A 2- factor ANOVA of the mean biomass of epifauna between the different stations in transect E and the months showed that there were no significant differences between the stations ($F_{(3,9)}= 3.09$, $p> 0.05$) and between the months ($F_{(3,9)}= 0.46$, $p> 0.05$). In transect C there were no significant differences between the stations ($F_{(3,9)}= 1.08$, $p> 0.05$) and between the months ($F_{(3,9)}= 1.37$, $p> 0.05$). However, there were no significant differences in the epifaunal biomass between the two areas and the months.

Overall transect C had a higher density of epifauna than transect E. In transect E, the temporal variation in density was less compared to transect C (Fig. 19). There was a more or less constant density throughout the sampling sessions. The lowest density (109 individuals/m^2 ± 1.03 SE) was recorded in February and the highest density (139 individuals/m^2 ± 5.36 SE) was recorded in August. The annual epifaunal density in transect C (Fig. 19) shows that November had the highest number of epifauna (228 ± individuals/m^2 12.04 SE) and the lowest density was in August (88 individuals /m^2 ± 11.64 SE). Overall, the annual mean density of epifauna shows that station E1 recorded the highest mean density (63.42 individuals/m^2 ± 2.01 SE) and station E4 had the lowest mean density (11.67 individuals/m^2 ± 3.92 SE). In C, though there was less variation of mean density of epifauna in the different stations compared to transect E, station C3 recorded the highest mean density (46 individuals/m^2 ± 9.08 SE) (Figs. 20).

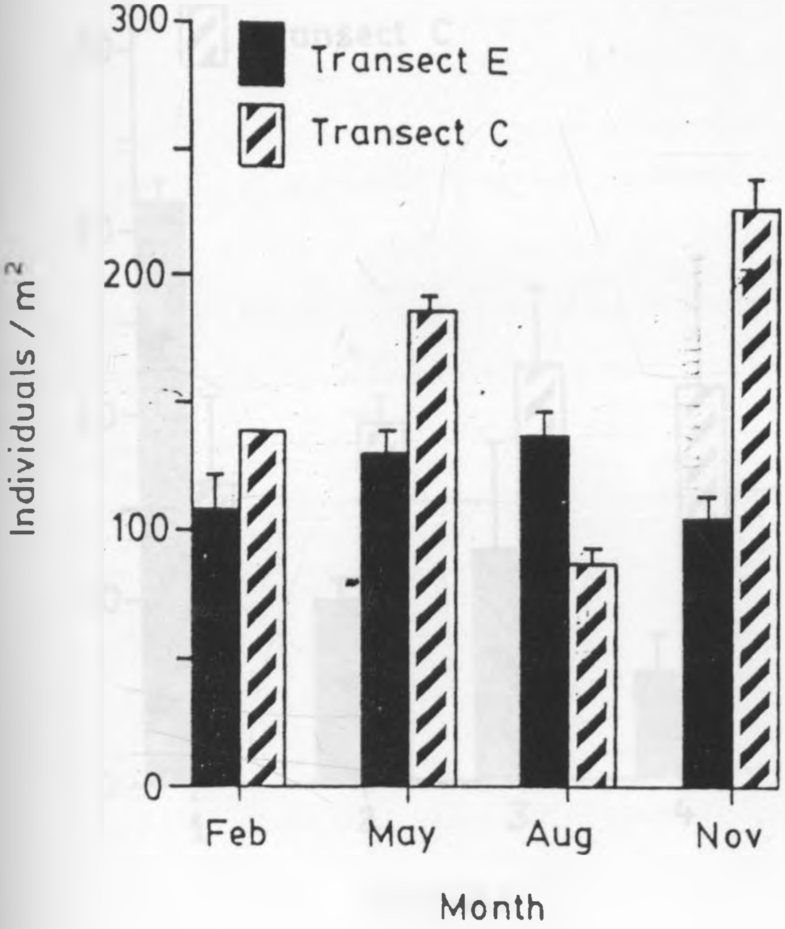


Fig. 19: Temporal mean density of epifauna in transects E and C

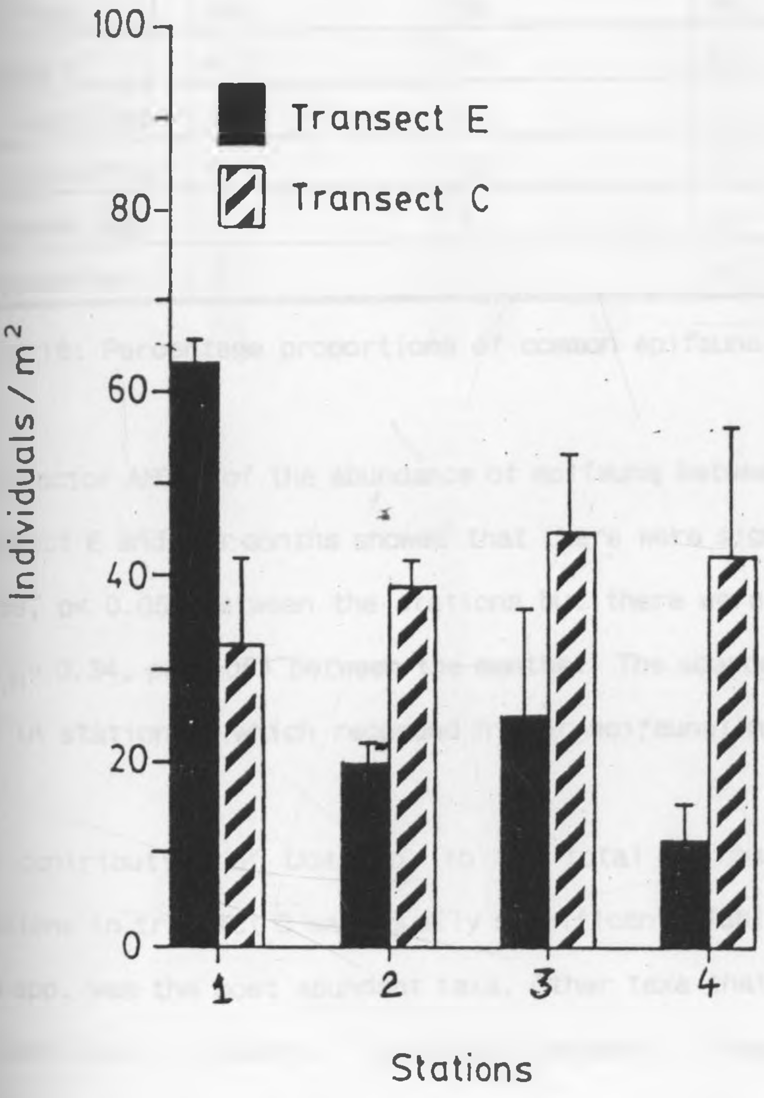


Fig. 20: Mean density of epifauna in the different stations in transect E and transect C during the sampling period

A detailed analysis of the epifauna in transect E during the sampling sessions (Table 16 and Figs. 21 a-d) shows that the *Uca* spp. contributed a lot to the epifaunal density. Other taxa that contributed significantly to the total epifauna were anomurans, *C. decollata*, *T. palustris*, *Sesarma* spp. and Ocypodes.

Taxa	February	May	August	November
Uca spp.	68	50	49	56
Anomura	4	13	6	4
C. decollata	13	11	11	17
T. palustris	0	12	11	4
Sesarma spp.	9	6	13	8
Ocypode spp.	0	7	8	1

Table 16: Percentage proportions of common epifaunal taxa in area E

A 2- factor ANOVA of the abundance of epifauna between the different stations in transect E and the months showed that there were significant differences ($F_{(3,9)}$= 10.69, $p < 0.05$) between the stations but there were no significant differences ($F_{(3,9)}$= 0.34, $p > 0.05$) between the months. The source of variation in the months was in station E1 which recorded higher epifaunal numbers.

The contribution of *Uca* spp. to the total epifauna throughout the sampling sessions in transect C was equally significant (Table 17 and Figs. 22 a-d). The *Uca* spp. was the most abundant taxa. Other taxa that were also abundant include *C. decollata*, *L. scabra*. The aranae (spiders), though in low numbers, more were recorded in transect C than in transect E this must be due to the dense vegetation in C that allows them to construct webs.

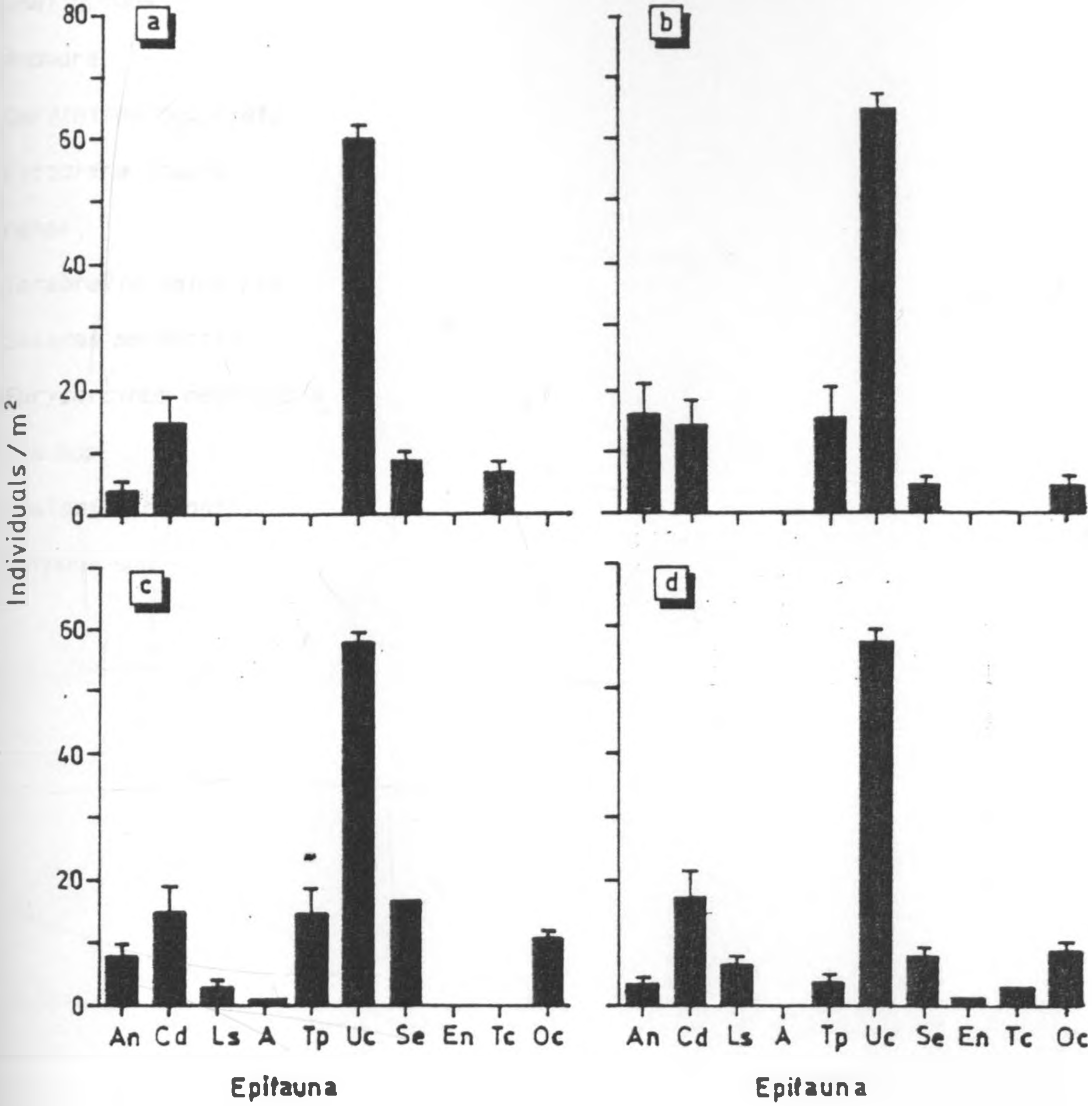


Fig. 21: The mean densities of epifaunal groups in transect E during February (a), May (b), August (c) and November (d). See legend next page.

Legend for Figs. 21 & 22

Epifaunal groups

An - Anomura

Cd - *Cerithidea decollata*

Ls - *Littorina scabra*

A - Aranae

Tp - *Terebralia palustris*

Se - *Sesarma meinertii*

En - *Eurycarcinus natalensis*

Uc - *Uca* spp

Tc - *Thalamita crenata*

Oc - *Ocypode* spp

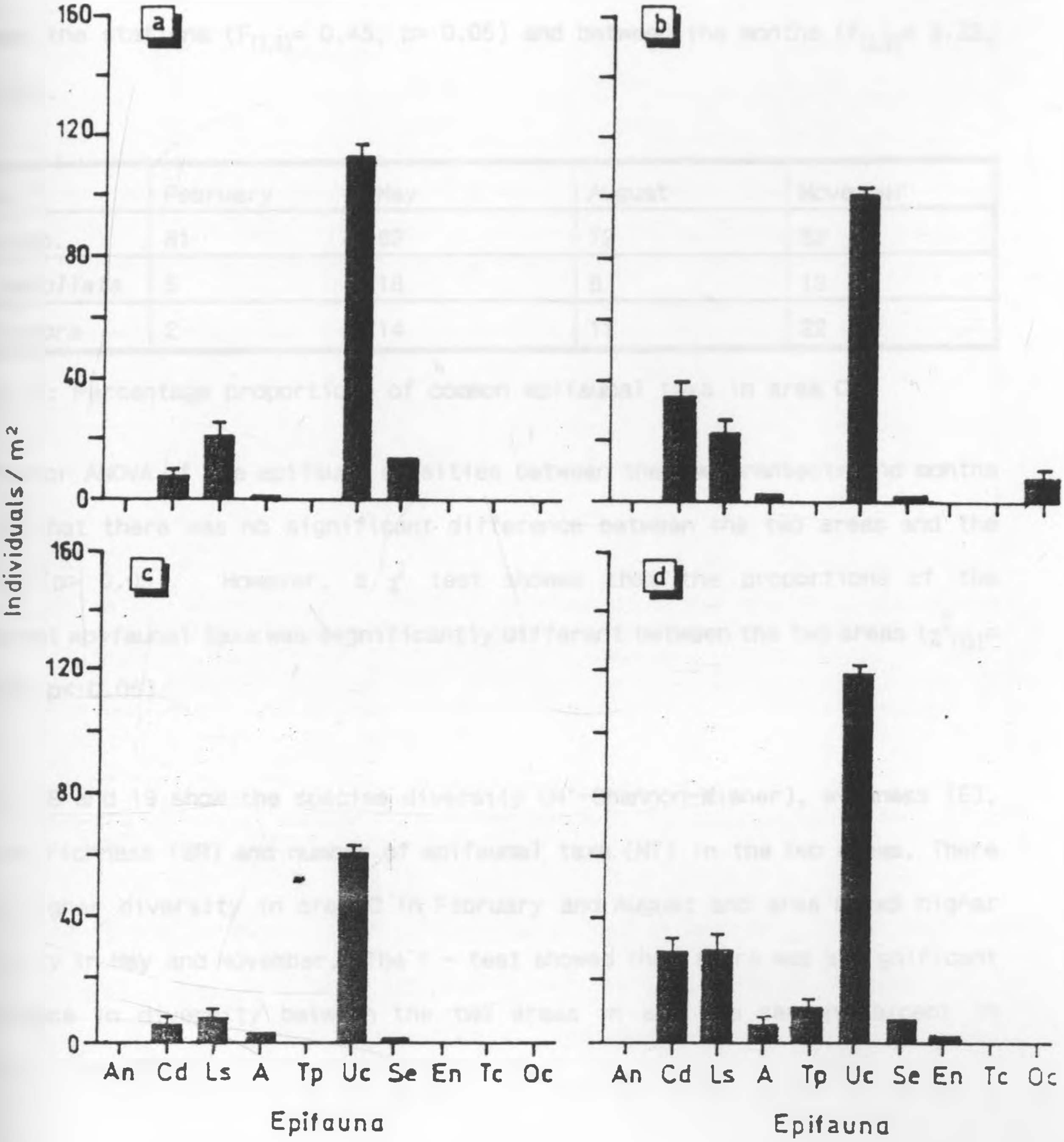


Fig. 22: The mean densities of epifaunal groups in transect C during February (a), May (b), August (c) and November (d). See legend page 77.

A 2- factor ANOVA of the abundance of epifauna between the different stations in transect C and the months showed that there were no significant differences between the stations ($F_{(3,9)} = 0.45$, $p > 0.05$) and between the months ($F_{(3,9)} = 3.32$, $p > 0.05$).

Taxa	February	May	August	November
Uca spp.	81	62	72	52
C. decollata	5	18	8	13
L. scabra	2	14	11	22

Table 17: Percentage proportions of common epifaunal taxa in area C

A 2-factor ANOVA of the epifauna densities between the two transects and months showed that there was no significant difference between the two areas and the months ($p > 0.05$). However, a χ^2 test showed that the proportions of the different epifaunal taxa was significantly different between the two areas ($\chi^2_{(15)} = 163.06$; $p < 0.05$)

Tables 18 and 19 show the species diversity (H'-Shannon-Wiener), evenness (E), species richness (SR) and number of epifaunal taxa (NT) in the two areas. There was a higher diversity in area C in February and August and area E had higher diversity in May and November. The t - test showed that there was a significant difference in diversity between the two areas in all the seasons except in February ($p > 0.05$).

	H'	E	SR	NT
FEBRUARY	0.8060	0.8924	1.15	8
MAY	0.8740	0.8099	1.83	12
AUGUST	0.9832	0.9110	1.94	12
NOVEMBER	0.8527	0.7440	2.15	14

Table 18: The H', evenness (E), species richness (SR) and number of epifaunal taxa (NT) in transect E during the sampling sessions

	H'	E	SR	NT
FEBRUARY	0.8247	0.8640	1.40	9
MAY	0.6605	0.6605	1.61	10
AUGUST	1.7240	1.8067	1.39	9
NOVEMBER	0.4243	0.4243	1.56	10

Table 19: The H', evenness (E), species richness (SR) and number of epifaunal taxa (NT) in transect C during the sampling sessions

Month	t_{cal}	df	$t_{0.05}$
February	0.140	17	1.740
May	1.925*	22	1.717
August	7.060*	21	1.721
November	4.103*	22	1.717

t-test for the epifaunal diversity indices between the two areas. * indicates significant difference.

Overall there was no significant difference in the diversity between the two areas ($t_{0.05(27)} = 1.703$, $p < 0.05$). The overall epifaunal diversity indices for E and C were 0.8077 and 0.8723 respectively. The percentage of total epifauna recorded in E decreased towards the sea while the percentage of number of species remained invariable (Fig 23a). Along transect C, both the percentage of total epifauna and the precentage of number of species increased towards the sea (Fig 23b).

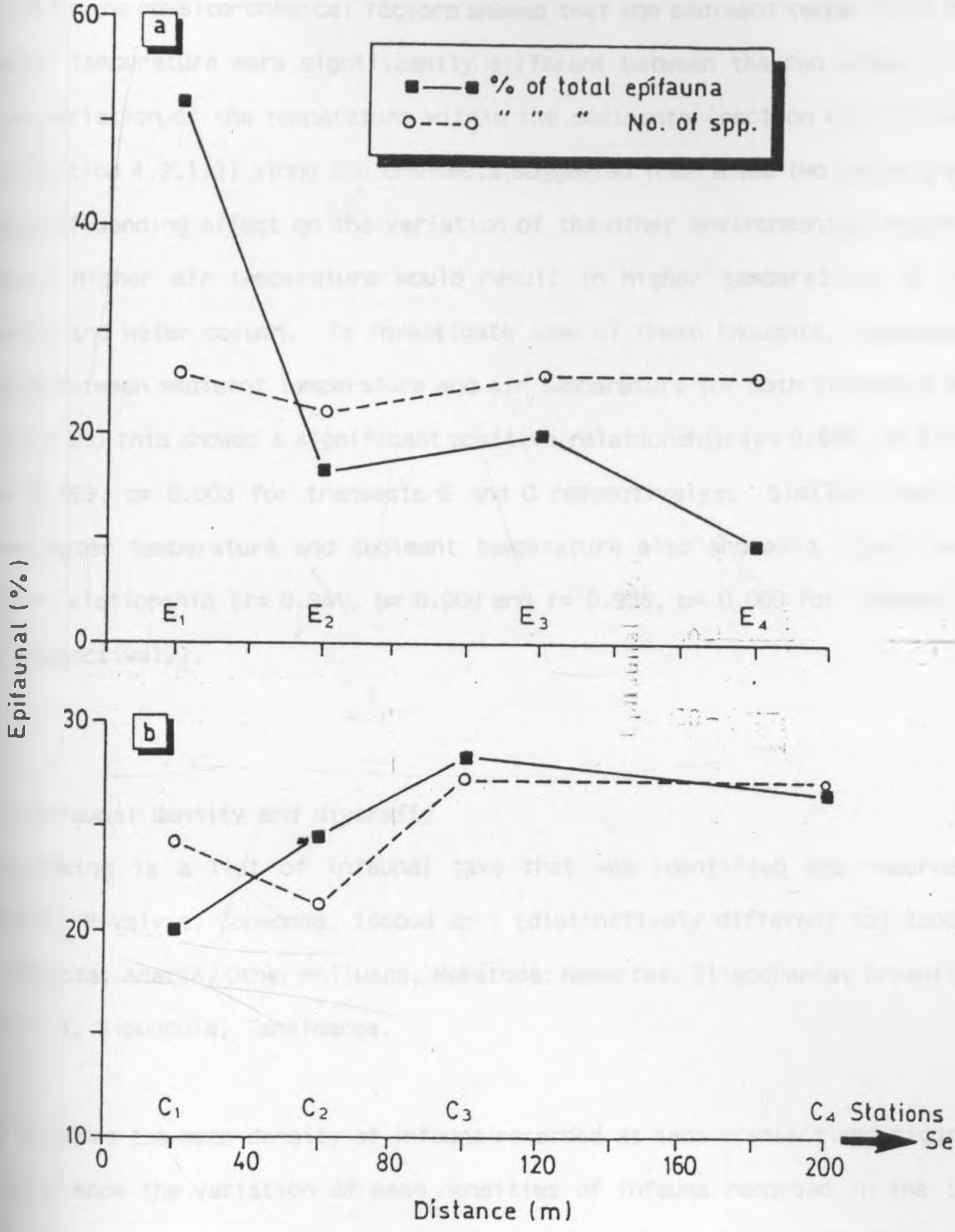


Fig 23. Epifaunal percentages along transect E (a) and transect C (b)

Generally these findings may be attributed to the difference in vegetation cover in relation to the physico-chemical factors prevailing in the two areas. Analysis of the physico-chemical factors showed that the sediment temperature and the water temperature were significantly different between the two areas. The data on variation of the temperature within the sediments (section 4.2.1.2) and water (section 4.2.1.3) along the transects suggested that these two factors may have an influencing effect on the variation of the other environmental factors. Logically higher air temperature would result in higher temperatures in the sediments and water column. To investigate some of these thoughts, regression analysis between sediment temperature and air temperature for both transects was performed and this showed a significant positive relationship (r= 0.686, p= 0.003 and r= 0.699, p= 0.003 for transects E and C respectively). Similar analysis between water temperature and sediment temperature also showed a significant positive relationship (r= 0.841, p= 0.000 and r= 0.956, p= 0.000 for transect E and C respectively).

4.3.2 Infaunal density and diversity

The following is a list of infaunal taxa that was identified and recorded: Amphipoda, Bivalvia, Copepoda, Isopod sp 1 (distinctively different to) Isopod sp 2, Insecta, Acaria, Other Molluscs, Nematoda, Nemertea, Oligochaeta, Errantia, Sedentaria, Sipuncula, Tanaidacea.

Table 20 shows the mean density of infauna recorded at each transect and figures 24a & 24b show the variation of mean densities of infauna recorded in the two areas. Along transect E, there was a peak at station E3 in all the seasons with the highest peak (8510.42 individuals/m^2 ± 641.94 SE) recorded in February. This peak was contributed by sedentary polychaetes and in the rest of the seasons the peaks were contributed by high numbers of nematodes, oligochaetes and errant polychaetes. The location and edaphic conditions of this station seems to be favourable to these groups. Along transect C, there was small variation in the density in February but this increased towards the sea during May and November (the rainy seasons).

Month/Site	E	C
February	2379.67 ± 2044	867.58 ± 31.96
May	1152.09 ± 382.98	2269.04 ± 661.73
August	1715.63 ± 898.40	819.80 ± 210.43
November	2935.94 ± 1470.40	2367.19 ± 511.19

Table 20: Mean density (individuals/m^2) ± SE of infauna in the two areas during the sampling sessions (n = 12)

In transect E, the temporal (seasonal) variation in the mean density was high (Fig. 25). In November an exceptionally high number of infauna was recorded (11744 individuals/m^2 ± 1470.40 SE) while the lowest mean density (4608 individuals/m^2 ± 382.98 SE) was recorded in May. The seasonal ranges of mean density in transect C (Fig. 25), shows that November recorded the highest mean density (9469 individuals/m^2 ± 511.19 SE) which was also close to the record in May (9076 individuals/m^2 ± 661.73 SE). The lowest mean density (3279 individuals/m^2 ± 210.43 SE and 3470 individuals /m^2 ± 31.96 SE) were recorded in August and February respectively. There was little variation in the annual mean infaunal density between the stations in transect C compared to transect E. The annual mean density was highest (5546 individuals/m^2 ± 550 SE) in station E3. The

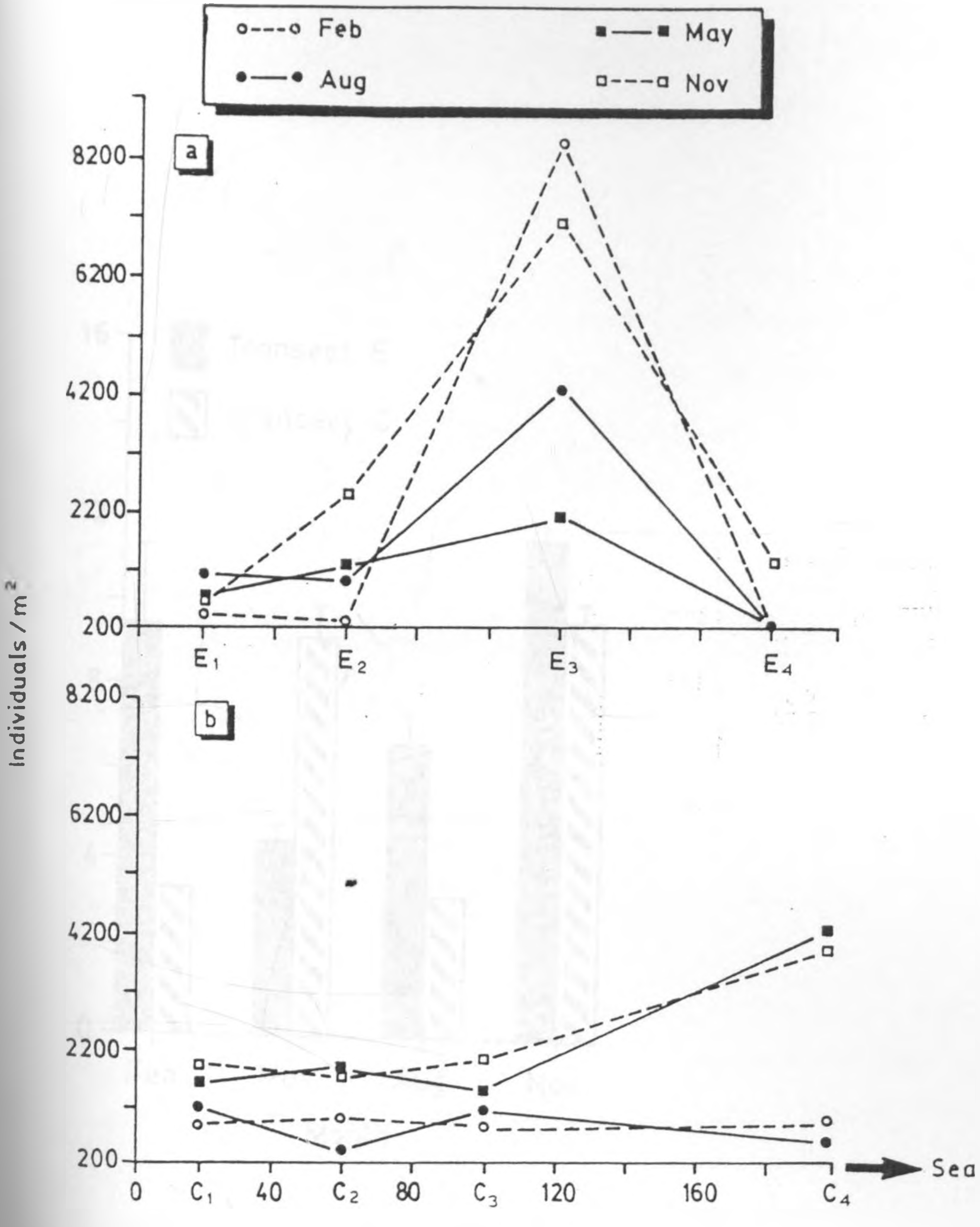


Fig. 24: Variations of infaunal densities along transect E (a) and transect C (b)

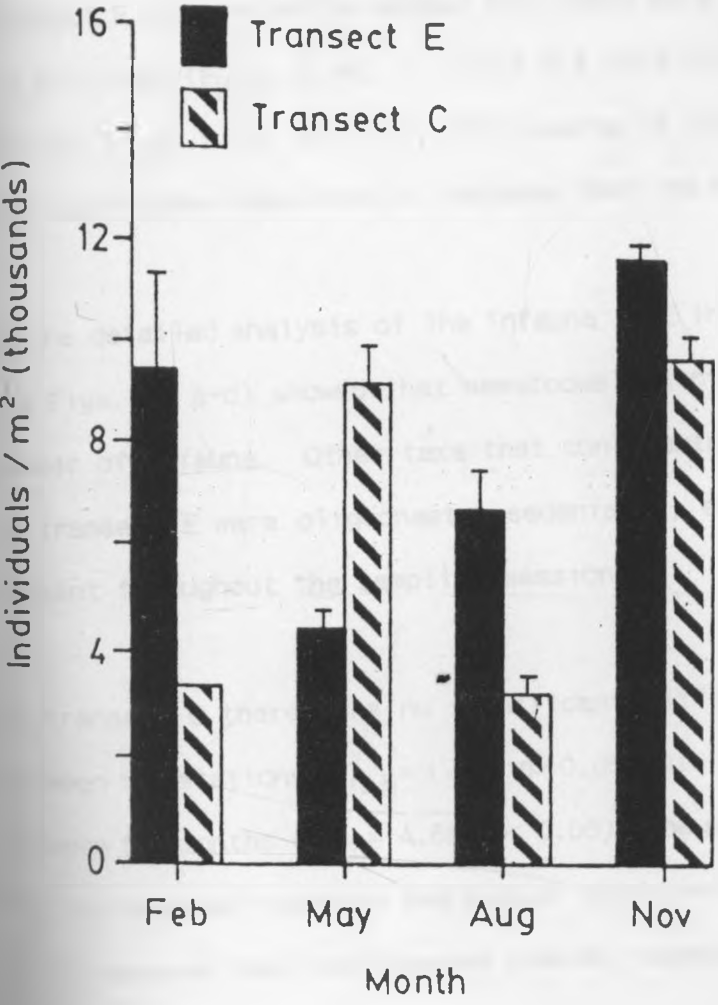


Fig. 25: Temporal mean density of infauna in transects E and C

other stations recorded lower numbers and the lowest mean density for the sampling sessions was recorded in station E4 (Fig. 26). In transect C, the highest mean density (2361 individuals/m^2 ± 1050 SE) was recorded in station C4. The lowest density (1222 individuals/m^2 ± 320 SE) was recorded in station C2 (Fig. 26).

A 2- factor ANOVA of the infaunal abundance between the different stations in transect E and the months showed that there were significant differences between the stations ($F_{(3,9)}$= 9.48, $p< 0.05$) but no significant differences between the months ($F_{(3,9)}$= 1.03, $p> 0.05$). The source of variation was in station E3 which recorded higher densities of infauna than the other stations.

A more detailed analysis of the infauna in E in the different seasons (Table 21 and Figs. 27 a-d) showed that nematodes contributed significantly to the total number of infauna. Other taxa that contributed mostly to the infaunal density in transect E were oligochaeta, sedentaria, errantia and nemertea. These were present throughout the sampling sessions.

In transect C there were no significant differences in the infaunal abundance between the stations ($F_{(3,9)}$= 1.77, $p> 0.05$) but there were significant differences between the months ($F_{(3,9)}$= 4.65, $p< 0.05$). The source of variation was between the two dry seasons (February and August which recorded lower densities) and the two rainy seasons (May and November) which recorded higher densities of infauna.

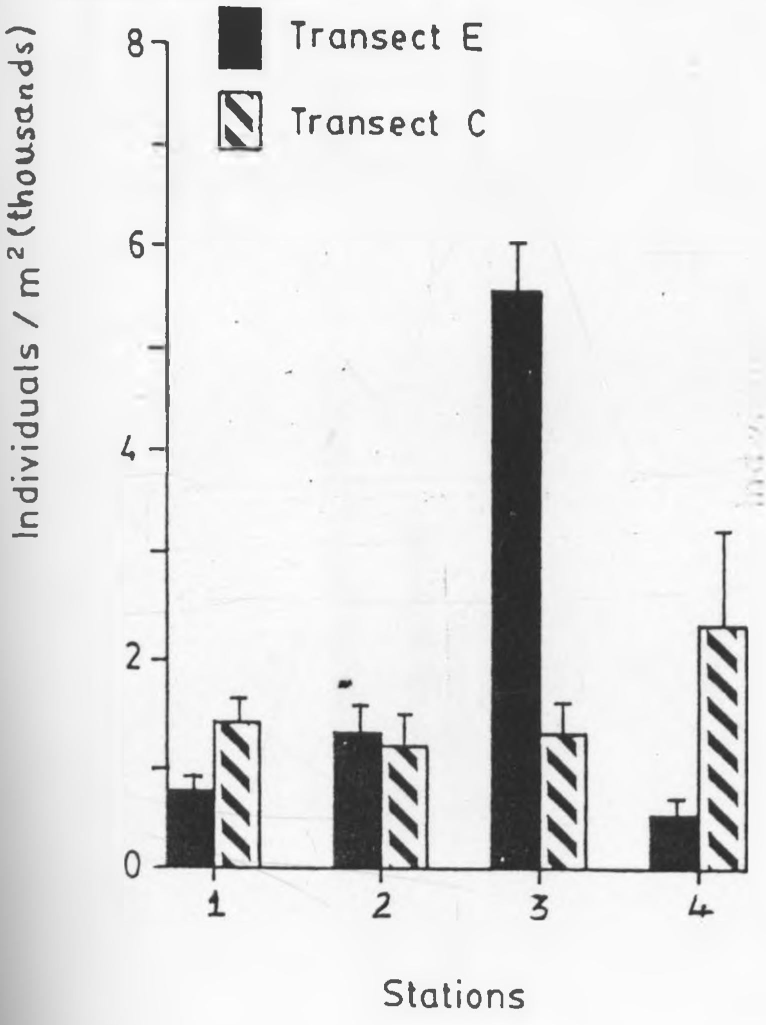


Fig. 26: Mean density of infauna in the different stations in transect E and transect C during the sampling period

Taxa	February	May	August	November
Nematoda	17	64	66	25
Oligochaeta	4	19	25	31
Sedentaria	59	0	0	0
Errantia	0.5	9	2	29
Nemertea	4	3	2	3

Table 21: Percentage proportions of common infaunal taxa in area E

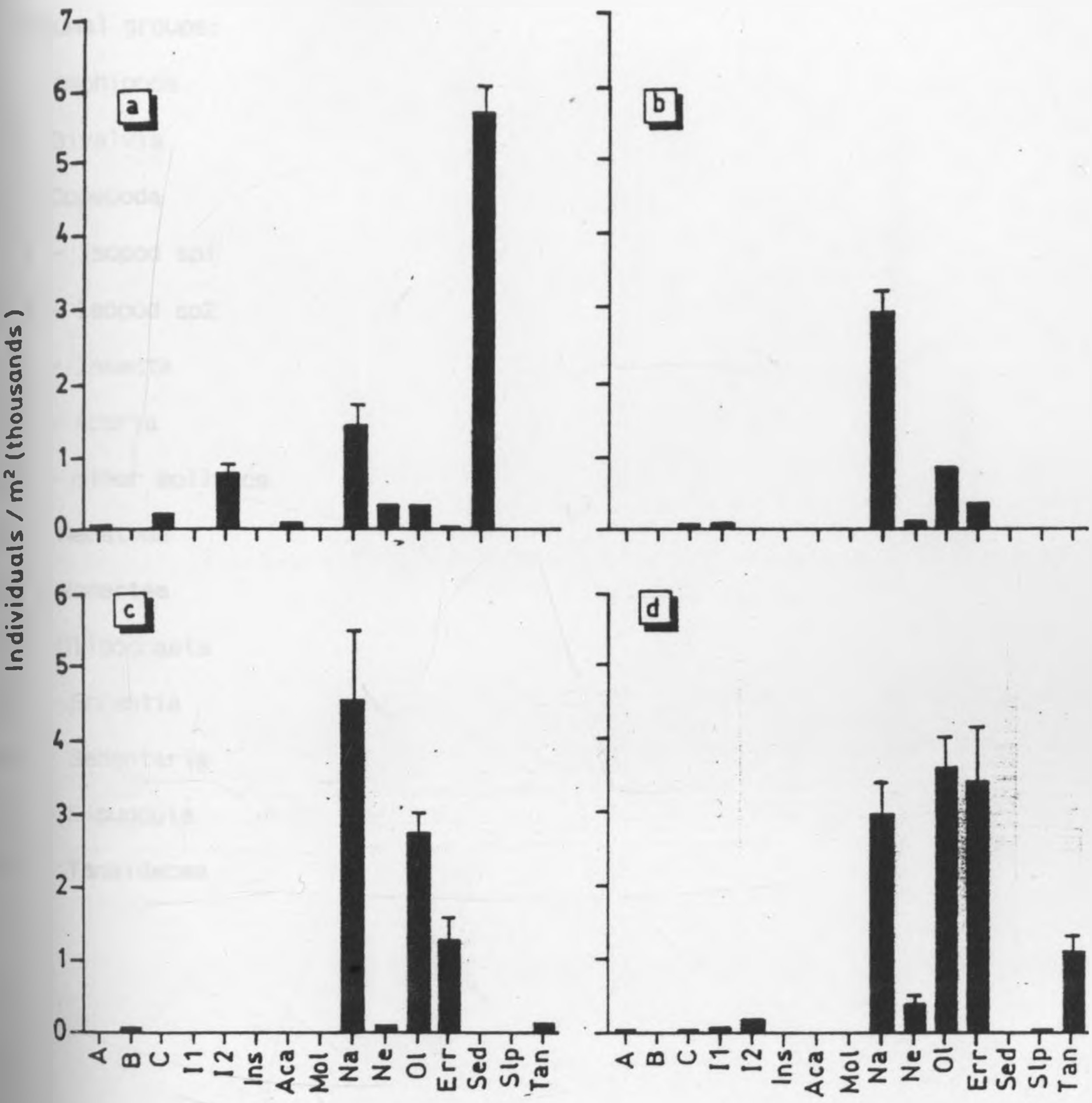


Fig. 27: The mean densities of infaunal groups in transect E during February (a), May (b), August (c) and November (d). See legend next page.

Legend for Figure 27 & 28

Infaunal groups:

A - Amphipoda

B - Bivalvia

C - Copepoda

I 1 - Isopod sp1

I 2 - Isopod sp2

Ins - Insecta

Aca - Acaria

Mol - other molluscs

Na - Nematoda

Ne - Nemertea

Ol - Oligochaeta

Err - Errantia

Sed - Sedentaria

Sip - Sipuncula

Tan - Tanaidacea

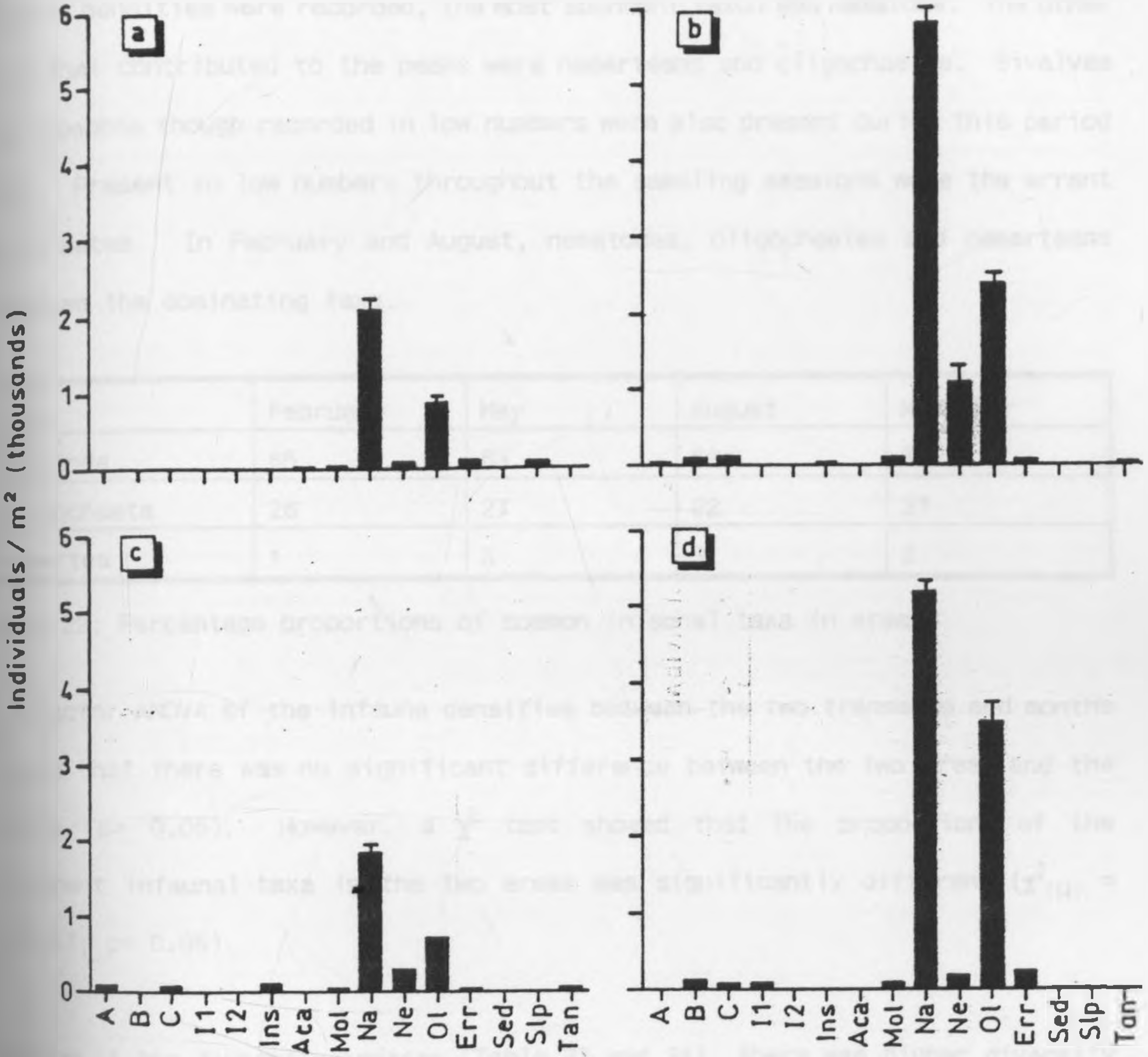


Fig. 28: The mean densities of infaunal groups in transect C during February (a), May (b), August (d) and November (d). See legend page 90.

A more detailed analysis of the different infaunal taxa recorded in the different seasons in C (Table 22 and Figs. 28 a-d) showed that in May and November when the highest densities were recorded, the most abundant taxon was nematoda. The other taxa that contributed to the peaks were nemerteans and oligochaetes. Bivalves and copepods though recorded in low numbers were also present during this period only. Present in low numbers throughout the sampling sessions were the errant polychaetes. In February and August, nematodes, oligochaetes and nemerteans remained the dominating taxa.

Taxa	February	May	August	November
Nematoda	65	63	56	55
Oligochaeta	26	27	22	37
Nemertea	1	3	9	2

Table 22: Percentage proportions of common infaunal taxa in area C

A 2-factor ANOVA of the infauna densities between the two transects and months showed that there was no significant difference between the two areas and the months ($p > 0.05$). However, a χ^2 test showed that the proportions of the different infaunal taxa in the two areas was significantly different ($\chi^2_{(14)}$ = 4279.47; $p < 0.05$).

Looking at the diversity indices (Table 23 and 24), there was higher diversity of infauna in area E than C in all the seasons except for August. Using t - test to compare the diversity indices in the two areas during the different sampling sessions, it was shown that, there were no significant differences ($p > 0.05$) in the infaunal diversity in the two areas.

	H’	E	SR	NT
FEBRUARY	0.6280	0.6280	0.99	10
MAY	0.5020	0.4652	1.04	12
AUGUST	0.4393	0.4220	1.04	11
NOVEMBER	0.5648	0.5234	1.13	12

Table 23: The H’, evenness (E), species richness (SR) and number of infaunal taxa (NT) in transect E during the sampling sessions

	H’	E	SR	NT
FEBRUARY	0.5187	0.4526	1.49	14
MAY	0.4332	0.3889	1.18	13
AUGUST	0.4920	0.4920	0.95	10
NOVEMBER	0.5053	0.4854	1.01	11

Table 24: The H’, evenness (E), species richness (SR) and number of infaunal taxa (NT) in transect C during the sampling sessions

Month	t_{cal}	df	$t_{0.05}$
February	1.179	19	1.729
May	0.920	25	1.708
August	0.605	21	1.721
November	1.050	23	1.714

t-tests for the infaunal diversity indices between the two areas.

Overall there was no significant difference in the diversity between the two areas ($t_{0.05(28)} = 1.701$, $p < 0.05$). The overall infaunal diversity indices for E and C were 0.5917 and 0.5077 respectively. The percentage of total infauna recorded in E decreased both landwards and seawards with a peak at station E3 however the percentage of number of taxa remained constant (Fig. 29a). Along transect C, both the percentage of total infauna and the percentage of number of taxa increased towards the sea (Fig. 29b).

CHAPTER 5

5. DISCUSSION AND CONCLUSIONS

5.1 Macroflora

In Gazi, 8 species of mangrove trees have been recorded, with *A. marina, C. tagal* and *R. mucronata* being the most dominant. A similar zonation pattern of mangrove species was observed as that reported in other studies on mangroves (Isaac and Isaac (1968), Kokwaro (1986), Ruwa and Polk (1986)). *S. alba* occurs closest to the low water line, followed by *R. mucronata*, *B. gymnorrhiza*, *C. tagal*, *A. marina* and *X. granatum* heading towards the land. Analysis of physiography and hydrology provides evidence that ground - water salinities are an important influence on mangrove distribution. The simplest evidence is that where ground water seepage is abundant, there is a landward fringe of mangrove, otherwise it is absent. At the landward fringe of the salt flat, there may or may not be a second reduced mangrove zone finally transitional to terrestrial communities beyond the influence of tides (Tomlinson, 1986). This phenomenon seems to apply to the Gazi area, where stunted *A. marina* trees are common, forming a landward fringe transitional to the terrestrial communities in some areas. Factors that can influence mangrove distribution and zonation can be divided into abiotic and biotic. However, it is not one of these factors, but their effect in concert that establishes the vegetation pattern. Abiotic factors influencing zonation include: geomorphology, inundation classes and physiological responses to gradients (e.g. salinity). The biotic factors influencing zonation include: propagule sorting and competition.

In this study, the exploited area which was dominated by tree stumps, had *S. alba* ranking first in the Importance Value. This is expected, since *S. alba* is a pioneer species and also people do not like to cut this species for poles. In the less exploited area where more species of mangrove trees were encountered in higher densities, *C. tagal* ranked top in Importance Value. The grass *S. spicatus* was present in both areas and was observed in the bare areas of the sand dunes not dominated by mangrove trees. Grasses and sedges are known to occur only when they penetrate the more open parts of mangroves from adjacent fresh - water or saline marshes. Otherwise mangroves form forests with no understorey except for their own seedlings. This was a prominent feature in the less exploited area and the non-mangrove species of plants recorded, occurred on the raised area of the sand dune. The fern *Acrostichum sp.*, though not recorded in the transects surveyed, was common in the open areas and Tomlinson (1986) reports that this fern may become dominant in disturbed sites, and it exists in the undisturbed mangrove by virtue of its ability to colonise elevated sites that are not inundated at high tide. Such mangrove associates though may not seem so significant, interact with mangroves at two important levels: they may share or compete for the same pollinators, and they may share the same predators and parasites so that as alternative hosts their influence may not be entirely negligible.

The seedings observed in the exploited area is probably an effort to regenerate. However, it is noteworthy that crabs e.g. *Sesarma* destroy and prevent regeneration. In Gazi for instance, crabs accounted for more than 30% loss in seedlings in regeneration plots (Kairo pers. comm.). *Avicennia* is one genera that persists in the face of overexploitation because they coppice.

5.2 Macrofauna

5.2.1 Epifauna

The groups of epifauna recorded in this study are similar to the ones recorded in mangrove areas, with crabs and molluscs dominating (Jones, 1984). It has been reported that decapod crustaceans are the most important element in the resident fauna in terms of species numbers and biomass in the mangrove environment (Macintosh, 1988). On suitable substrata, individual species are zoned according to their tolerance of high temperatures, salinity extremes and desiccation, parameters that increase in severity towards the landward mangrove limit. For instance, among the *Uca* species found in Gazi, it was observed that *U. inversa* and *U. lactea* flourished in the most hardy conditions, on the landward side which is more exposed. In the exploited areas where conditions are more harsh, these species were dominant.

Frith *et al*. (1976), found 103 species of macrofauna (consisting predominantly of polychaetes, crustaceans and molluscs) within a mangrove biotope in Phuket Island, Thailand. Of these, 77 species (74.6%) were exclusive to the mangrove biotope. The distribution of macrofauna was limited in extent and density within biotopes studied by substrate conditions (particle size, consolidation, organic and moisture content) and tidal factors.

Warner (1969) in his investigations on the occurrence and distribution of crabs in a Jamaican mangrove swamp showed that the distribution of most of the crab species are related to that tidal levels. Following Macnae's findings (1963) that the fauna of mangroves is one characteristic of sheltered shores on which grow some shade-giving plants and that, mangrove animals are not normally limited to mangrove swamps that are often commonest there. Warner gave the following conclusion. "The fauna is characteristic of sheltered shore and there is a definite, characteristic mangrove fauna depending, not just on the conditions on which the trees depend, but on the environment produced by the presence of the trees". From the present study it may be said that the presence of trees is not only the controlling factor, other factors come into play but the trees play a crucial role in producing the most suitable environment for the fauna.

Macintosh (1984), described the distribution and abundance of some common genera and species of crabs in Malaysian mangrove shores and found crab densities ranging from 10 to 70 crabs/m^2 which corresponds to the 0 to 90 crabs/m^2 range recorded in the present study. In both areas, *Uca* was the most numerous and had the broadest distribution from the mean tidal level to mean high water at spring.

A study of the distribution of molluscs across a pneumatophore boundary in a Bay in Northwestern Australia by Wells (1986), revealed more species of molluscs in the mudflat, but a lower total density and total biomass than in the *Avicennia* zone. The stations among the pneumatophores on the seaward fringe of the *Avicennia* zone were more diverse and had a greater density and biomass than the stations among the trees. Possible reasons for this distribution were given as nutrition and physical factors (particularly acidity). There is no family of molluscs which is specific to the mangrove areas however, some species such as *L. scabra*, *L. angulifera* and *T. palustris* and several melampids are exclusive to the mangrove areas (Plaziat, 1984). The two species *L.scabra* and *T. palustris* were encountered in the present study.

It is clear from the results that similar epifaunal taxa were recorded in both areas and these differed in abundance between the two areas during the seasons. For instance, it may be noted that in August (dry season of the S.E. monsoon) when the exploited area recorded the maximum density, the less exploited area recorded the minimum density. However, it is interesting to note that during this time the exploited area recorded the lowest diversity (H'= 0.9832) and the less exploited area recorded the highest (H'= 1.724). This may have been as a result of sporadic movement or migration of the epifauna between the two areas resulting in higher numbers of epifauna being recorded in the exploited area.

Alongi (1989) stated that macrofaunal densities vary with seasons and sediments, and that (1987), in mangrove areas, tannins may play a role in controlling densities of macrofauna. The tannin concentrations were not assessed in the present study and therefore it is difficult to state its effects on the macrofauna, however, it may be one of the factors affecting the colonisation and therefore densities of macrofauna. One thing that was obvious, the less exploited area had higher concentrations of tannins than the exploited area.

The percentage of total epifauna in the exploited area decreased towards the sea while the percentage of number of species was constant. In the less exploited area, both the percentage of total epifauna and the percentage of number of species increased towards the sea. This may be due to the change of vegetation structure (zonation) from the land towards the sea (as that observed in the less exploited area) and its influence on the epifauna which show zonation patterns, such that species are abundant in their distinctive zones they occupy. In the exploited area due to less vegetation cover, the area offers more "homogeneous" environment and limited niches / habitats resulting in a more constant percentage of the number of species. This is supported by the fact that overall the less exploited area recorded higher diversity (H'= 0.872) than the exploited area (H'= 0.807).

Comparisons between 4 zones within the mangrove biotope in Phuket Island, Thailand, by Frith *et al.* (1976), showed that whilst macrofaunal compositions were similar in all the 4 zones, species diversity and its abundance were notably higher within the forest than in areas with less vegetation. Ruwa (1988) while studying the changes in patterns of macrofaunal distribution in mangrove ecosystems due to natural and un-natural causes, along the Kenyan coast observed that species numbers of macrofauna was higher under shade conditions while species numbers increased from sandy to muddy substratum. Schrijvers (1991), in an ecological study of mangrove macrobenthos at Gazi Bay, distinguished a total of 18 macrobenthic taxa and calculated diversity values (Shannon - Wiener diversity indices) ranging from 1.65 to 3.35. These diversity indices are higher than what was calculated in the present study. Differences in methodology and sampling areas and times could be some of the reasons for the differences, however, environmental factors such as temperature, salinity and sediment particle size cannot be ruled out.

Overall, the less exploited area had higher numbers of epifauna than the exploited area. The mangrove vegetation provide different niches thus supporting more groups of epifauna e.g. certain *Uca* species were not observed in the open area of the exploited site e.g *U. urvillei*. Some species of crabs are known to show vertical movements along the mangroves in relation to the tides, staying up the mangrove trees during the high tides and moving down as the water moves out during the low tides (Oluoch, pers comm.). In East Africa, the crab *S. leptosoma* which shows vertical migration is the only crab that spends all its life on the roots and branches of mangroves (mostly *R. mucronata*, *B. gymnorrhiza* and *C. tagal*) and feeding on fresh leaves. Its West Atlantic relative is *Aratus pisoni* (Vannini, 1993). The mangrove covered area is ideal to hide from predators and protects the animals against desiccation. However this does not imply that some epifauna groups were found in the less exploited area only. The exploited area also had some fauna that did not occur in the less exploited area, for instance the ocypodid crabs (*Ocypode ceratopthalmus* Pallas and *Ocypode ryderi* Kingsley) which preferred sandy areas (the sand dune) on the exploited area. Besides, the tree stumps proved to be a very ideal resting substrate for the molluscs such as *L. scabra* and *C. decollata* during the low tides and thus equally high numbers of molluscs were recorded in the exploited area.

Ecological isolating mechanisms such as feeding adaptations in relation to substrate type could be one factor that influences the zonation, distribution and abundance of epifauna. Frith *et al.* (1976) observed that, *U. lactea annulippes* was found only in substrates with relatively high proportions of sand to which the setae on their maxillipeds are well adapted to feed. *U. urvillei* was found in areas with a relatively high proportion of mud, and their mouth parts are adapted to feed on a muddier substrate. There is evidence to suggest that the more terrestrial mangrove crabs have adapted physiologically to cope with stresses such as temperature and salinity variations and water availability. For instance, the gills of *Uca* and *Sesarma* are reduced in size in comparison to less terrestrially adapted crabs, suggesting that aerial breathing contributes significantly to their oxygen requirements and reduction of water loss. Although water is still required to wet the respiratory surfaces, including lung - like walls of the branchial chamber, it is used conservatively; *Sesarma* crabs actually recycle respiratory water (Macintosh, 1984; 1988).

The gastropod molluscan fauna of the mangrove environment, are able to breathe air and thus withstand long periods of exposure, an adaptation that allows them to be active during low waters periods and to colonise the more landward shore areas (Frith *et al.*, 1976). This may account for the presence of high numbers of *C. decollata* and *L. scabra* recorded in the exploited area, which had more exposed areas. Molluscs are usually faced by stress caused by salinity fluctuations both seasonally and tidally. The lower intertidal species of the bivalve zone and the mangal channels are known to withstand salinity variations of 20 p.p.t. within each tidal cycle (Plaziat, 1984).

In the exploited area, the epifaunal density was less variable with both the highest and the lowest densities recorded during the dry seasons. In the less exploited area the highest epifaunal density was recorded in November (the rainy season of the N. E. monsoon period) while the lowest density was recorded in August (dry season of the S. E. monsoon period). Taking this area as a control and therefore representing a normal and an ideal situation as far as the epifauna are concerned, it seems that there is a discrepancy in the seasonality of epifauna in the exploited area and this may be caused by the different abiotic factors prevailing during the seasons and the absence of vegetation in the exploited area.

Pearson correlation coefficient was used to test whether there were any correlations between the total epifauna and abiotic factors. For transect E, there were no significant relations except for the pH which showed a significant negative relationship with the total epifauna (r= -0.489, p= 0.027). In transect C, there were significant relationships between the total epifauna and air temperature (r= 0.556, p= 0.016), sediment temperature (r= 0.643, p= 0.005), water temperature (r= 0.471, p= 0.038), ammonium concentration (r= -0.473, p= 0.037), nitrate concentration (r= 0.568, p= 0.014). Surprisingly there were no significant relationships between the total epifauna and the salinity or particle size as would be expected. This may suggest that, other abiotic factors were important in controlling the populations of the epifauna, for instance, the ammonium concentration had a strong negative relationship with the epifauna. The epifauna would influence the ammonium concentration in their environment through their excretion of urea, and should the ammonium concentration increase in a given area, the epifaunal abundance would decrease.

5.2.2 Infauna

The results revealed similar infaunal taxa in both the highly exploited and the less exploited areas. For both areas the highest densities of infauna were recorded in November (the rainy season of the N.E. monsoon period), probably the most favourable season for the infauna. Rainfall may play a role in increasing food resources, decreasing the salinity and keeping the temperatures within acceptable range. Seasonal variation due to variable effects of predation and environmental factors may be considerable especially in the exploited area which is more open. Epibenthic predators are important in limiting the numbers of macrofauna and biological interactions may occur between the infaunal species sharing a common resource of space or food.

Though equal numbers of taxa (14) were recorded overall in both areas, the exploited area had higher diversity of infauna. The percentage of total infauna in the exploited area decreased both landwards and seawards with a peak at station E3, however the percentage of number of taxa remained constant. It is important to note that station E3 is located at the shallowest point around sand dunes (see profile diagram Fig. 5) and had the highest median grain size. The infauna groups that dominated this station in the different seasons were sedentary polychaetes, nematodes, oligochaetes and errant polychaetes. In relation to the ecology of these infaunal groups, (and also taking into account that sampling was done during low tide) station E3 provided an ideal habitat. Being the shallowest point, the water table was closer therefore had high pore water content favourable for these infauna. The larger grain size (high median grain size) provided larger pore sizes and therefore sufficient oxygen concentration and more space to be colonised by these groups.

In addition to the above, the behaviour and physiology of these groups need to be taken into consideration. Polychaetes exhibit swarming (a behaviour that congregates sexually mature individuals to increase likelihood of fertilization) therefore would aggregate together. As far as oligochaetes are concerned, station E3 was an ideal environment for them. It may be noted that the pH in this station was highest along the transect. Acid soils (i.e. low pH) are particularly unfavourable habitats for most oligochaete species owing to the lack of free calcium ions necessary for the worm to maintain a higher pH in the blood (Barnes, 1982).

Nematodes in particular were the most dominant group amongst the infauna in both the exploited and the less exploited areas. Other studies on infauna in Gazi have shown nematodes to be numerically dominant (Vanhove and Vincx (1990); Schrijvers (1991)). Nematodes are known to be widespread and numerous and their slender, elongated bodies enable them to manoeuvre through and colonise the narrow interstitial spaces in the sediment (Barnes, 1982; Higgins & Thiel, 1988). For this reason, it seems that nematodes are less affected by the sediment grain size which is the primary factor affecting the abundance and species composition of infauna. Besides many nematodes do not need a rich supply of oxygen (regarded as facultative anaerobes) and would therefore thrive in the oxygen depleted soils of the mangroves. Other factors that may have resulted in nematodes being the most dominant include patchiness due to small - scale physical inhomogeneities in these areas, attraction to food items, and also females of some nematodes are known to produce pheromones that attract males.

In the less exploited area, both the percentage total of infauna and the number of taxa increased towards the sea. The most likely reason for this is the variation in the vegetation zones and the change in the edaphic conditions, especially the sediment grain size which increased towards the sea along this transect.

Faunal assemblages in relation to sediment type has been well documented (Sanders, 1958; Gray, 1974). Gray dealt with this topic in detail and states that, "consideration of the relationship of organisms to sediments is complex since a number of subsidiary parameters are influenced by sediment characters and the subsidiary factors may in fact be the limiting ones". The relationship of the individual to the substratum involves selection of suitable sites to be established by larvae or adults (selection mechanisms are influenced by the physical, chemical and biological conditions of the substrate). Once the population is established, by its functioning and interaction with the sediment, changes in sediment composition frequently occur, which lead to changes both spatially and temporally in the population.

As it may be recalled from the results, sediment temperature and the interstitial water temperature were the only environmental factors that were significantly different in the two areas. The sediment temperature influenced the water temperature and these two factors are suspected to cause the observed patterns of the other physico-chemical factors and in turn the abundance and diversity of the macrofauna especially the infauna that live within the sediment. Pearson correlation coefficients showed significant relationships between the total infauna and pH ($r= 0.589$, $p= 0.037$) and the median grain size ($r= 0.582$, $p= 0.009$) for transect E. For transect C, there were significant relationships between the total infauna and sediment temperature ($r= 0.652$, $p= 0.004$), salinity ($r= 0.590$, $p= 0.010$), ammonium concentration ($r= -0.654$, $p= 0.004$). However, no significant relationship was shown between the total infauna and the sediment particle size. Other factors may play a role in controlling the infaunal abundance, as already mentioned in section 5.2.1.

5.3 CONCLUSIONS

From this study it has been revealed that the abundance of macrofauna was not significantly different between the exploited area and the less exploited area, however, the distribution of macrofauna differed in the two areas. There were no significant differences in the species diversity between the two areas, but the exploited area recorded a higher diversity for infauna while the less exploited area recorded a higher diversity for epifauna. The less exploited area having dense vegetation cover provided more niches, shelter and protection for the epifauna and therefore supported more epifauna.

Clearly, cutting down of mangrove trees results in a significant manipulation of physical factors such as temperature, through intense heating. This has an influencing effect on the chemical factors such as salinity and manipulation of these environmental factors together, will affect the macrofaunal populations.

Little evidence of loss of biodiversity due to mangrove depletion was shown in the data collected in the present study because of alot of variability within samples, small sample sizes, frequency and duration of sampling. In addition, the exploited area still had mangrove vegetation existing.

It was difficult to point out species of macrofauna that may be affected by mangrove exploitation (depletion) due to lack of taxonomic expertise. Generally, it may be suggested that the mangrove macrofauna are more resistant to environmental change (particularly due to mangrove removal) contrary to what maybe thought, and there may be a time lag before the distinct mangrove macrofauna are lost and / or replaced by other species.

5.4 RECOMMENDATIONS

It is only some aspects of the biology of mangrove macrofauna that have been studied and there is still more to be learnt about the life histories of even the most common species. As a result of this lack of information, our understanding of the ecological role and importance of macrofaunal populations in mangrove swamps is very limited.

A great deal of additional research is necessary to fully elucidate the effects of mangrove exploitation on biodiversity. Certainly, the present study, done on a long-term is just one of the suggestions. Systematic information on species of fauna, inter-specific relationships between fauna e.g. predation, life cycles and reproduction are some of the areas that need to be studied in greater details.

REFERENCES

Alongi, D. M. 1987. The influence of mangrove - derived tannins on intertidal meiobenthos in tropical estuaries. **Oecologia.** 71: 537 - 540.

Alongi, D. M. 1988. Bacterial productivity and microbial biomass in tropical mangrove sediments. In: **Microbial Ecology** 15: Springer- Verlag NY. 59 - 79.

Alongi, D. M. 1989. The role of soft - bottom benthic communities in tropical mangrove and coral reef ecosystems. **Aquatic Sciences.** Vol I, Issue 2, 243 - 280.

Aksornkoae, S. 1993. **Ecology and management of mangroves.** IUCN, Bangkok, Thailand. 176 pp.

Banyikwa, F. F. 1986. The geographical distribution of mangrove forests along the East African coast. In: (Eds.) J. R. Mainoya and P. R. Siegel: **The status and utilization of mangroves: Proc. of Workshop on save the mangrove ecosystems in Tanzania, 21 - 22 Feb, 1986, Dar es Salaam.** 5 - 14.

Barnes, R. D. 1982. **Invertebrate Zoology.** Fourth Edition. Holt - Saunders International Edition. Japan. 252 - 799.

Beeckman, H.; Gallin, E. and Coppejans, E. 1990. Indirect gradient analysis of the mangal formation of Gazi Bay (Kenya). **Silva Gandavensis.** 54: 57 - 72.

Berry, A. J. 1963. Faunal zonation in mangrove swamps. **Bull. Nat. Mus. State Singapore.** 32: 90 - 98.

Bilyard, G. R. 1987. The value of benthic infauna in marine pollution monitoring studies. **Marine Pollution Bulletin.** 18 (11): 581 - 585.

Blasco, F. 1984. Climatic factors and the biology of mangrove plants. In: Snedaker, S. C. and J. C. Snedaker (Eds.). **The mangrove ecosystem: Research**

methods. UNESCO/SCOR. 18 - 35.

Boga, H. I. 1993. Aspects of the decomposition process in the mangrove swamp at Gazi Bay, Kenya. MSc. Thesis, Kenyatta University. 149pp.

Bossi, R. and G. Cintron. 1990. **Mangroves of the wider Caribbean. Towards sustainable management.** Caribbean conservation-UNEP. The Panos Institute. 30pp.

Boto, K. G. 1984. Waterlogged saline soils. In: Snedaker, S. C. and J. C. Snedaker (Eds.). **The mangrove ecosystem: Research methods.** UNESCO/SCOR. 114 - 130.

Boto, K. G. 1991. Nutrients and Mangroves. In: D. W. Connell and D. W. Hawker. **Pollution in tropical aquatic systems.** 129 - 144.

Boto, K. G. and J. T. Wellington. 1988. Seasonal variations in concentrations and fluxes of dissolved organic and inorganic materials in a tropical, tidally dominated, mangrove waterway. **Mar. Ecol. Prog. Ser. 50:** 151 - 160.

Brakel, W. H. 1982. Tidal patterns on the East African coast and their implications for the littoral biota. In: **UNESCO/ALESCO Symposium on the coastal and marine environment of the Red Sea, Gulf of Eden, and Tropical Western Indian Ocean. 9 -14 Jan, 1980, Khartoum.** Vol 2: 403 - 418.

Bwathondi, P. O. J. and G. L. A, Mwaya. 1986. Should mangrove habitats be converted for aquaculture and agrofood production. In: J. R. Mainoya and P.R. Siegel (Eds.). **The status and utilization of mangroves; Proc. of Workshop on save the mangrove ecosystems in Tanzania. 21 - 22 Feb, 1986, Dar es Salaam.** 81 - 88.

Chakrabarti, K. 1988. Generic and species diversity of animal vegetation dynamics of Sunderbans mangrove, south Bengal laterite tracts of west Bengal and north Bengal Forests - An Ecological Study. **Indian For.** Vol 112

(5): 407 - 416.

Chapman, V. J. 1976. **Mangrove Vegetation.** J. Cramer Voduz. 477 pp.

Chapman, V. J. (Ed.). 1977. **Ecosystems of the world 1. Wet coastal ecosystems.** Elsevier Sc. Publ. Co. Amsterdam. 428 pp.

Cintron, G. & Y. S. Novelli. 1984. Methods for studying mangrove structure. In: Snedaker, S. C. and J. C. Snedaker (Eds.). **The mangrove ecosystem: Research methods.** UNESCO/SCOR. 18 - 35.

Coppejans, E. and E. Gallin. 1989. Macroalgae associated with the mangrove vegetation of Gazi bay (Kenya). **Bull. Soc. r. Bot. Belg.** 122: 47 - 60.

Crane, J. 1976. **Fiddler crabs of the world (Ocypodidae: genus *Uca*).** Prineton. U. P. 736 pp.

Day, J. H. 1974. **A guide to marine life of South African shores.** 2nd Edition. Balkema, Capetown. 300pp.

FAO. 1994. Forestry paper 117. **Mangrove forest management guidelines.** Rome. 319 pp.

Frith, D. W.; R. Tantanasiriwong and O. Bhatia. 1976. Zonation and abundance of macrofauna on a mangrove shore Phuket island, (Thailand). **Res. Bull. Phuket Mar. Biol. Center.** 10: 1 - 37.

Frith, D. W. and S. Brunenmeister. 1980. Ecological and population studies of fiddler crabs (Ocypodidae, genus *Uca*) on a mangrove shore at Phuket Island, Western Peninsular Thailand. **Crustaceana.** 39(2): 157 - 184.

Gallin, E.; E. Coppejans and H. Beeckman. 1989. The mangrove vegetation of Gazi bay. **Bull. Soc. r. Bot. Belg.** 122: 197 - 207.

Gang, P. O. and J. L. Agatsiva. 1992. The current status of mangroves along the

Kenyan coast: A case study of Mida creek mangroves based on remote sensing. In: V. Jaccarini and E. Martens (Eds.). **The ecology of mangroves and related ecosystems. Proceedings of the international symposium held at Mombasa, Kenya, 24 - 30 Sept, 1990.** 29 - 36.

Graham, R. M. 1922. Notes on the mangrove swamps of Kenya. **J. E. Africa. Uganda Nat. Hist. Soc. 36**: 157 - 164.

Gray, J. S. 1974. Animal-Sediment relationships. **Oceanogr. Mar. Biol. Ann. Rev. 12**: 223 - 261.

Hagrave, B. T. and H. Thiel. 1983. Assessment of Pollution-induced changes in benthic community structure. **Marine Pollution Bulletin. 14(2)**: 41 - 46.

Hamilton, L. S. and S. C. Snedaker. 1984. **Handbook for mangroves area management**. EPI,IUCN,UNESCO,UNEP. 123 pp.

Higgins, R. P. and H. Thiel (Eds.). 1988. **Introduction to the Study of meiofauna**. Smithsonian Institution Press. Washington, D. C. London. 287 - 437.

Icely, J. D. and D. A. Jones. 1978. Factors affecting the distribution of the genus Uca (Crustacea: Ocypodidae) on an East African shore. **Est. & Coast. Mar. Sci. 6**: 315 - 325.

Isaac W. E. and F. M. Isaac. 1968. Marine botany of Kenya Coast 3. General account of environment, flora and vegetation. **Journal E. Afr. Nat. Hist. Soc. 1 (116)**: 7 - 27.

Johnstone, I. M. and D. G. Frodin. 1982. Mangroves of the Papuan subregion. In: J. Z. Gressit (Ed.). **Biogeography and Ecology of New Guinea. Vol I (3)**: 513 - 528.

Jones, D. A. 1984. Crabs of the mangal ecosystem. In Por, F. D. and I. Dor (Ed.). **Hydrobiology of the mangal**. Dr. W. Junk Publishers. 89 - 109.

Kairo, J. G. 1993. Artificial regeneration and sustainable yield management forests in Gazi bay, Kenya. MSc. Thesis, University of Nairobi, Botany department. 116 pp.

Katz, L. C. 1980. Effect of burrowing by the fiddler crab *Uca pugnax* (Smith) Est. & Coast. Mar. Sci. 11: 233 - 237.

Kazungu, J. M.; F. Dehairs and L. Goeyans. 1986. Nutrient distribution patterns in Tudor estuary (Mombasa, Kenya) during the rainy season. **Kenya Journal of Science. Series B, Vol.10 (1-2)**: 47 - 61.

Kazungu, J. M.; F. Dehairs and L. Goeyans. 1993. Distribution of nutrients and particulate organic material in Gazi Bay. In: Woitchik, A. F. (Ed.). **Report on the dynamics and assessment of Kenyan mangrove ecosystems.** No.TS2-0240-182 (GDP). Netherlands Belgium Kenya Mangrove Ecosystem Project. 175 -182.

Kokwaro, J. O. 1986. The distribution and economic importance of the mangrove forests of Kenya. **J. E. Africa Nat. Hist. Soc. 75**: 1 - 12.

Kwale District Environmental Assessment Report. 1985. National Enviroment Secretariat, Ministry of Environment & Natural Resources, No. 67839. Nairobi. pp.

Macintosh, D. J. 1984. Ecology and Productivity of Malaysian mangrove crab populations (Decapoda: Brachyura). In: Saepadmo, E.; A. N. Rao and D. J. Macintosh (Eds.). **Proceedings of the Asian Symposium on Mangrove Environment, Research and Management, Kuala Lumpur, 25 - 29 August, 1990.** 354 - 377.

Macintosh, D. J. 1988. The ecology and physiology of decapods of mangrove swamps. **Symp. Zool. Soc. Lond. No. 59**: 315 -341.

MacNae, W. 1968. A general account of the fauna and flora of mangrove swamps and forests in the Indo - West Pacific region. **Adv. Mar. Biol. 6**: 73 - 270.

MacNae, W. 1974. Mangrove forests and fisheries. **Indian Ocean Programme Publ. No. 34.** Rome, Indian Ocean Fishery Commission. 35 pp.

MacNae, W. and M. Kalk. 1962. The ecology of the mangroves at Inhaca Island, Mozambique. **J. Ecol. 50:** 19 - 34.

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

Mainoya, J. R. 1986. The uses of mangrove and their products by the local community in Tanzania. In: J. R. Mainoya and P. R. Siegel (Eds.). **The Status and Utilization of mangroves: Proceedings of workshop on save the mangrove ecosystem in Tanzania, 21 - 22 Feb, 1986, Dar es Salaam.** 37 - 48.

Mall, L. P.; S. K. Billore and D. Amritphale. 1982. Certain Ecological observation on mangroves of the Andaman Islands. **Tropical Ecology. Vol. 23(2):** 225 - 233.

Martens, E. E. 1992. Coastal Wetland Utilization. In: Crafter, S. A.; S. G. Njunguna and G. W. Howard (Eds.). **Wetlands of Kenya. Proceeding of a seminar on wetlands of Kenya, 3 - 5 July, 1991.** National Musuem of Kenya. IUCN Publication. 115 -134.

Martens, E. E. 1994. Marine wetlands in Kenya: Ecology, threats, conservation. In: **Wildlife Clubs of Kenya. Workshop on wetlands conservation.** Internal report. Nairobi. 25 pp.

Martin, E. B. 1973. **The History of Malindi**: A geographical analysis of an East African coastal town from the portuguese period to the present. East African Literature Bureau. 301 pp.

Mbwana, S. B. 1986. Mangrove conservation and utilization in Tanzania. In: J. R. Mainoya and P. R. Siegel (Eds.). **The status and utilization of mangroves: Proc. of Workshop on save the mangrove ecosystems in Tanzania, 21 - 22 Feb, 1986, Dar es Salaam.** 49 - 58.

Micheli, F.; F. Gherardi and M. Vannini. 1991. Feeding and burrowing ecology of two east African mangrove crabs. **Marine Biol.** 111: 247 - 254.

Miller, D. C. 1961. The feeding mechanisms of fiddler crabs, with ecological consideration of feeding adaptations. **Zoologica.** 46: 87 - 100.

Moorjani, S. A. 1977. The ecology of marine algae of the Kenya coast. PhD. Thesis, University of Nairobi. 285 pp.

Muhando, C. A. 1990. Some of the factors affecting the distribution and abundance of the mangrove crab, *Uca lactea* (Milne Edwards) in the Kunduchi mangrove creeks, Dar es Salaam, Tanzania. In: **Kenya- Belgium Project Progress Report, 1990.**

Odum, W. E. and E. J. Heald. 1975. The detritus based food web of an estuarine research. In Cronin, L. E. (Ed.). **Estuarine Research.** Academic Press, New York. 265 - 286.

Pinto, M. L. 1984. Some ecological aspects of a community of mangrove crabs occuring within the islets of Negombo Lagoon (Sri Lanka). In: Soepadmo, E.; A. N. Rao & D. J. Macintosh (Eds.) **Proc. As. Symp. Mangr. Env. - Res. & Manag. 25 - 29 August, 1980.** Kuala Lumpur. University of Malaya and UNESCO. 311 - 330.

Plaziat, J. C. 1984. Molluscs distribution in the Mangal. In Por, F. D. and I. Dor (eds). **Hydrobiology of the mangal.** Dr. W. Junk Publishers. 111 - 143.

Rainbow, P. S. and A. C. Campbell. 1984. Possible directions for shore based marine biological research in Kenya. **Kenya Aquat.** 2: 13 - 19.

Ristich, S. S.; M. Crandall and J. Forties. 1977. Benthic and epibenthic macroinvertebrates of the Hudson river. I. Distribution, Natural History and Community Structure. **Est. & Coast. Mar. Sci.** 5: 255 - 266.

Robertson, A. I. and P. A. Daniel. 1989. The influence of crabs on litter processing in high intertidal mangrove forests in tropical Australia. **Oecologia.** 78: 191 - 198.

Rützler, K. and C. Feller. 1988. Mangrove swamp communities. **Oceanus. Vol. 30 No. 4:** 16 -24.

Ruwa, R. 1988. Changes in patterns of macrofaunal distribution in mangrove ecosystems at the Kenyan Coast due to natural and un-natural causes. In **Kenya Belgium Project, 4th Quarterly Report.** 98 - 116.

Ruwa, R. K. 1990. The effects of habitat complexities created by mangroves on macrofauna composition in brackishwater intertidal zones at the Kenya coast. **Discovery and Innovation. Vol. 2. No. 1.** 49 - 55.

Ruwa, R. K. 1992. Mangrove wetlands in Kenya. In: Crafter, S. A.; S. G. Njuguna and G. W. Howard (Eds.). **Wetlands of Kenya. Proceedings of a seminar on wetlands of Kenya, 3 - 5 July, 1991.** National Musuem of Kenya. IUCN Publication. 65 - 78.

Ruwa, R. K. 1993. Zonation and distribution of creek and fringe mangroves in the semi-arid Kenyan coast. In: H. Lieth and A. Al Masoom (Eds.). **Towards the rational use of high salinity tolerant plants.** 1: 97 - 105.

Ruwa R. K. and P. Polk. 1986. Additional information on mangrove distribution in Kenya. Some observations and remarks. **Kenya Journal of Science and Technology.** Series B. 7(2): 41 - 45.

Saenger, P.; E. J. Hegerl and J. D. S. Davies (Eds.). 1983. Global status of mangrove ecosystems. Commission on ecology papers Numbers 3. IUCN Comm. on Ecol./UNEP/WWF. 88pp.

Sanders, H. L. 1958. Benthic studies in Buzzards Bay. I. Animal-Sediment relationships. **Limnology and Oceanography.** Vol III No.3: 245 - 358.

Sanders, H. L. and R. R. Hessler. 1969. Ecology of deep-sea benthos. **Science.** 163: 1419 - 1424.

Sasekumar, A. 1974. Distribution of macrofauna on a Malayan mangrove shore. **J. Anim. Ecol.** 43: 51 - 69

Schrijvers, J. 1991. Ecological study of the benthos of the mangroves and surrounding beaches at Gazi bay, Kenya. MSc. Thesis summary, 1 - 18.

Selvam, V.; J. Azariah and H. Azariah. 1992. Diurnal variation in physical - chemical properties and primary production in the interconnected marine, mangrove and freshwater biotopes of Kakinanda coast, Andhra Pradesh, India. In: V. Jaccarini and E. Martens (Eds.). **The ecology of mangroves and related ecosystems. Proceedings of the international symposium held at Mombasa, Kenya, 24 - 30 Sept, 1990.** 181 - 186.

Semesi, A. K. 1986. Zonation and vegetation structure of mangroves in Tanzania. In: J. R. Mainoya and P.R. Siegel (Eds.). **The status and utilization of mangroves: Proc. of Workshop on save the mangrove ecosystems in Tanzania, 21 - 22 Feb, 1986, Dar es Salaam.** 6 - 15.

Semesi, A. K. 1991. Management plan for the mangrove ecosystem of mainland Tanzania. **Mangrove management plan of Mafia district.** Prepared by Ministry of Tourism, Natural resources and environment; Forest and bee keeping division. Vol.6: 1 - 36.

Semesi, A. K. 1992. Developing management plans for the mangrove forest reserves of mainlnd Tanzania. In: V. Jaccarini and E. Martens (Eds.). **The ecology of mangroves and related ecosystems. Proceedings of the international symposium held at Mombasa, Kenya, 24 -30 Sept, 1990.** 1 - 10

Shokita, S. 1989. Macrofaunal community structure and food chain in the Mangals. In: **Training course on the life history of selected species of flora and fauna in mangrove ecosystems;** Thailand, 2 - 16 October, 1985. pp 1 - 45.

Smith III, T. J. 1987. Seed predation in relation to tree dominance and distribution in mangrove forests. **Ecology.** 68: 266 - 273.

Smith III, T. J.; H. T. Chen; C. C. McIvor and M. B. Robblee. 1989. Comparisons of seed predation in tropical tidal forests from three continents. **Ecology.** 70 (1): 146 - 151.

Smith III, T. J.; K. G. Boto; S. D. Frusher and R. L. Giddins. 1991. Keystone species and mangrove dynamics: The inluence of burrowing by crabs on soil nutrient status and forest productivity. **Est. Coast. & Shelf Sc.** 33: 419 - 432.

Snedaker, S. C.; M. S. Brown, E. J. Lahmann & R. J. Araujo. 1992. Recovery of a mixed-species mangrove forest in South Florida following canopy removal. **Journal of Coastal Research.** Vol. 8, No.4: 919 - 925.

Thom, B. G. 1967. Mangrove ecology and Deltaic geomorphology Tabasco, Mexico. **J. Ecol.** 55: 310 - 343.

Tomlinson, P. B. 1986. **The Botany of Mangroves.** Cambridge University Press, Cambridge. 413pp.

Vanhove, S. and M. Vincx. (1990). Study of the meiobenthos in five mangrove vegetation types in Gazi Bay, Kenya. Paper presented at the Symposium on " The Ecology of mangroves and related ecosystems", 24 - 30 Sept, 1990. Mombasa.

Van Speybroeck, D. 1990. Field course to the Kenya Coast. 3 - 9 June, 1990. University of Nairobi, Botany Department. Internal report. 65 pp.

Van Speybroeck, D. 1992. Regeneration strategy of mangroves along the Kenyan coast: A first approach. **Hydrobiologia.** 247: 243 - 251.

Vannini, M. 1993. Ecological research on mangrove crustaceans. In: A. F. Woitchik (Ed.). **Report on the dynamics and assessment of Kenyan mangrove** ecosystems. No. TS2-0240-182 (GDP). Netherlands-Belgium-Kenya mangrove ecosystem project. 99 - 135.

Walsh, G. E. 1974. Mangroves: A review. In: R. Reimhold and W. Owen (Eds.). **Ecology of Halophytes.** Academic Press, NY and London. 51 - 174.

Walsh, G. E. 1977. Exploitation of mangal. In: V. J. Chapman (Ed.). **Ecosystems of the world. Wet coastal ecosystems.** Elsevier Scientific. Amsterdam. 347 - 362.

Warner, G. F. 1969. The occurence and distribution of crabs in a Jamaican mangrove swamp. **J. Animal Ecol.** 38: 379 - 389.

Wells, F. E. 1984. Comparative distribution of macromolluscs and macrocrustaceans in a northwestern Australian mangrove system. **Aust. J. Mar. Freshw. Res.** 35: 591-6.

Wells, F.E. 1986. Distribution of Molluscs across a pneumatophore boundary in a small bay in North western Australia. **J. Moll. Stud.** 52: 83 - 90.

Zar, H. J. 1984. **Biostatistical analysis.** Prentice, Hall Inc., Englewood Cliffs. N. J. 718 pp.