UNIVERSITY OF GHANA

SEASONAL DYNAMICS OF BENTHIC MACROFAUNA IN THE KETA LAGOON

A THESIS

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DECLARATION

“This thesis is the result of research work undertaken by Emmanuel Lamptey in the Department of Oceanography and Fisheries, University of Ghana, under the supervision of Mr. A. K. Armah”.

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DEDICATION

I dedicate this work to God Almighty and my sweet mother, Miss Mary Adjei.

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to influence habitat heterogeneity, possibly serving as strong predictors of macrofaunal assemblage and abundance in the Keta lagoon.

Some lagoons are dumping areas for disposal of waste from urban and industrial areas. In some places their water is used for the cooling of generators of electric power plants, which return effluent of warmed water to the lagoon. Coastal lagoons are economically important in their use for aquaculture facilities ((Day and Yanez-Arancibia, 1985; De Wit, 2003). Coastal lagoons facilitate processes, particularly those resulting in loss or accretion of natural wetland. Despite all these uses, most coastal lagoons are unstable succumbing to the vagaries of climatic conditions.

Depending on the local climatic conditions, coastal lagoons exhibit salinity levells, which ranges from completely fresh to hypersaline (i.e. salinity values above 35ppt) (Knoppers *et al.*, 1991), such high levels are tolerable to few organisms. However, some coastal lagoons in Ghana are functionally stable because of the influence from the sea that has one or more narrow opening(s) to the lagoons most of the time.

In Ghana, there are over 90 lagoons and wetlands along the entire 550 km coastline, which among others, are important feeding/foraging sites for migratory birds (Armah, 1993). The largest among these, is the Keta lagoon. Together with its associated wetlands, Keta lagoon has been estimated to be about 702 km^2 in area (Armah, 1993). The water body however has an estimated surface area of 350 km^2 (Ababio, 2001). This makes it the largest lagoonal wetland in West Africa. The lagoon is a closed system and stretches for about 40km along the coast, separated from the sea by a narrow coastal ridge or strip of land, which is only about 2.5 km at its widest point and about 0.92 km at the narrowest portion (Piersma and Ntiamoah-Baidu, 1995).

In recent times the narrow strip of land separating the lagoon from the sea has experienced very severe erosion from the sea leading to the inundation of the peripheral settlements of the lagoon in the catchment area during periods of heavy rainfall. The situation necessitated mitigating measures to be taken by the Ghana Government to protect life and property with the initiation of the Keta Sea Defence Work Project (KSDWP). The KSDWP is of five years duration. The construction activities were initiated in early 2000, and consisted of four principal components, namely, sea defence, land reclamation, construction of road and construction of flood relief structure.

Under the Project a total area of approximately 283 ha of land would be reclaimed by construction of groynes from the shore to a depth approximately 4.5 meters NLD (National Land Datum) and extending 140 – 200 meters from the existing shore at the seaward section. The project has also led to the dredging of portions of the lagoon about 8 km long from Havedzi to Keta for road construction and land reclamation. The principal biological impacts of such dredging activities include disturbance and removal of benthos and alteration of the substrate upon which colonization depends. Dredging activities also affect certain physical and chemical conditions such as degree of oxygenation and mineralization, temperature, salinity, water flow, depth and fluctuations of water level. Some of these changes, beside protecting life and property will also enhance the ecological conditions of the lagoon in terms of fisheries. For instance, the author observed lots of *Mugil sp.* and crabs (e.g. *Uca tangeri*) in the dredged channel created by the project. In spite of these and others of ecological importance that have earned the Keta lagoon the position of a Ramsar Site and the high fisheries yield, very little benthic work has been carried out. Benthic-pelagic coupling is known to drive fisheries of coastal lagoons (Kjerfve, 1994).

Benthic invertebrates are essential to the ecology of coastal water bodies. Many benthic species are themselves harvested for human consumption, and they also provide the means by which primary food resources are passed up the food chain to fish. Changes in the structure of benthic communities are now used routinely in several countries to monitor the biological effects of man's activities in coastal waters, pollution, and disturbances caused by major engineering work (dredging) etc. Most researches on benthic communities have been conducted in temperate latitudes, and to a lesser extent, subtropical and boreal (mountaneous) latitudes

(Gray, 1981). However, with currently increasing interest in bio-diversity coupled with industrialization and urbanization near water bodies, it seems timely to undertake comparable studies in a tropical area such as Ghana.

Most early work was necessarily taxonomic or consisted of compilations of faunal lists. Hence, little comprehensive work exists detailing factors affecting the distribution and abundance of soft-bottom benthic assemblages in the tropics (Longhurst and Pauly, 1987). Information on seasonal variability of macrobenthic fauna in lagoonal systems is very scanty. The Keta lagoon is no exception in particular, its macrobenthic fauna.

The only benthic investigation in the Keta lagoon was carried out by Finlayson et al., (2000). It however, lacks certain critical elements. These are (1) explanation for the distribution pattern of macrofauna (2) assessment of the organic matter and sulphur contents in the sediment; (3) intervals between sampling stations were approximately 2 km but such a long interval has a potential danger of masking valuable information on habitat structure, and lastly but quite significantly (4) the study was restricted to a short period between November and December and hence could not explain seasonality or otherwise of the distribution and abundance of benthic macrofauna as well as habitat structure. Thus, the macrofaunal information of the Keta lagoon from the work of Finlayson *et al.*, (2000) may be severely distorted by lack of adequate data on temporal and spatial variability. The abundance and spatial distribution of macrofauna assemblages determine, to a large extent, the composition of higher trophic organisms of commercial importance such as fishes and birds (Kjerfve, 1994; Colwell and Landrum, 1993; Liang et al., 2002). Understanding the observed patterns of distribution and abundance of organisms often must involve an evaluation of the relationship between these organisms and the structure of the habitat.

This study was therefore, undertaken to investigate the seasonal dynamics of benthic macrofauna distribution and abundance in relation to environmental variables of the Keta lagoon. The studyl provides an understanding into benthic ecology in the Keta lagoon. The study also will provide animportant baseline information on the likely long-term impacts of constructional activities of Keta Sea Defence Work Project and anthropogenic impacts of the settlements around the lagoon especially from the growing populations on the coastal belt.

The specific objectives of the study are to:

(i) analyse, in detail, the benthic macrofauna distribution pattern and abundance in the Keta lagoon at spatial and temporal scales that will better explain the relationships between the organisms and habitat heterogeneity

(ii) investigate the key environmental (physico-chemical parameters) variables affecting the benthic macrofaunal community structure

(iii) Further, the study will assess

(a) the recolonisation/colonization of benthic macrofauna in the modified sections of the lagoon as a result of the KSDWP, notably, dredged canal and areas impacted by dredge spoil, and

(b) sediment distribution and its relationship to spatial occurrence of the macrofauna as well as provision of sediment map of the lagoon.

CHAPTER TWO

LITERATURE REVIEW

2.1 GEOMORPHOLOGICAL HISTORY OF COASTAL LAGOONS

All coastal lagoons are recent and transitional geological happenings. The fundamental processes that contributed to their formation took place in the Holocene and were due to changes in sea level about 6000 to 7000 years ago (Phleger, 1969;Emery and Stevenson, 1957) together with the rise and fall of the coastal area (Zenkovitch, 1969). In the case of an emergent coastline, the shallowness of the water and the plain may give rise to a submerged beach that contributes to the formation of a barrier, which isolates interior water and, thus, forms a lagoon. In the case of sinking coastline the mechanism that operates is a continual and gradual rise in sea level forming a barrier (Zenkovitch, 1969) or with regard to a slight sloping coast, the coastal water from the sea may flood a coastal depression, in a process that under certain circumstances may form a barrier that encloses the depressions and forms a lagoon (Lankford, 1977).

In geomorphologic terms, coastal lagoons usually occur where valley mouths or lowlands have been submerged by the sea during the later stages of the Late

Quaternary marine transgression, which on tectonically stable coasts brought the sea up to approximately its present level about 6000 years ago (Bird, 1994).

Once formed, coastal lagoons are modified by erosion and deposition. Infilling by accumulation of inwashed sediment, organic deposits such as peat or shells, precipitated material, results in shallowing and shrinkage of lagoons (Bird, 1994). Contrasting sea-level histories have exerted a fundamental control on coastal sedimentation (Dominguez, 1984). Under conditions of sea-level rise, barrier island/lagoonal systems become important environments of sedimentation. Barrier islands form preferentially under conditions of sea-level rise. According to Bruun's rule (Bruun, 1962), if the coastal profile is accepted as an equilibrium response of the sea floor to the coastal fluid power expenditure, then the effects of a sea-level rise could be deduced as a landward and upward translation of the profile. Thus, as sea level rises along a low-relief coastal plain, the beach and dune are nourished by the longshore drift and grow upwards at the same rate of sea-level rise following Bruun's rule. The swale behind the dune, however, remains at the same altitude and, as sea level rises, becomes a lagoon (Martin and Dominguez, 1994). When sea level falls, the inverse of Bruun's rule applies, resulting in a seaward and downward translation of the coastal profile, and shallow back-barrier lagoons eventually become emergent (Martin and Dominguez, 1994). Because lagoons are generally shallow, they are very sensitive to fluctuations of sea level; small rises and falls translate respectively into widespread inundation and emergence of coastal lagoons. Thus, coastal lagoons during their geological history may be affected by multiple episodes of invasion and emergence.

Ecological conditions, particularly water salinity and temperature, are important in the geomorphological evolution of coastal lagoons. They control the extent to which vegetation can colonize lagoon shores, impeding erosion, promoting pattern of sedimentation and generating organic deposits (Bird, 1994). Coastal lagoons around the world show great contrasts, but the same processes have operated in similar situations

Lagoons fed by rivers receive sediments ranging from coarse sand to silt and clay. The coarser material is deposited as the river enters the lagoon, and may be added to lagoon beaches and spread around the shore by wave action; the finer sediment is carried out into the lagoon and deposited on the floor, progressively reducing the depth. Rates of fluvial sediment yield to lagoons may be accelerated by the reduction of vegetation cover and the onset of soil erosion in the river catchments (Bird, 1994).

2.2 GENERAL CHARACTERISTICS OF BENTHIC COMMUNITIES

Benthic communities comprise hard-bottom benthos and soft-bottom benthos. Hard-bottom benthos includes epifauna (encrusting forms e.g corals) and motile fauna (both macrofauna and meiofauna e.g, epifauna). Soft-bottom benthos includes microbenthos (i.e those organisms that are retained on a 63-µm sieve) and meiobenthos (i.e. those organisms retained on 300-µm sieve) (Clarke and Warwick, 1994). The macrofauna forms are by far the better known and used component of the marine biota in environmental impact studies (Clarke and Warwick, 1994). Macrobenthos (benthic organisms that are retained by 0.5 to 1.0 mm mesh) are generally in the size range of 1mg to 2g dry tissue weights (Reise, 1985). Their most pronounced characteristic is a relatively high degree of mobility, including the ability to burrow rapidly. Their migrations may be mediated by endogenous rhythms (i.e. physiological conditions) triggered by changing environmental factors such as salinity, temperature etc. The most conspicuous members of the benthic macrofauna are the molluscs, crustaceans and annelids (Day and Yanez-Arancibia, 1985). Other groups include nemerteans, anthozoans, platyhelminthes, sipunculids, echiurids, insects and echinoderms. The role of benthic faunal assemblages in lagoons has been well documented. Macrobenthic communities may directly affect biogeochemical processes in the sediment (Aller and Yingst, 1985) and sediment stability (Kristensen *et al.*, 1985; Woodin and Jackson, 1979 ;). They also improve the conditions within the sediment, such as oxygenation (Reise, 1985) and loosen subsurface sediments and render them inhabitable by other macrofauna (Flint and Kalke, 1986) while providing a coupling between meiofaunal and nekton communities (Josefson and Rasmussen, 2000; Bell and Woodin, 1984; Hodson *et al.*, 1981).

A “major benthic community is one which is self–sustaining without other communities, and is defined as a group of organisms occurring in a particular environment presumably interacting with each other and with the environment, and separated by means of ecological survey from other groups” (Mills, 1969). Within such communities, analysis of differences in benthic community structure is one of the mainstays of detecting and monitoring the biological effects of marine pollution and habitat disturbance (Warwick and Clarke, 1993) as well as for ecological modeling (e.g. Josefson and Rasmussen, 2000; Tumbiolo and Downing, 1994). Potential benefits of research on macro-invertebrates include quick assessment of biological resources for conservation purposes and the detection of pollution through differences between predicted and actual faunal assemblages (Ormerod and Edwards, 1987).

2.2.1 DISTRIBUTION OF BENTHIC FAUNA

Benthic fauna community distributions vary considerably in time and space (Boesch, 1973; Carriker, 1967), due, in great part, to the patchiness of species occurrences (Pearson and Rosenberg, 1978) and overall heterogeneity of the benthic habitat (Mistri *et al.*, 2000). This heterogeneity has been ascribed to such factors as bottom sediment, spatial variability (Tenore, 1972), climatic irregularity (Bourcier, 1995; Hassle and Sanders, 1967), anthropogenic perturbations (Kröncke *et al.,* 1992; Rosenberg, 1973) and biogenic structures (Woodin, 1981). According to Alongi (1990), temporal and spatial patterns of benthos are determined by primary production in the water column and by sediment types and associated physico-chemical conditions. Physical or environmental factors, such as water depth and sediment type and movement, are considered to determine large-scale patterns of distribution (e.g. Barry and Dayton, 1991; Thorson, 1957). Within these patterns, however, spatial heterogeneity exists at various scales, forming a mosaic of patches. It has been suggested that heterogeneity of lagoons is maintained by a variety of disturbances and other biotic and abiotic factors (Barry and Dayton, 1991; Thrush *et al.*, 1989). Physical disturbance was defined as that subset of processes that lead to the disruption (movement) of sediment which include bioturbation processes caused by the animals that live in or on the sediment, and some of the disturbances caused by man's activities e.g. fishing, dredging and gravel extraction (Hall, 1994). Coastal soft-bottom macrobenthic communities receive considerable habitat disturbance from natural phenomena, which can result in major changes in salinity, temperature, currents (Flemer *et al.*, 1997), and wave-generated resuspension of sediments (Thistle, 1981; Parker *et al.*, 1980). Anthropogenic sources of stress, often interacting with natural process, include energy production (Gaston and Edds, 1994; Gaston, 1985); channel dredged material disposal operations (Kirby *et al.*, 1975);

nutrient over-enrichment (Rabalais, 1992) leading to hypoxia (Gaston *et al.*, 1985) and toxic materials (Macauley *et al.*, 1994).

Natural communities of organisms comprise a large number of species. A suite of different environmental variables to which each of the species in the community may respond differently determines changes in community structures (Warwick and Clark, 1991). Wide variations in faunal densities and species richness have been found to coincide with great variety of habitats and environmental conditions (Alongi, 1990). Temporal changes have been recorded both in whole macrofauna communities and in individual populations. The most dramatic of these are associated with the monsoon in India, where much of the fauna disappear from the beaches during this period (McLusky *et al.*, 1975; Ansell *et al.*, 1972). Seasonal changes have been recorded for most of these macrofaunal species studied. Macrofauna dynamics follow such seasonal patterns (Mistri *et al.*, 2001) and are characterized by high variability in abundance and dominance patterns within the years (Posey, 1986; Nichols, 1985). The variability in abundances of the organisms has been attributed to temporal variability in physical conditions that may affect recruitment, survival and reproduction (Posey *et al.*, 1998). The seasonal dynamics of the macrofauna communities have therefore been ascribed to the complex interactions between physical (environmental) variables and biological attributes or structures of the habitat.

Most of the correlations between habitat heterogeneity and species diversity- a measure of the species composition of an ecosystem, in terms of the number and relative abundance of the species" (Legendre and Legendre, 1983) - are usually viewed as an expression of the outcome of competition (e.g. MacArthur, 1972). They may, however, reflect reduction in the effectiveness of a predator as a result of increased habitat heterogeneity, e.g. fish preying on benthic amphipods (Ware, 1972). Increased habitat complexity increases the diversity and abundance of organisms as a result of the increased diversity of living space (Morse *et al.*, 1985), increased protection from predation (Gibbons, 1988) and increased particle variety for deposit-feeding organisms (Whitlatch, 1981). Variation in relative abundances of deposit feeders and suspension feeders may reflect seasonal variation in food supply (Levinton, 1972), annual lifespans, and/or variation in recruitment. Changes in numbers of individual taxa can, in some instances, simply represent replacement within guilds and it has been suggested that numbers within guilds based on feeding type (Levinton, 1972) or living position (Posey, 1990) may exhibit more temporal stability than observed with individual taxa.

2.2.2 ENVIRONMENTAL VARIABLES STRUCTURING BENTHIC MACROFAUNA

Environmental variables (such as sediment structure, organic matter content, temperature, salinity, dissolved oxygen, nutrient concentrations, pH, turbidity, water transparency and depth) have been found to correlate with abundance, density and diversity of macrofauna and these variables may vary seasonally (Mistri *et al.*, 2001; Hagberg and Tunberg, 2000; Mistri *et al.*, 2000; Arvanitidis *et al.*, 1999; Nicolaidou *et al.*, 1988). The variability of these environmental factors and their potential influence on the macrofaunal pattern in lagoonal environments support the hypothesis of Barnes (1980) that coastal lagoons are highly dynamic and extremely unpredictable systems. It is therefore, very important to understand the dynamics of these environmental variables in a bid to evaluate their impact in structuring macrofaunal communities.

The understanding of the physical, chemical, geological and ecological dynamics of lagoon is important for the planning and implementation of coastal management strategies in coastal lagoons (Kjerfve, 1994).

2.2.2.1 **Physico-chemical Parameters**

Coastal lagoons are ecosystems with strong spatial gradients concerning the chemical characteristics of the water and of the biological populations present (Kjerfve, 1986). Closed lagoons are functionally (physical, chemical and biological) more unpredictable, with conditions changing very rapidly from one point in time to another, while open lagoon systems are more stable due to influence of the sea (Finlayson *et al.*,2000). The situation fundamentally creates variability in the functional conditions such as salinity, sediment, depth, temperature, turbidity and nutrients concentrations of the water column. The interplay of these factors forms identifiable biotopes resulting in distinct assemblages of organisms. Knowledge of the variability of physico-chemical parameters is important in understanding primary production, which in turn determines the distribution and abundance of macrofauna (Alongi, 1990). There is a very strong benthic-pelagic coupling with primary production passing through macrobenthos. On a large scale, benthic communities tend to coincide in regions where primary production is high (Cushing, 1988). Primary production is mainly controlled by environmental variables.

Alongi (1990) has suggested that the dynamics of benthos might be more closely related to total water-column production. Physico-chemical parameters affect total water-column production directly or indirectly and help in structuring macrofauna communities. Higher densities of macrofauna ($> 500\ m^2$) found in a saline lagoon on the Saudi Arabian coast of the Arabian Gulf (Jones *et al.*, 1978), were attributed to comparatively high primary production (Alongi, 1989).

According to Warwick and Clark (1991) changes in community structure of macrofauna are determined by a suite of different environmental variables to which each of the species in the community may respond differently.

The understanding of the dynamics of most of the physico-chemical parameters is therefore crucial, in that some of the parameters may directly or indirectly affect macrofaunal community abundance and distibution. For instance, salinity changes in lagoonal environment follow the seasonal changes in evaporation and/or freshwater inflow. Salinity has been reported to control the distribution and the reproduction of certain macrofauna. For instance, the blood cockle or clam, *Anadara* had been shown to thrive in different environmental preferences, but the most significant parameter regarding their distribution is salinity, among others (Broom, 1985). Salinity appears to be a key regulatory factor in the breeding cycle of *Anadara* (Macintosh, 1994). Yankson (1982) reported that *Anadara senilis* occurring in Fosu lagoon in Ghana could tolerate salinity up to 50 ppt in the dry season. It has also been reported that the fall in salinity appears to be responsible for the increased in reproductive output of species with a planktonic larval stage, such as the bivalves *Anadara granosa* and *Pelecyora trigona* (Alongi, 1990).

High levels of turbidity have been found to inhibit the settlement of *Pecten novaezelandiae* veligers, are depressed the growth rate of adults (Stevens, 1987). However, the main ecological effect of turbidity is a marked decrease in the penetration of light. This, in turn, decreases photosynthesis by phytoplankton and benthic plants, thereby reducing productivity.

Irrespective of the cause, low dissolved oxygen concentrations, have important consequences for benthic fauna. For instance, along the west coast of India, coastal upwelling results in the placement of warmer subsurface waters of low dissolved oxygen content to the bottom, displacing many macrofauna (Banse, 1968). Since the solubility of oxygen in water decreases with increased temperature and salinity, the precise amount of oxygen in the water will vary as those parameters vary.

Abundant source of nutrients, efficient means of conservation, and high rates of recycling characterize some lagoon environments (Day and Yanez-Arancibia, 1985). Riverine incursion inputs relatively large amounts of allochthonous nutrients (e.g phosphorus and nitrogen). These are supplemented by materials in rain and nitrogen fixation (Mee, 1978). These nutrients carried by river runoff are trapped and incorporated into the biochemical pathway including sediments (Day and Yanez-Arancibia, 1985), especially when they come into contact with salt water. Nixon (1982) stated that lagoonal sediments are characterised by a release of phosphates under anoxic conditions. It has been reported that net production of organic matter takes up phosphorus, while net consumption releases phosphorus (Smith and Atkinson, 1994).

Elements such as phosphorus, nitrogen, and sulphate exist in almost every possible chemical state. The presence of both anaerobic and aerobic spheres makes chemical cycling much more complex (Mee, 1978). Anaerobic conditions allow reactions like solubilization of precipitated phosphorus, denitrification, and methane formation to take place (Day and Yanez-Arancibia, 1985). These can be made available for primary producers (e.g phytoplankton) uptake via mineralization. Denitrification caused by anaerobic conditions result in loss of nitrogen (Day and Yanez-Arancibia, 1985). Scott Nixon cited in Day and Yanez-Arancibia (1985) has suggested that it is this permanent loss of nitrogen to the atmosphere, which is primarily responsible for nitrogen limitation in some lagoons.

Sulphate reduction is probably an important pathway of organic oxidation in many sediment-dominated aquatic systems containing a significant fraction of seawater (to supply sulphate ion) and exhibiting relatively high rates of metabolisms in the sediments (Smith and Atkinson, 1994). Under such circumstances, there is non-conservative alkalinity production rather than consumption (Smith and Atkinson, 1994). If reactions involving carbonate minerals appear minor, then alkalinity production can be used as an estimate of the production rate of sulphide minerals (Smith and Atkinson, 1994).

As nutrient concentrations input increases, phytoplankton can undergo a rapid population increase, which can have profound effects on the benthic community. Strong nutrients pulses sometimes facilitate strong recruitment of species with planktotrophic larvae (Birkeland, 1987).

2.2.2.2 **Sediment structure**

The most basic way of characterizing any community is by the habitat type and for benthic community habitat normally means sediment type (Hall, 1994). The distribution of many of the macrofauna communities shows a clear correlation with sediment type. An analysis of sediment is a means of quantifying the result of an essentially dynamic process from a sample taken at a moment in time (Buchanan, 1984). Sediment composition varies greatly among lagoons depending upon their openness to the sea and the presence or absence of rivers and coastal vegetation (Webb, 1958). Lagoon sediments are mixtures derived from multiple sources: external sources (allochthonous source) like streams or the sea, and internal sources (autochthonous source) from within the lagoon (Nichols and Boon, 1994) such as biogenic processes, shell and chemical precipitation. Sediment supply to a whole lagoon is not uniform. Surficial sediment distributions are determined by (i) the sediment source (relict or modern), (ii) interactions between sediment particles (including adsorption of chemicals), (iii) the hydrodynamic regime, and (iv) biological effects (Snelgrove and Butman, 1994). Fine sediment dispersal is broadly organised along a hydrodynamic gradient resulting in a downstream decrease in competence from source to sink (Nichols and Boon, 1994). Climatic variations lead to the formation of many sedimentary facies and habitats peculiar to the tropics (Alongi, 1990). Lagoon sediments therefore, are potential climatic indicator. Climate influences terrestrial sediment sources because it controls the intensity and type of weathering, together with relief, the sediment yield (Nichols and Boon, 1994). It also controls the availability of source sediment through precipitation and runoff rates or vegetation development. Additionally, the lagoon circulation and the advective and dispective processes are all linked to climate through the amount of precipitation, runoff, temperature and evaporation (Nichols and Boon, 1994), which are processes that give rise to sediments in lagoons. The distribution of relict shell, however, has been shown not to be related to climate (Alongi, 1990).

Early studies suggested that macrobenthic communities could be distinguished on the basis of sediment composition (van Dalfsen *et al.*, 1999; Flint, 1981; Buchanan *et al.*, 1978; Thorson, 1957). Other studies, however, have shown little correlation (Seiderer and Newell, 1999; Day *et al.*, 1971; Buchanan, 1963;) and suggested that the distribution of macrofuana in many sedimentary habitats is controlled by complex interaction between physical and biological factors at the sediment–water interface, rather than by the granulometric properties of the sediments themselves (Snelgrove and Butma, 1994). However, density-dependent variables play a minor role in structuring the macrobenthic communities, which were probably affected more by other variables, such as the kind of habitat and sediment structure (Mistri, 2000).

Benthic organisms continually process, transport, and modify lagoon bed sediments. There are those that bind, protect and stabilize near-surface sediment and those that loose and destabilize the sediment (Nichols and Boon, 1994). Woodin and Jackson (1979) proposed five functional groups of benthic organisms in relation to their effects on the sediment: (i) mobile burrowers that destabilize the sediment (including their feeding activity); (ii) sedentary organisms that cause the sediment to be more easily resuspended; (iii) sedentary organisms that do not inhabit tubes that still straddle the sediment-water interface and modify the local hydrography such as to reduce resuspension and, by virtue of buried parts, bind the subsurface particles together; (iv) tube builders that stabilize the sediment by incorporating it, often in mucus-bound form into their tubes; and (v) neutral species having no impact on sediment deposition or resuspension. For macro-invertebrates, the requirements of life in unconsolidated sediments inevitably involve the need to move particles around in some way, whether as a consequence of locomotion through the sediments, or feeding upon the organic material associated with them. This is known as bioturbation (Hall, 1994).

Bioturbation of sediments by burrowing or deposit-feeders through processes such as irrigation, pelletization and tube construction, usually increases sediment pore space and thus, water content in the upper sediment layer (Rhoads, 1974; Rhoads and Young, 1970). Bioturbation lowers erosion resistance of the surface, and thus destabilizes the bed sediment. Bioturbation can be important in excluding particles and pore water nutrients across the sediment-water interface as well as through various vertical chemical gradients in the sediment (Nichols and Boon, 1994).

Depending upon its life style, an organism may require a given size range of sediment for tube building, burrowing or feeding (Wieser, 1959). The feeding type of the benthic community is considered as an adaptation to the sediment characteristics (Rosenberg, 1995). Certain mechanisms result in sediment-specific distribution. One of these is the preferential ingestion or retention of specific grain sizes during feeding. Adults of a variety of deposit-feeders have been shown to ingest specific grain sizes of sediments (Whitlatch, 1977; 1980). For instance, newly settled larvae may be restricted to feeding on the finest material within the bed or on particular rich food items (Jumars *et al.*, 1990) thus, optimal grain size may be different for settling larvae and adults. Larger particles may be preferred by larger organisms within a given species (Whitlatch and Weinberg, 1982 cited in Snelgrove and Butman, 1994). Some species show little affinity with any one particular sediment type, and the fauna within different sediment environments invariably show some degree of overlap, which might be due to the grain size being a correlate of the actual causative factor(s) (Snelgrove and Butman, 1994).

Much of the potential food for benthic organisms are located within the upper 2cm of the sediment (Whitlatch, 1980,1977) and most of the organisms produce faecal pellets that are deposited at or near the sediment surface. This process may result in a change in the grain size of surface sediments (Hall, 1994). In mud, for instance, this can result in a pelletised silt-clay matrix. It is, therefore, evident that physical processes impact upon biological features to structure the benthic organisms and its habitat. Habitat selection based on the availability of a preferred grain size in feeding is difficult to conceptualise in view of the ontogenic and hydrodynamic changes in feeding behaviour and particle selectivity (Snelgrove and Butman, 1994).

It has been suggested that animal and sediment correlation is a result of hydrological and geological processes associated with sediment granulometry rather than a function of organism is available space within sediment (Parry *et al.*, 1999).

2.2.2.3 **Organic matter content**

The organic matter content of bottom sediments may be a more likely causal factor than sediment grain size in determining infaunal distribution (Snelgrove and Butman, 1994). This is because it is a dominant source of food for deposit-feeders (Pearson and Rosenberg, 1978), indirectly (e.g through resuspension) for suspension feeders

(Snelgrove and Butman, 1994). The sediment must be considered as an indicator of the availability of food, and not as a first order factor directly determining the distribution of feeding types (Snelgrove and Butman, 1994). Nichols (1970) and Field (1971) have suggested that there is a strong relationship not only between animal and grain-size distribution but also between animal and organic-carbon distributions as well. However, a similarity between the type of sediment and the percentage of organic matter, which have been ascribed to the hydrodynamic conditions established during heavy rains, has been observed (Estacio *et al.*, 1999).

Several deposit-feeding opportunistic species have been shown to colonize, preferentially, organic-rich sediments over non-enriched sediments with comparable grain size in shallow-water (Tsutsumi *et al.*, 1990; Grassle *et al.*, 1985) and in associated slow water movements (Mistri *et al.*, 2001). Organic matter was also found to be correlated with annelid distribution (Arvanitidis *et al.*, 1999). Seasonal variations in particulate organic matter are greatly influenced by monsoonal rains. Total organic matter levels decrease during the monsoon season as a result of increase river discharge and scouring of surface silt and clay and associated organic matter (Alongi, 1990). The highest concentrations of organic matter in sediments are in regions of upwelling and in proximity to rivers and more generally, relate to the patterns of pelagic primary production (Alongi, 1990).

2.2.2.4 **Climatic variability**

Coastal lagoons are ecosystems with strong spatial gradients concerning the chemical characteristics of the water and of the biological populations present (Kjerfve, 1986; Guelorget and Perthuisot, 1983). These changes in the spatial heterogeneity follow the seasonal climatic pattern (Herrera-Silveira, 1994).

Environmentall factors responsible for these changes include rainfall, temperature, evaporation, and wind (Herrera-Silveira, 1994). The basic factor producing climatic variations is the intensity of solar radiation, which varies with latitudes (Nichol and Boon, 1994).

Temperature is an important factor controlling many of the ecological and physical functions of lagoons. For instance, primary production is controlled to a certain extent by temperature (Groffman and Taylor, 1995). Temperature also affects rates of evaporation, which has implication for hydrological regimes. The hydrological regimes/parameters may account for the biological organization of lagoons (Nicolaidou *et al., 1988).* Changes in water mass characteristics induced by excessive evaporation may lead to changes in faunal distributions and abundances or to the development of a unique fauna (Alongi, 1990) such as in the hypersaline lagoons of the Red Sea (Fishelson, 1971).

Precipitation regulates the direct inflow and amount of water to the lagoon systems, as well as runoff from land drainages via streams. A change in water availability throughout the drainage area or region will affect flooding and hydrological regime in complex ways (Groffman and Taylor, 1995). Most benthic organisms suffer increased mortality or migrate during monsoons to escape sediment erosion and low salinities (Alongi, 1990).

Changes in the frequency and duration of flooding and drought and any alterations in disturbance regimes will be particularly important in determining how the ecological function of lagoons ultimately is affected. Climate changes resulting in increased or decreased temperature and water availability will affect the quality of habitats, species composition and diversity (Junk, 1993; Bradbury and Grace, 1983; Bernard and Gorham, 1978). Climate changes also can affect the chemical property of lagoons, which, in turn has consequences for biological and ecological characteristics affecting vegetation value, and species composition (including the invertebrate community; Swanson *et al.*, 1988).

The coastal regions in Ghana, like most of West Africa are influenced by high temperature regimes with little variation throughout the year (Biney, 1986). Thus, differences in climate are largely due to the amount and distribution of rainfall. There are two wet seasons in the year, the major one from May to June and a minor season from August to October. It is only in the major wet season that monthly rainfall may exceed evapotranspiration (Biney, 1986).

Wind stress has profound effect on the functional characteristics of lagoons. Wind stress regulates environmental factors such as water temperature, mixing depth, food supply and sediment transport (Hall, 1994). The fetch of wind stress is not linear and, therefore, lower energy habitats will tend to have finer sediments which by virtue of their increased surface area, may support greater microbial biomasses which may in turn lead to higher benthic productivity in larger taxa (Hall, 1994). Emerson (1989) has shown that 90% of variation in benthic secondary production estimates could be accounted for by wind stress, amongst other factors. Wind stress, therefore, indirectly controls secondary production in shallow water benthic communities. This seems to support the hypothesis that secondary production in shallow water benthic communities may be controlled indirectly by wind stress. This finding gives credence to the Trophic Group Mutual Exclusion hypothesis advanced by Wildish (1977), which proposes that benthic productivity is food limited, the supply of food being controlled by hydrodynamic factors (e.g. wind). Since food transport and sediment transport by the water flow regimes are influenced, to a greater extent, by the wind.

Climatic variations have been found to affect macrofauna, but it is reasonably clear that faunal response is dependent upon the frequency and intensity of climatic disturbances as well as the time of the year in which it occurs (Alongi, 1990)

2.3 ANTHROPOGENIC DISTURBANCE

Man-induced disturbances usually cause non-linear responses in coastal lagoon ecosystems (Cadee *et al.*, 1994). The disturbances lead to the disruption (movement) of sediments. Anthropogenic disturbances that impact on the sediment include fishing activities and dredging/aggregate extraction among others.

2.3.1 Fishing activities

There is increasing recognition of the role man plays in physically disturbing lagoon environments, the most obvious and widespread mechanism being fishing. Among others, the main reason for the increased concern in fishing activties is the increase in the size and weight of gears that are used. Any fishing gear which is towed over the sediment bed will disturb the sediment and the resident community to some degree, but the intensity of this disturbance is very much dependent on the gear and the sediment type (Hall, 1994). Vodzogbe, (1994) has described the fishing methods employed by certain communities around the Keta lagoon. He identified seven different fishing methods, which include: "Dokpokplo", cast net (sabu), acadja (Tsidja), gill net (Axli), trap (Xadodo), "Tekali" and bottle trap ("Tukpaxe"). According to him "Dokpokplo" recorded the highest percentage of usage (33.3%) followed by Acadja (26.7%), Cast net (15%), Trap (11.7%), Gill net (10.0%) and "Tekali" and Bottle trap (1.7%). These fishing methods have direct contact with the bottom of the shallow lagoon. This invariably impacts on the sediments through resuspension, hence affecting its stability. It also increases the turbidity, which in turn affects the productivity of the lagoon. The severity of such an impact is dependent on the combined effect of the intensity of fishing and widespread use of the fishing methods.

The type of sediment over which gears are towed is another factor that determines the intensity of disturbance. For instance, penetration of gear into soft mud will be considerably greater than into hard packed sands and sediment resuspension will follow accordingly (Hall, 1994).

It is often suggested that fishing disturbance results in slower growing, long-lived species (particularly molluscs) being replaced by short-lived polychaete species (Hall, 1994). Owing to the fact that disturbance events are unevenly distributed in space and time, a mosaic of patches is generated at different stages in a successional sequence (e.g Grassle and Sanders, 1973). The characteristics of such mosaics will depend on the spatial scale and level (kind, frequency and intensity) of disturbance and the subsequent rate and character of the community response as recovery proceeds (Hall, 1994).

2.3.2 **Dredging and aggregate extraction**

Coastal erosion threatens to be an unrelenting environmental problem due to compound impacts from coastal development and emerging global geophysical changes, such as rising sea levels (Rakocinski, 1996). To counteract coastal erosion, beach restoration projects are now commonly undertaken, involving redistribution of massive amount of sediment. Dredging invariably accompanies these restoration projects.

The dredging may change the physical environment and could directly impact on macrobenthic organisms through (i) compaction of sediment, (ii) burial of organisms, or (iii) smothering through increased turbidity and siltation (Goldberg, 1989). The principal biological impacts of such dredging activities include disturbance and removal of benthos and alteration of the substrate upon which colonization depends. Dredging has effects at two locations, the site of removal and the site where the material is dumped (Hall, 1994). Bonsdorf (1983) examined recolonization after dredging at three shallow brackish sites in Finland. The study showed that the pool of available colonists is important in determining the dynamics of disturbed patches. At one site dredging occurred to below the thermocline and the benthos at this level were exposed to deoxygenation events every year which defaunated the sediment. Deoxygenation took approximately two months to kill the fauna and this was followed by a gradual recovery with the peak in species richness occurring after about 10 months. In contrast, just above the thermocline a stable community developed over the six years of the study and this region provided colonists for deeper parts. With the progressive recovery of the upper region, a more diverse and abundant pool of colonists was available to recolonise the deeper parts, which led to successively higher peaks in species richness each year. At a second site at 8-9m depth in a channel, it took 4-5 years for the community to return to a background level, despite the area containing only about three species. Interestingly, early in the colonization sequence, three species established which had not occurred in the area before dredging. Species richness declined after five years and these three species were not found in the final community which itself contained only three species.

Maurer *et al.*, (1986) reviewed studies of burial effects and concluded that the pattern of susceptibilities can be reversed when sediments containing silt/clay are compared with those comprising sand. This was based on earlier experimental studies, which indicated that atypical sediments for the area caused the highest mortalities in estuarine bivalve species following burial in natural and exotic sediments (Maurer *et al.*, 1981). Maurer *et al.*, (1986) cited Kranz (1972) who studied the burrowing of 30 species of bivalves showed that the life habits of the taxa affected the susceptibility of the fauna to mortality. Mucous tube feeders and labial palp deposit feeders were most susceptible, followed by epifaunal suspension feeders, boring species and deep burrowing siphonate suspension feeders, none of which could cope with more than 1 cm of sediment overburden. Infaunal non-siphonate suspension feeders were able to escape 5 cm of their native sediment, but normally less than 10 cm. One potentially complicating factor, when considering the effects of dumping dredge spoil, is that many types of sediment will be contaminated (Hall, 1994). Indeed, much of the motivation for studies on dumping dredge spoil effects stems from concern over chemical pollutants rather than dumping per se.

Flemer *et al*., (1997) concluded that there was no apparent consistent gross effects of dredged material disposal on macrobenthic community structure at coastal Louisiana and suggested that some long-term unidentified factor (e.g sediment toxicity) maintained differences in macrobenthic community structure in the three different study areas.

CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY SITE

The Keta lagoon is located in the coastal area of the southeastern part of Ghana. The area falls between latitudes 0^0 49' and 1^0 02', and longitudes 5^0 47' and 6^0 03'. It covers an area of approximately 340 km^2 (figure 3.1). . The water depth ranges from 0.6m to 1.2m. The lagoon has a maximum coastal length (east –west) and width (north – south) of 25km and 13.5km respectively.

The Keta basin was formed from coastal subsidence during the Precambrian era. The upper geologic strata (about 24m) is composed of coarse, unconsolidated beach sand and gravels both of fluviatile and shallow marine to estuarine origin (Akpati, 1975). Most areas in the lagoon are typically muddy. The sea grass *Ruppia maritima* occurs in the northeastern part of the lagoon and portions of the southern part..

3.1.1 Hydrology

Keta lagoon receives freshwater from a large catchment area which is drained by the following systems: (1) run-off from the Tordzie river which originates from the Akwapim-Togo ranges and enters the Avu lagoon during the rainy seasons of May-July and October and overflows into the Keta lagoon via the Aglor, Agbatsivi lagoon and other small streams, (ii) run-off from Aka and Belikpa streams which enter the Keta lagoon from the north, and (iii) interflow into the Keta lagoon from the Volta estuary through the Anyanui creek (Entsua-Mensah and Dankwa, 1997). The Tordzie river has a catchment area of 2200 km^2 and mean annual flow of 11m^{3}s^{-1};

Aka and Belikpa have 280 km^2 amd 420 km^2 respectively; the total drainage area of the Volta estuary is 37900 km^2 (Finlayson *et al.*, 2000). Nevertheless, the volume of water (84446 m^3) transferred to the lagoon during one flood period from the Volta estuary via the Anyanui resulted in a tidal excursion of 5.4 km (Sørensen *et al.*, 2003). This mean that such parcel of water flows back during the low tide, creating sinusoidal oscillation based on the tidal regimes. The observation seems to suggest that water inflow from the larger catchment area of the Volta estuatry into the Keta lagoon is insignificant. This might due to the sedimentation of the Volta estuary and also the damming of the Volta Lake at Akosombo, 105 km upstream. The estimated static capacity of the Keta lagoon is 360 x 10^6 m^3 where there is no inflow of water into it (Finlayson *et al.*, 2000).

The climate of the study area lies within the dry Equatorial climatic region of Ghana, which also covers the entire coastal belt of the country. The coastal region of Ghana enjoys high temperature with little variation throughout the year. Thus the difference in climate is largely due to the amount of and distribution of rainfall (Biney, 1986). The rainfall pattern in the area is bimodal. The mean annual rainfall in the area is 750mm (Dickson and Benneh, 1988). The minimum average temperature is 24^{0}C, whereas the maximum average temperature is 32^{0}C.

The prevailing wind direction is from the southwest (the southwest monsoon). The mean monthly averages of daily wind speeds range from 21.1 to 29.0 Km h^{-1} (Finlayson *et al.*, 2000). Evaporation in the area far exceeds rainfall and hence the lagoon loses much water from the former, owing to its large surface area resulting in hypersalinity in the dry month. It is only in the major wet season that monthly rainfall may exceed evapo-transpiration during which temporal streams flow (Biney, 1986).

3.1.2 **Ecological importance**

The Keta lagoon is internationally recognized and has been designated as a Ramsar Site on the basis of their total waterbird population and occurrence of internationally important numbers of several species (Ryan and Ntiamoa-Baidu, 1998). The dominant avi-fauna are waders (eg. greenshank, ringed plover, grey plover, Black wing stilt, curlew, curlew sandpiper, Avocet etc.); terns (black tern, little tern, common tern, royal tern, sandwitch tern etc), herons and egrets. A total of 37,519 waterbirds belonging to 46 species have been reported (Piersma and Ntiamoa-Baidu, 1995).

3.1.3 **Socio-economic importance**

Socio-economically, Keta lagoon supports many average-sized communities such as Afiadenyigba, Havedzi, Kedzi, Vodza, Keta, Dzelukope, Tegbi, Woe, Anloga, Alakple, Atiavi, Anyako, Seva and less known villages such as Norlopi, Borlove, Atsito, Kodzi, Deta, Fiahor, Latame and Borlokopi. Fishing and farming are the main occupations of the communities surrounding the lagoon. The major fishing communities include Afiadenyigba, Konu, Havedzi, Woe, and Anloga. The lagoon has no restriction to fishing except one or two villages (eg. Atsito) that have taboos not to fish on certain days (especially Sundays). This has an indirect social objective of fishermen making time to mend their nets and also attend to other activities of the village.

3.1.4 **Fisheries**

Fish is the principal and preferred source of protein for these communities. Finfishes caught in the lagoon include *Sarotherodon melanotheron, S. galilaeus, Tilapia zilli, T. guineensis, Gerris nigris, Gobius species* (Vodzogbe, 1994). Other species observed by Addo (2000) and Ababio (2001) include *Hemichromis fasciatus, H. bimaculatus,* Heterotis *niloticus* and *Ethymylosa fimbriata*, *Macrobrachium sp.* and *Psettias sebae*. Two other species of crustacean are also found in commercial quantities especially towards the eastern part of the lagoon; These are the swimming crabs, *Callinectes amnicola* and to a lesser extent, the marine shrimp, *Penaeus notialis* (Addo, 2000). However, the author observed lots of *Mugil sp.* and crabs in the dredged canal.

3.2 SAMPLING PROTOCOL

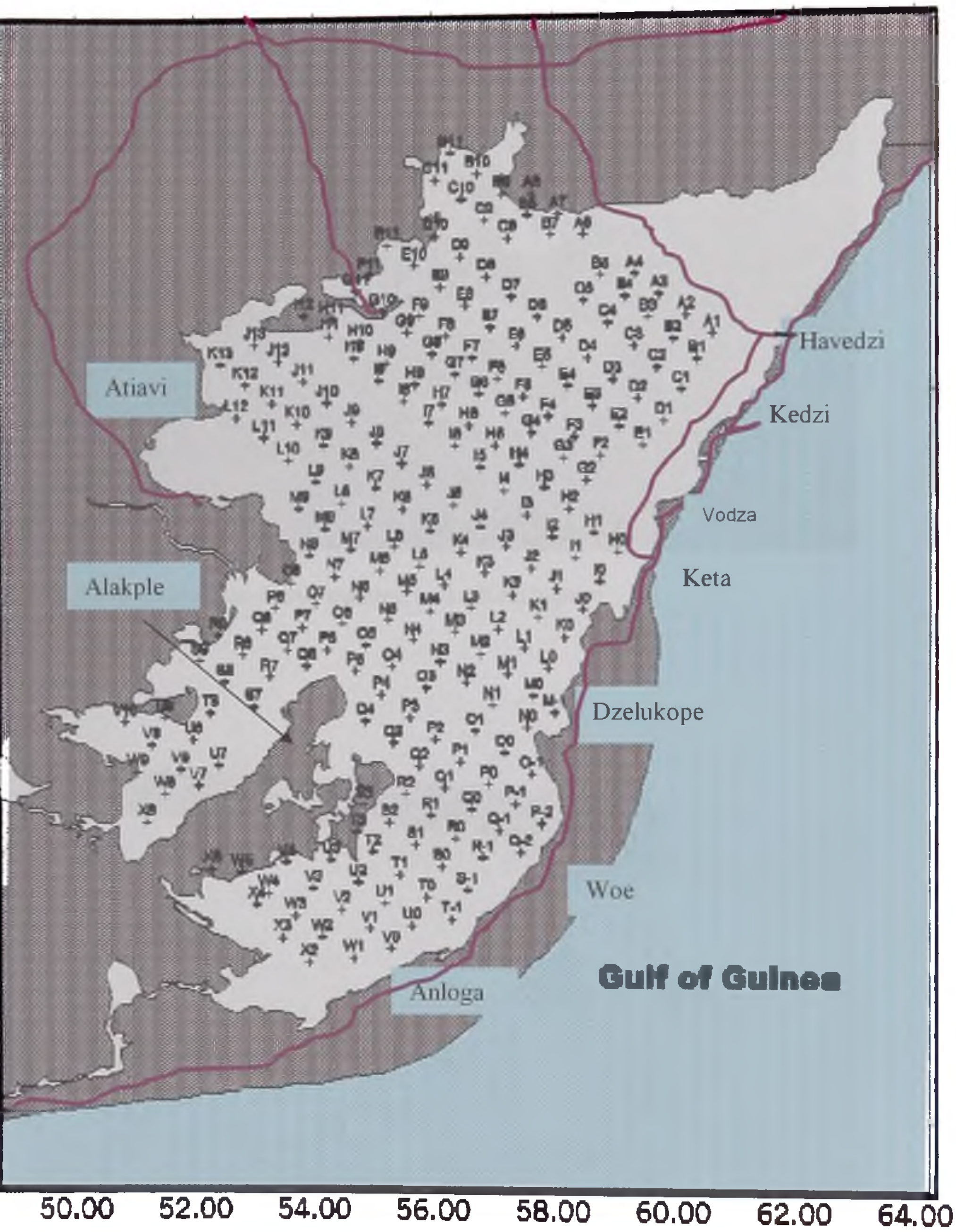
A stratified grid of 1km interval of the study area was drawn on a map prior to the sampling to indicate the various sites in the lagoon where the samples were to be taken. Reference points were established using a Magellan GPS 4000 with an accuracy of 10 m. The coordinates of the 1 km^2 grids were then plotted on a map of the lagoon area. The stations were named alpha-numerically along each transect (e.g. A0 to A8 up to X2 to X8) (Figure 3.1)

3.2.1 FIELD SAMPLING OF THE KETA LAGOON

The sampling of the was carried out in wet and dry seasons. The major rainfall period occurs in May and June reaching peak in July, and the minor one between September and November. The dry season begins from November to April. The wet season sampling started in September and ended in November 2001, which covered 238 stations in the lagoon. The dry season started and ended in March 2002, during which 20 stations were sampled as the other stations were not accessible as a result of low water levels. Water parameters, sediments and macrobenthos samples were taken during these seasons. Sampling began in the 8:30 am and ended in 5:30 pm.

A canoe with an outboard motor (Yamaha 40 hp) was used to navigate between stations during the wet season sampling, while a smaller canoe was used to get access to stations where the water levels were very low. Binoculars were used to locate stations marked by wooden poles planted in the lagoon, whilst the Magellan GPS 4000 was used to locate stations without poles.

At each station, water parameters, dissolved oxygen, salinity, water temperature, pH, depths and transparency were taken *in situ*. Water was collected in sampling bottles for laboratory analysis for parameters that could not be determined *in-situ*. The water samples were taken 0.30 m below the surface. The samples for nutrient analyses were put in an ice chest containing ice cubes to reduce biological activity. Water transparency was recorded using a Secchi disk. The "Secchi depth" recorded was the mean of the depths at which the Secchi disc disappeared when lowered and reappeared when raised. Salinity was measured using ATAGO S 28E refractometer whereas YSI Model 55 dissolved oxygen probe was used for dissolved oxygen determination.



igure 3.1 Sampling stations of the study Area. The coordinates of these stations ave been given in Appendix 1.

Figure 3.2 Macrobenthic fauna washing in the Keta lagoon

Figure 3.3 Measurement and recording of in-situ water parameters in the Keta lagoon.

The benthic macrofauna were sampled using a 0.0762 m diameter polyvinylchloride (PVC) pipe corer to a depth of 0.125 m. Three cores constituted a sample. Four replicate samples were taken at each station, corresponding to a total volume of 0.9198 m^3. An additional core was taken for determination of sediment characteristics. The samples were sieved through a 0.5 mm mesh to get rid of excess silt and sand. The material retained on the sieve was fixed in 10% buffered formaldehyde (Formalin), and stained with Rose Bengal to facilitate sorting and identification in the laboratory.

3.2.2 SAMPLING AND PROCESSING OF SAMPLES FROM THE DREDGED CHANNEL

Constructional activities of the Keta Sea Defense Work Project (KSDWP) were initiated in early 2000. The Project has four components namely: sea defense, land reclamation, road construction and construction of flood relief structure. After mobilization, construction of access road, which consisted of a “sand core” with stones armoring on the landside was initiated. Appropriate material to construct road, nourish beach, and infill the land reclamation area was obtained from the lagoon by construction of two burrow pits, connected with access channels. The total material deposited on each constructional site was 2,861,000 m^3 for beach with average daily production of approximately 11,800 m^3; production to the birds islands was 2,010,000 m^3 with average daily production of approximately 9,050 m^3. At the reclamation site a total of 4,220,000 m^3 with daily production of approximately 10,300 m^3 was deposited. The water to solids ratios were 10 –16 % in medium sand and 12 – 20 % in cohesive soils.

The dredged channel was sampled following the same methodology used for the main lagoon except that sampling for water parameter was done at different depths depending on the total depth of the stations. Water parameters were sampled at subsurface and bottom. The water sampling was done using a Van Dorn water sampler.

Quantitative sampling of the benthos was carried out using Orange-peel grab. This grab has four teeth, which come together when the grab is closed. Four replicates were taken at each station, treated and processed as has been described for the main stations in the lagoon. One grab constituted a sample with a sediment volume of 2.036 x 10^{-3} m^3. The dredged channel sampling was done at intervals of four-months from September 2001 to September 2002 to capture the seasonal differences. Figure 3.4 shows the approximate dimensions and relative locations of burrowed pits and access channels as well as the seasonal sampling stations. The average depths are approximately 9.6 m for burrowed pit # 1, 11.1 m for burrowed pit # 2 and 4.0 m for access channels. The burrowed pits are approximately 300 m wide and the access channels 40 m wide.

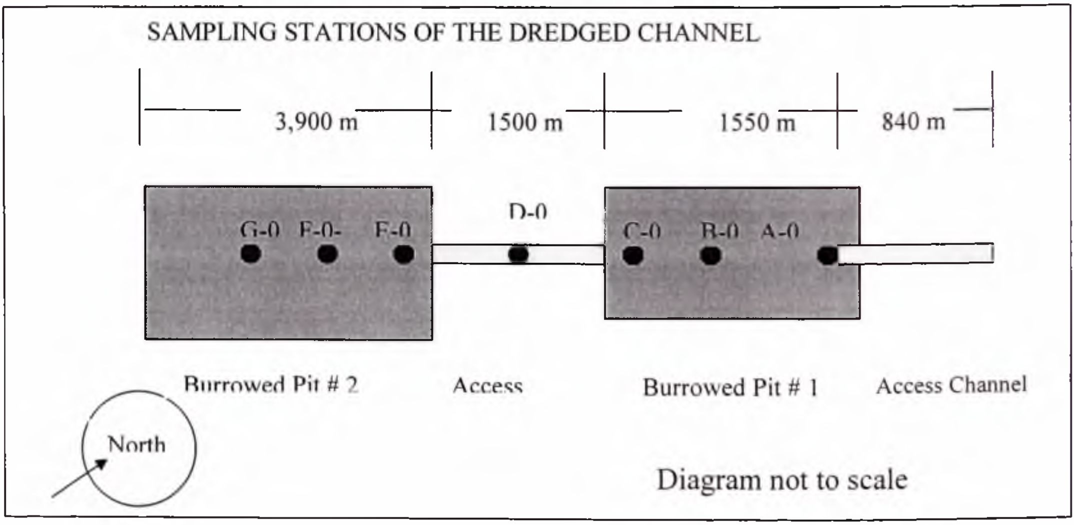


Figure 3.4 Schematic diagram of relative locations of burrowed pits and access channels and their approximate lengths and the sampling stations of the dredged channel.

3.2.3 LABORATORY PROCESSING OF SAMPLES

The benthic organisms were washed thoroughly in 200-μm stainless sieves to get rid of the formalin. The washed sediments were then placed in 50 m x 40 m white tray, thinly spread and later sorted. The sorted organisms were preserved in 70% ethanol with glycerol. The abundance of individuals, identified to the species level where possible, were counted for each sample.

The sediments taken for organic matter and granulometry analyses were air-dried. and sieved through a 2- mm mesh size sieve. The analysis of the organic matter was done by pouring the sieved sediments into a small pyrex glass and treated with 10% HCl to get rid of the inorganic carbonates. The sediments were then oven-dried (at 60^0 C over night) so that moisture would not affect the individual weights of samples. The dried samples were weighed individually into a weighing boat of size 1.5 m X 0.15 m. The samples were then transferred to an ELTRA CS 500 Carbon Sulfur determinator (located at the Ecological Laboratory of the University of Ghana) where the proportions of carbon and sulfur were determined simultaneously. The furnace temperature for the combustion of the carbon and sulfur was 1100^0 C. The minimum time for the analyzer to display the result was 50 seconds, but few of the samples took about 280 seconds due to undue delay of the analysis caused by sulfur compounds, which were difficult to burn. Any ranges saturated during the analysis were automatically deactivated, and any deactivated ranges due to saturation, were automatically reactivated after the end of the analysis.

Figure 3.5 Benthic macrofauna analyses in the laboratory

The grain size distribution was determined according to Bouyoucous (1934) method. Forty grams of the air-dried and sieved sample was weighed into polyethylene containers. 100 ml of Calgon solution was added. This solution is dispersing agent containing sodium hexametaphosphate with sufficient Na_2CO_3 to give a pH of about 8.3 in a solution containing 100 g of the dissolved constituents. The solution was diluted to 1 litre. . The sediment was then stirred on a mechanical shaker for 90 minutes and transferred to a sedimentation cylinder after it was sieved through 45µm. The remaining sand fraction was put into a moisturizing container and 5ml of hydrogen peroxide added to dissolve any organic matter present. The samples were then put into an oven overnight at a temperature of 105^0 C, each sample was weighed afterwards. The suspension was poured into a cylinder and made up to the 1L mark by adding distilled water. The sediment particles were expected to settle in the water at a speed directly related to the square of their diameter and inversely related to the viscosity of the water. The sediment particles were thoroughly stirred with a hand stirrer and after about 5 hours a hydrometer was carefully inserted into the suspension and the readings taken. The hydrometer readings (top of the meniscus) for a blank were also taken. This was subtracted from the original hydrometer readings to give the actual weight of the clay fractions. The weights of both the clay and the sand were calculated in terms of percentages with respect to the initial weight taken, and the sum of their combined weight was subtracted from 100 to give the percentage weight of the silt.

In the laboratory, analysis of nitrate, phosphate, silicate, sulphate, turbidity, conductivity, total dissolved solids and pH were carried out using data-logging spectrophotometer HACh 2010 following methods outlined in (A.P.H.A., 1998). Analysis of phosphates and nitrates were carried out immediately in the laboratory to avoid any change in their measurable concentrations.

3.3 DATA ANALYSIS

Univariate and multivariate techniques were used to describe the environmental parameters and the macrobenthic communities. Multivariate techniques allow the identification of similar structures and permit the observation of temporal trends (Warwick and Clarke, 1991). Starting with a data matrix in which the data for the two seasons were analysed separately, the column represented the physical and chemical variables while the row represented the sample stations. In order to elucidate the effects of changes in the two seasons analyses were performed using the data corresponding to each season (dry and wet). Since concentrations and levels of each physico-chemical parameter had different units of measurement and to minimise the variances and also to avoid skewness, all data were log-transformed as X'= (log (x+1)) and normalised, and then subjected to ordination by means of Principal Component Analysis (PCA). The similarity matrix for the classification among the different stations was calculated as Bray-Curtis indices (Bray and Curtis, 1957). The results were then graphically described in the form of a dendrogram.

Macrobenthic fauna community structure and dynamics were analysed by means of taxa abundance, diversity (as Shannon-Wiener's H'), evenness (as Pielou's) and richness (as Margalef's d). Number of taxa, and abundance were then compared using ANOVA with season and sites as fixed factors.

In order to describe the connections between the changes in community structure and sites, and seasonal differences, multivariate analysis was utilized. Data were analysed using the PRIMER v. 5.0 software package (Plymouth Routine In Marine Ecological Research) (Carr, 1996). By these methods stations with similar environmental parameters were expected to cluster together.. Also, stations with similar benthic macrofauna abundance and compositions levels are expected to cluster together. A fourth-root transformation was applied to macrofauna abundance data and dendrograms produced based on the Bray-Curtis similarity indices of species composition between stations (Clarke and Green, 1988). This index was chosen, as it does not consider the double absences frequently found in the data, in its calculation. It is also unaffected by differences in sample size.

The macrobenthic community between the seasons was further investigated by means of non-metric multidimensional scaling (MDS) ordination. The fauna group contributing to dissimilarity between samples observed in the dendrogram was investigated using similarity percentage procedure (SIMPER). These results assisted in interpretation of the faunal changes causing the pattern observed in the ordination. The contribution of each species to the average similarity within each group was also examined. Finally, the relationship between species abundance and combinations of water parameters was analysed using the BIO-ENV procedure (Clarke and Ainsworth, 1993). The BIO-ENV procedure within the PRIMER software allows matching of biotic patterns with environmental parameters, in this case sediment and water parameters. The significance of the difference in biotic data between the two seasons was tested using one-way and two-way ANOVA.

CHAPTER FOUR

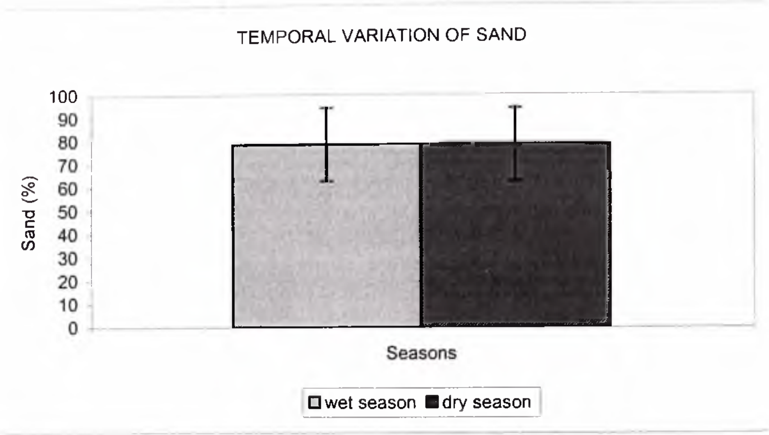
RESULTS

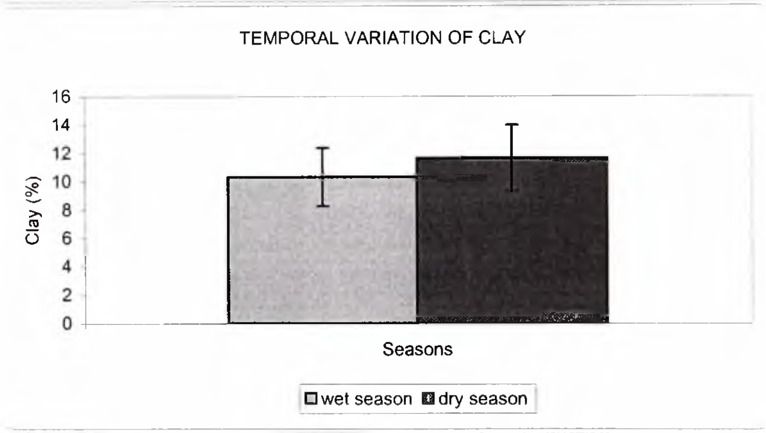
4.1 PHYSICO-CHEMICAL PARAMETERS

The environmental data showed large variation, however, some distinct temporal and spatial trends were observed. These parameters included salinity, conductivity, total dissolved solids, total suspended solids, turbidity, water depth, sulphate and silicate.

Temporally, the most drastically changed environmental variables were salinity and water depth, which directly and indirectly affected other environmental variables. Salinity values showed great fluctuation within stations and between the dry season and wet season, which was due mainly to water level fluctuations through evaporation, rainfall and/or riverine incursion. Water depth changes between stations ranged between an average of 0.72 m in the wet season to an average of 0.3m in the dry season. Figures 4.1 and 4.2 summarise the main sediment and water parameter characteristics of the seasons in the lagoon. From figure 4.1, there was no difference in temporal trends with regards to mean sand variation. Percentage mean variation for silt was slightly higher in the wet season than the dry season, however there was no significant differences between the two. Mean clay on the other hand, was higher in the dry season than the wet season, though the difference between the two seasons was not significant.

There were significant differences of the physico-chemical variables between the wet and dry sesons (mean water depth, mean total dissolved soloids, mean salinity, mean sulphate and silicate (Figure 4.2).


TEMPORAL VARIATION OF SAND


TEMPORAL VARIATION OF CLAY

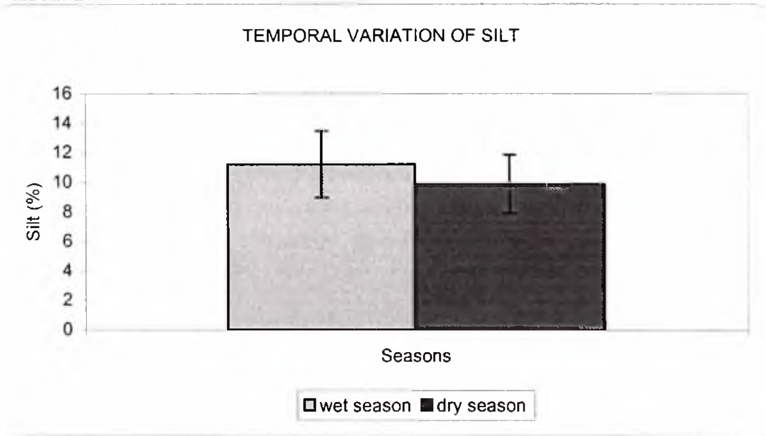
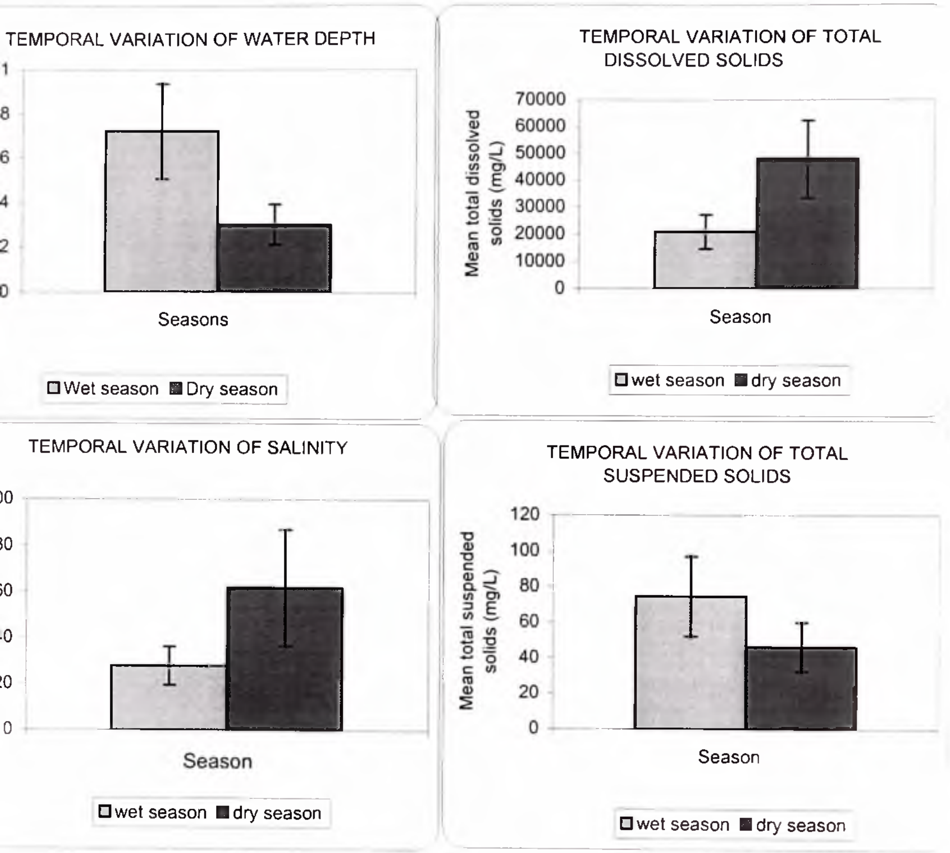
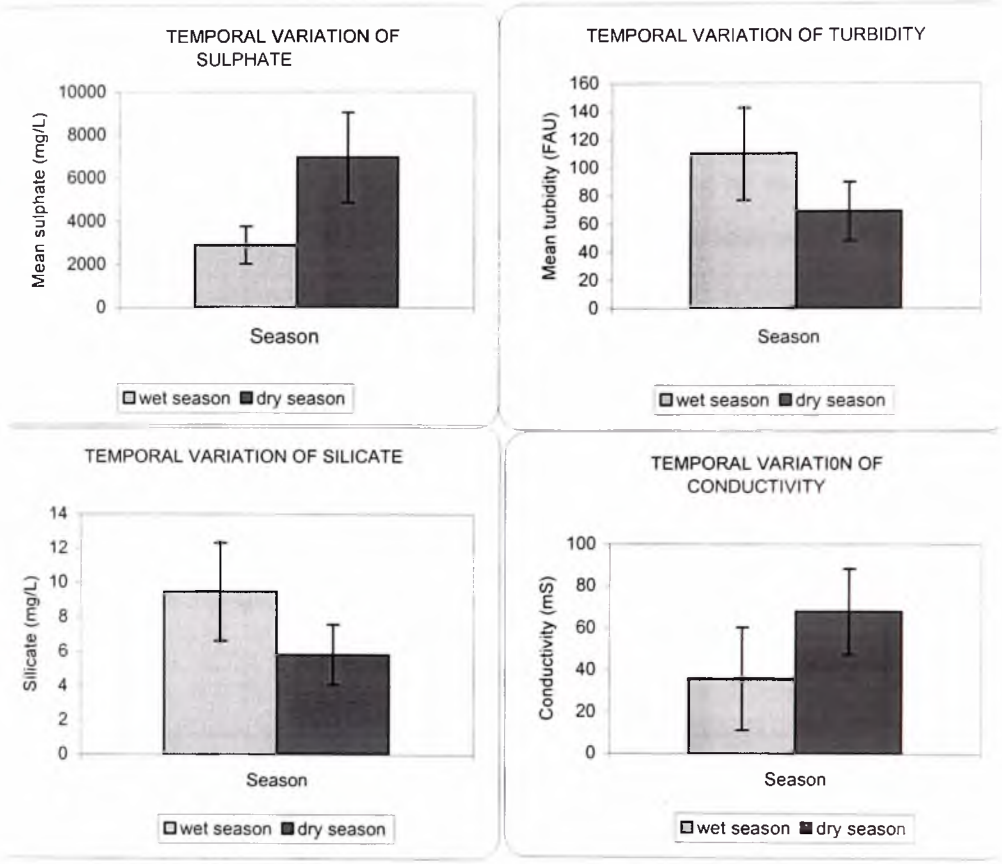

TEMPORAL VARIATION OF SILT

Figure 4.1 Mean temporal variation in sediment parameters. The error bars indicate stadard deviations at 95% confidence interval.



.2 Mean temporal variation of physico-chemical parameters in the Keta lagoon (error bars represent standard deviation at 95% confidence interval).

Fig. 4.2 Contd.



TEMPORAL VARIATION OF SULPHATE

TEMPORAL VARIATION OF TURBIDITY

TEMPORAL VARIATION OF SILICATE

TEMPORAL VARIATION OF CONDUCTIVITY

The PCA's applied to transformed environmental data from each season showed the changes in the variance explained by each component for the wet season (Table 4.1) and the dry seasn (Table 4.2), and the relationship between different variables for the wet and dry seasons (Figure 4.3). The scores from PCA analysis can be examined for their mathematical relationships with other variables not included in the analysis.

Table 4.1 Variance of the first three Principal Component calcdulated from data obtained in the wet season (the environmental variables used in the analysis are given in appendix III with their respective scores). .

Principal Component	**Eigenvalues**	**%Variation**	**Cum.%Variation**
1	19.02	95.1	95.1
2	0.48	2.4	97.5
3	0.34	1.7	99.2

Table 4.2 Variance of the first three Principal Component calcdulated from data obtained in the dry season (the environmental variables used in the analysis are given in appendix III with their respective scores).

Principal Component	**Eigenvalues**	**Variation**	**Cum.% Variation**
1	18.38	91.9	91.9
2	1.08	5.4	97.3
3	0.38	1.9	99.2

The first component accounts for much of the variability in the wet season and the dry season (95.1% and 91.9% respectively). For both wet and dry seasons, the first two components explained 97.5% and 97.3%. of the total variance respectively.. In essence, total variability for the first three principal components was similar (99.2%) for both seasons. In the wet season, the first component (95.1% of the total variance) was associated with high negative percent sand, percent silt, percent clay, salinity, turbidity, and silicate, and positive loadings of water depth, pH, nitrate and phosphate, the second component (2.4% of the total variace) gave high positive loadings to percent sand, percent clay, percent silt pH and salinity. This difference indicated the major opposing influence that the salinity gradient had on the relationships between the variables analyzed.

In the dry season, the first component (91.9% of the total variance) was associated with salinity, percent clay, percent sand, turbidity and pH, and the second component (5.4%) was associated with percent clay, percent silt, turbidity and silicate. Considering the first components for both seasons, the higher levels of percent silt and silicate in the wet season seemed to explain the variability between the seasons. Conversely, considering the second components for both seasons, higher levels of salinity, pH and percent sand in the dry season possibly explained the observed differences between the wet season and the dry season. These differences may possibly illustrate the relative importance of external factors (wind, rainfall, temperature) and internal processes (resuspension, minerilization) during the different seasons.

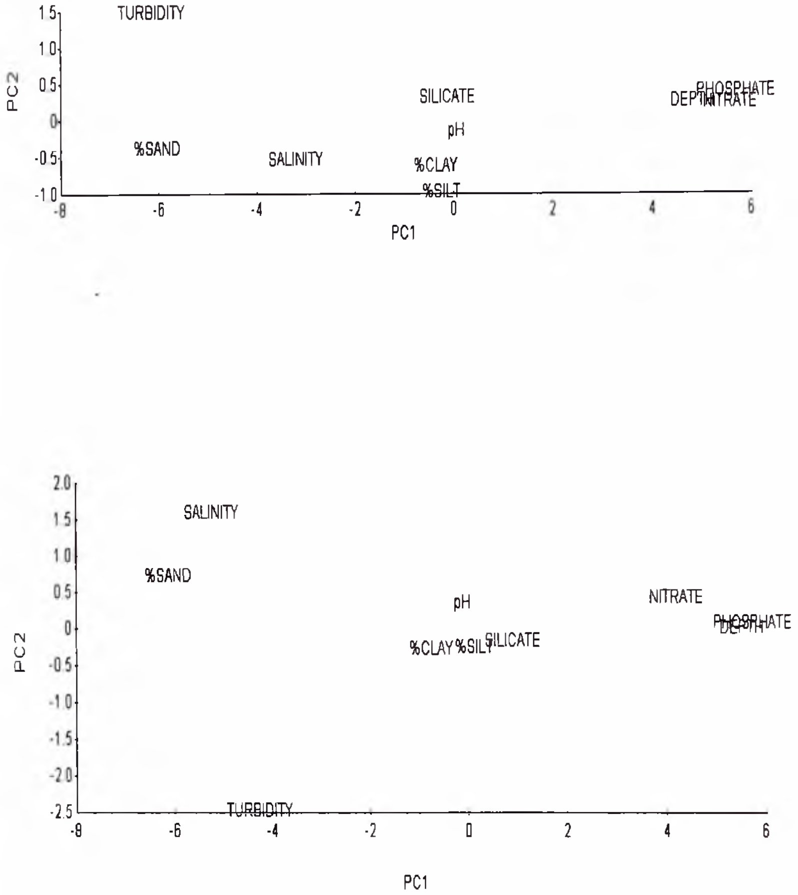


Figure 4.3 Projections of physico-chemical variables onto space defined by the first and second principal components (the co-ordinates are the scores relative to each variable) corresponding to PCA of wet season (top) and dry season (bottom). Environmental variables with negative scores have inverse relationship with those of positive scores.

Figures 4.4 and 4.5 show the dendrogram plots of clustering of sampling stations using the environmental variables for the wet season and dry season respectively. At 95% (wet season) and 95 % (dry season) there is homogeneity. Three zones are discernible for both wet season and dry season.. However, the station cluster that formed the various were different from the two seaons except stations S0, S1,S2 and O-1 that showed similarity (97%) between the two seasons.

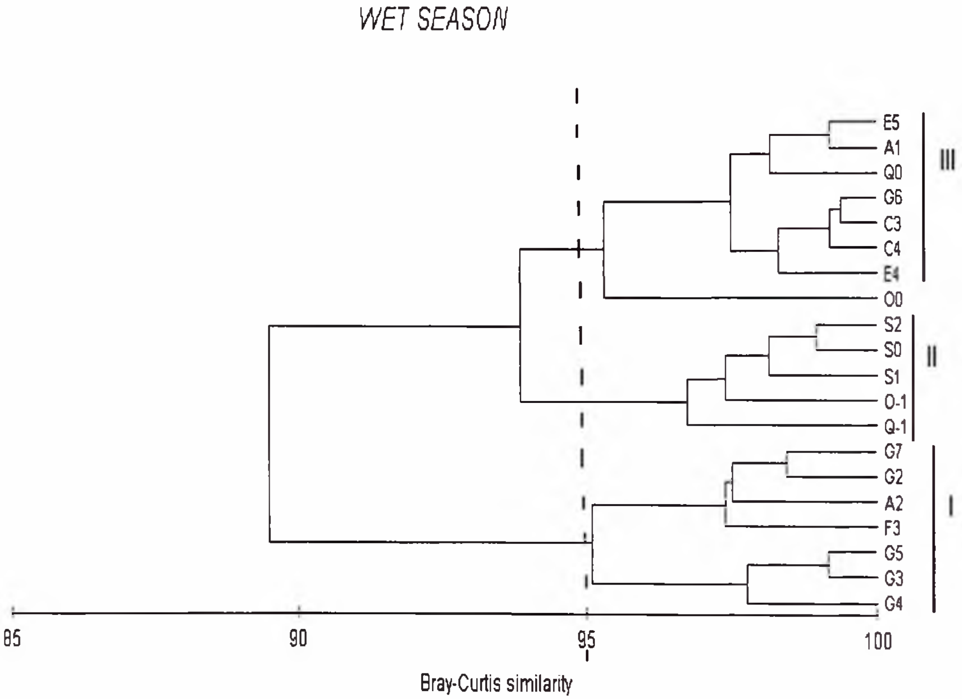
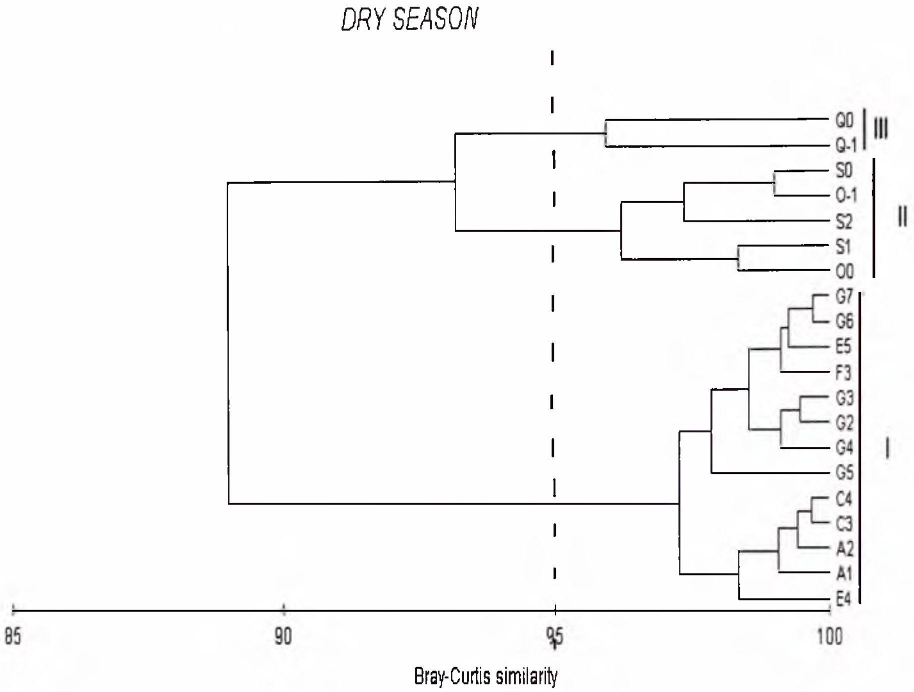


Figure 4.4 Dendrogram of Bray-Curtis similarity among stations using environmental parameters for the wet season.



igure 4.5 Dendrogram of Bray-Curtis similarity among stations using environmental arameters for dry season.

4.2 COMMUNITY ECOLOGY

4.2.1 COMMUNITY STRUCTURE ANALYSIS

Figures 4.6 and 4.7 show similarity dendrogram for the wet season and the dry season respectively using the species abundance data.

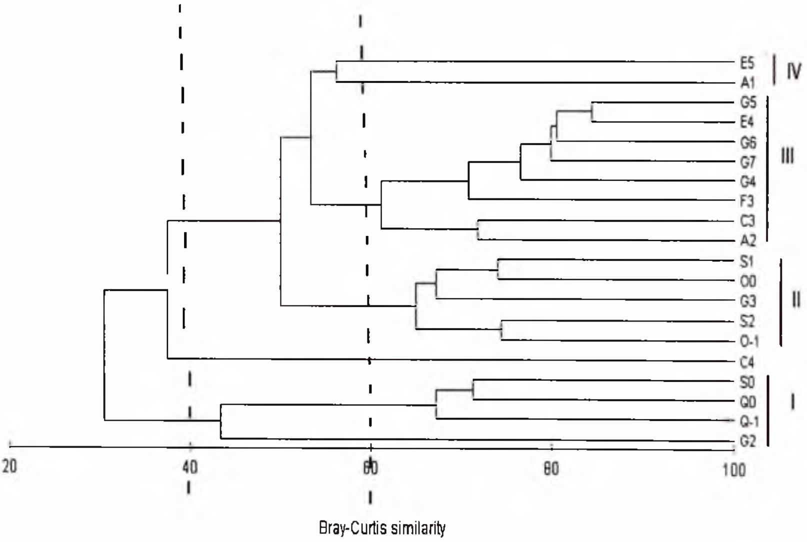


Figure 4 .6 Dendrogram of group- average clustering of Bray-Curtis similarity of benthic macrofauna among the stations for the wet season.

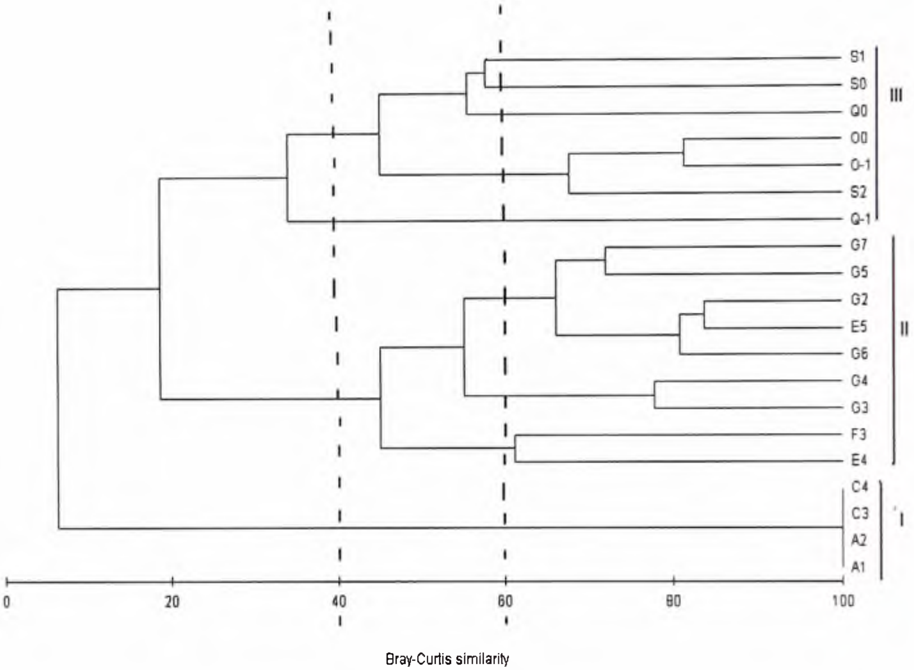


Figure 4.7 Group-average of dendrogram showing fauna affinity among stations for the dry season.

In the wet season two main zones (Zones II and III) of stations were formed at Bray-Curtis similarity level of 60 %. Zone II included stations S1, O0, G3, S2 and O-1while Zone III p B comprises stations G5, E4, G6, G7,F3,C3 and A2. During the dry season, an impoverished fauna occurred in certain stations which included A1, A2, C3 and C4 that gave sufficient ground to distinguish a Zone I comprising stations A1, A2, C3 and C4 close to southeastern part of the lagoon from a more rich fauna in the southwestern part of Zone III comprising stations S0, S1, S2, O-1, O0, Q-1 and Q0.. No species were recorded during the dry season at Zone I stations apparently due to very high salinity levels (88ppt to 93ppt). The highest polychaete species were recorded at stations comprising Zone III where salinity was relatively in a tolerable range (29ppt to 32ppt) during the dry season. Higher numbers of bivalves occurred at the middle stations (Zone II) where salinity ranges between 58ppt to 80ppt. The clustering zones were stations with distinct community structure. This is not to imply that other zones have no species in common, but that different characteristic patterns of abundance are found consistently in different zones.

Figure 4.8 shows similarity dendrogram and the corresponding MDS ordination plots of the stations for wet and dry season combined using species abundance data. This revealed stations which are very similar in terms of macrobenthic fauna abundance and composition between the two seasons. Comparing the same stations in both seasons, the macrobenthic fauna abundance and compositions at stations S-1, S2, O0 and O-1 were very similar at Bray-Curtis similarity level of 70 %. Referring to the figures 4.4 and 4.5, these stations (S-1, S2, O0 and O-1) were very similar in terms of levels of environmental parameters. It follows from this evident that macrobenthic fauna distribution and abundance are influence by environmental variables.

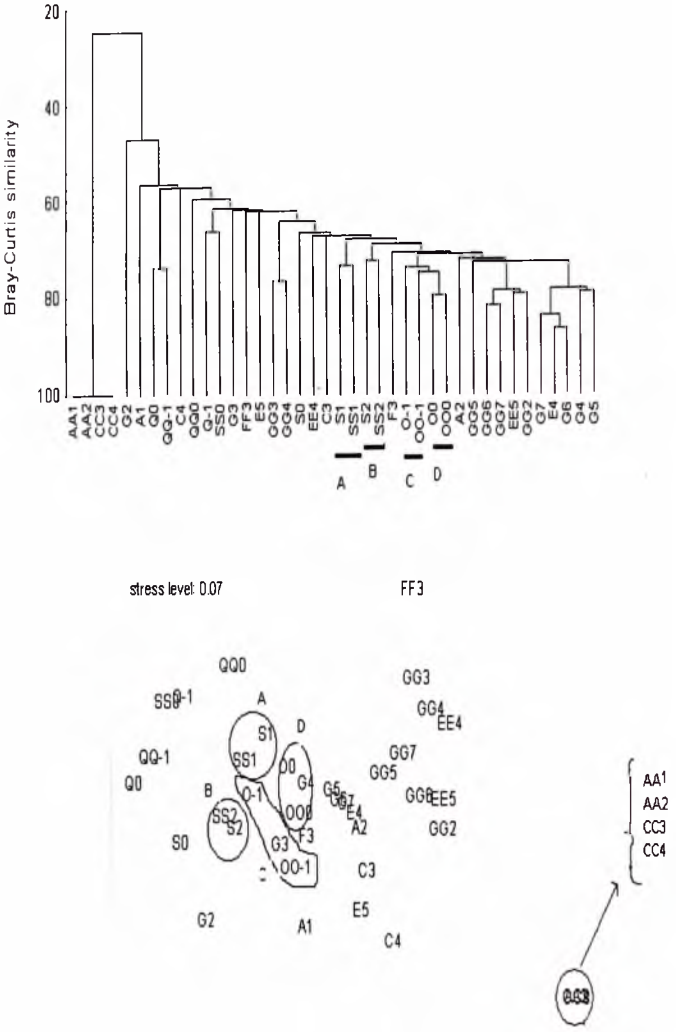


Figure 4.8 Dendrogram of clustering of Bray-Curtis similarity and the corresponding Multidimensional Scaling (MDS) of macrofauna among the stations for the wet and dry seasons combined. The double alphabets indicate stations sampled during the dry season while the single alphabet indicated wet season sampling stations.

Table 4.3 SIMPER analyses showing the similarities for the wet season and dry season and the contributions of each species to the average similarities.

Average similarity within the wet season: 46.10

Species	*Av.Abund*	*Av.Sim*	*Sim/SD*	*Contrib%*	*Cum.%*
Tellina	17.90	11.10	1.95	24.08	24.08
Nephthys	10.60	5.97	1.21	12.95	37.04
Tivela	9.60	5.67	1.24	12.29	49.33
Notomastus	6.00	3.83	0.92	8.31	57.63
Tivela bicolor	5.90	3.05	0.78	6.62	64.25
Capitellid	5.65	2.93	0.71	6.36	70.61
Eunice	2.70	2.60	0.60	5.65	76.25

Average similarity within the dry season: 27.47

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Tivela	6.45	6.31	0.66	22.96	22.96
Bivalve indet. B	1.40	6.03	0.33	21.96	44.93
Capitellid	2.90	3.20	0.52	11.65	56.58
Tellina	3.45	2.32	0.34	8.44	65.01
Capitella capitata	1.90	2.26	0.40	8.21	73.23
Tivela bicolor	2.05	1.62	0.40	5.89	79.12
Notomastus	1.95	1.42	0.40	5.16	84.27

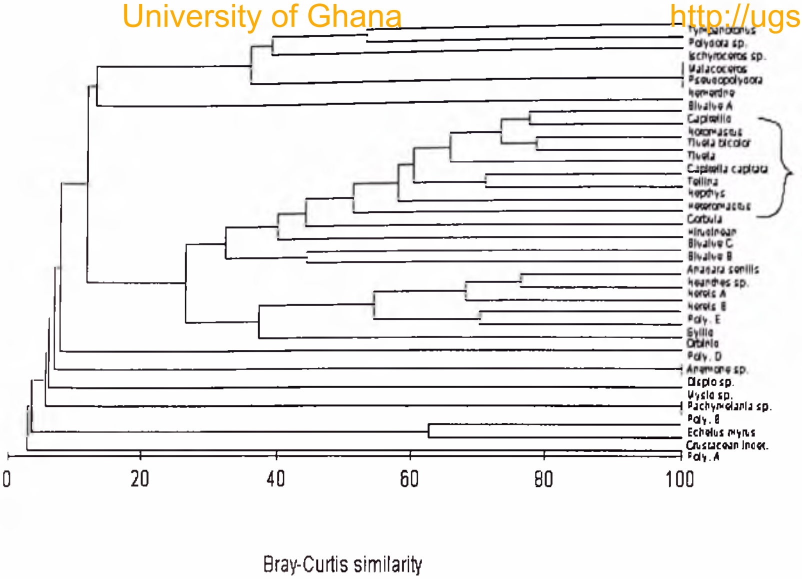
Table 4.4 SIMPER analysis results: species contributing to the average Bray-Curtis dissimilarity between the wet season and dry season.

Average dissimilarity between the wet season and the dry season = 70.35

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Tellina	17.90	3.45	6.71	1.21	9.54	9.54
Nephthys	10.60	0.45	5.45	1.33	7.75	17.29
Bivalve indet. B	0.85	1.40	5.02	0.74	7.14	24.43
Tivela	9.60	6.45	4.82	1.16	6.85	31.28
Eunice	2.70	2.00	4.00	1.01	5.68	36.96
Capitellid	5.65	2.90	3.95	1.06	5.61	42.58
Syllid	2.25	0.85	3.94	0.77	5.60	48.17
Notomastus	6.00	1.95	3.92	1.18	5.57	53.74
Tivela bicolor	5.90	2.05	3.72	1.12	5.28	59.02
Capitella capitata	1.90	1.90	3.61	1.00	5.13	64.15

Tables 4.3 and 4.4 give an account of similarity percentages (SIMPER) of the individual taxa that contributed to the average (dis) similarity among the stations. Ten species (72.76% of the total number) were responsible for most of the dissimilarities among station groups. These ten species contributed an average dissimilarity of 70.35% between the wet season and the dry season. These were *Tellina nymphalis, Nephthys sp.,* Bivalve indet. B, *Tivela tripla, Eunice sp.,* Capitellid indet A, *Ancistrosyllis robusta., Notomastus latericeus, Tivela bicolor,* and *Capitella capitata.* The abundance of these important species was higher in the wet season and lower in the dry season. This is possibly because environmental variables were milder in the wet season than the dry season.

Figure 4.9 shows the dendrogram of group-average fauna similarity for the wet season and the dry season. Certain species such as *Tivela spp., T. bicolour, Notomastus sp, Capitella capitata*, and Capitellid that clustered together (75%) in the wet season also clustered together in the dry season. These are mainly pollution or stress tolerant species. Some of these species (e.g. Capitellid, Capitella capitata) build tubes at or near surface of the sediment. These tubes maintain contact with the surface and allow the species to feed in anoxic muds, getting the necessary oxygen from the overlying waters by irrigation of the burrow (Jepsen, 1965).



DRY SEASON

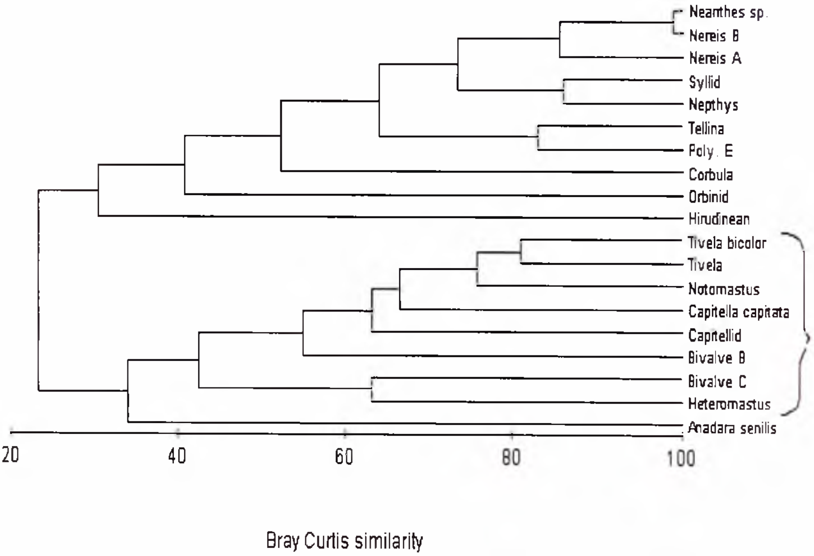


Figure 4.9. Dendrogram of Group average Bray-Curtis similarity of faunal affinity in the wet season (top) and the dry season (bottom). The half brackets indicated association of species that occurred in the two seasons.

Figure 4.10 shows the abundance and distribution of dominant species among the stations for the wet and dry seasons. The abundance of these species was generally higher in the wet season compared to the dry season. The spatio-temporal distribution of the dominant species seemed to follow the prevailing environmental conditions. These dominant species occurred in appreciable numbers at stations G6 and G7during wet season, except *Ancistrosyllis robusta* and *Marphysa sanguinea.* These species (*Ancistrosyllis robusta* and *Marphysa sanguinea)* did not occur in any of the stations during the dry season except stations O-1,O0,Q-1,Q0,S0,S1and S2. Apparently, these were stations where salinity range 27ppt to 32ppt.

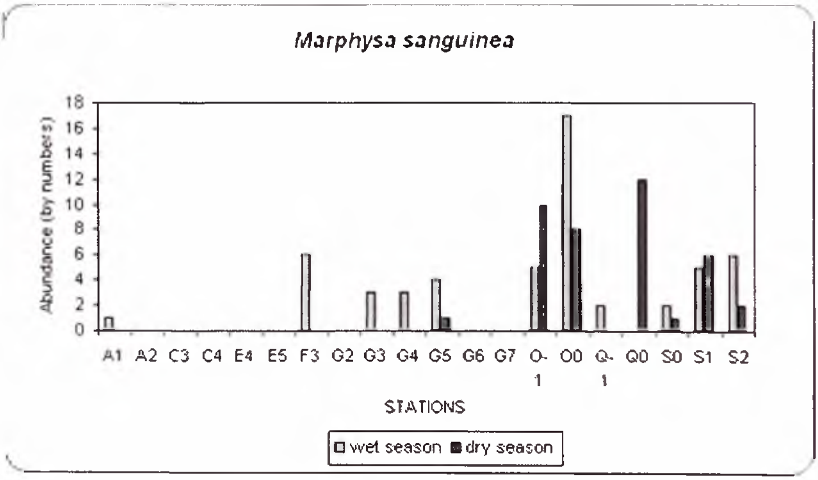


Figure 4.10 : Abundance and distribution of the dominant macrofauna of the Keta lagoon.

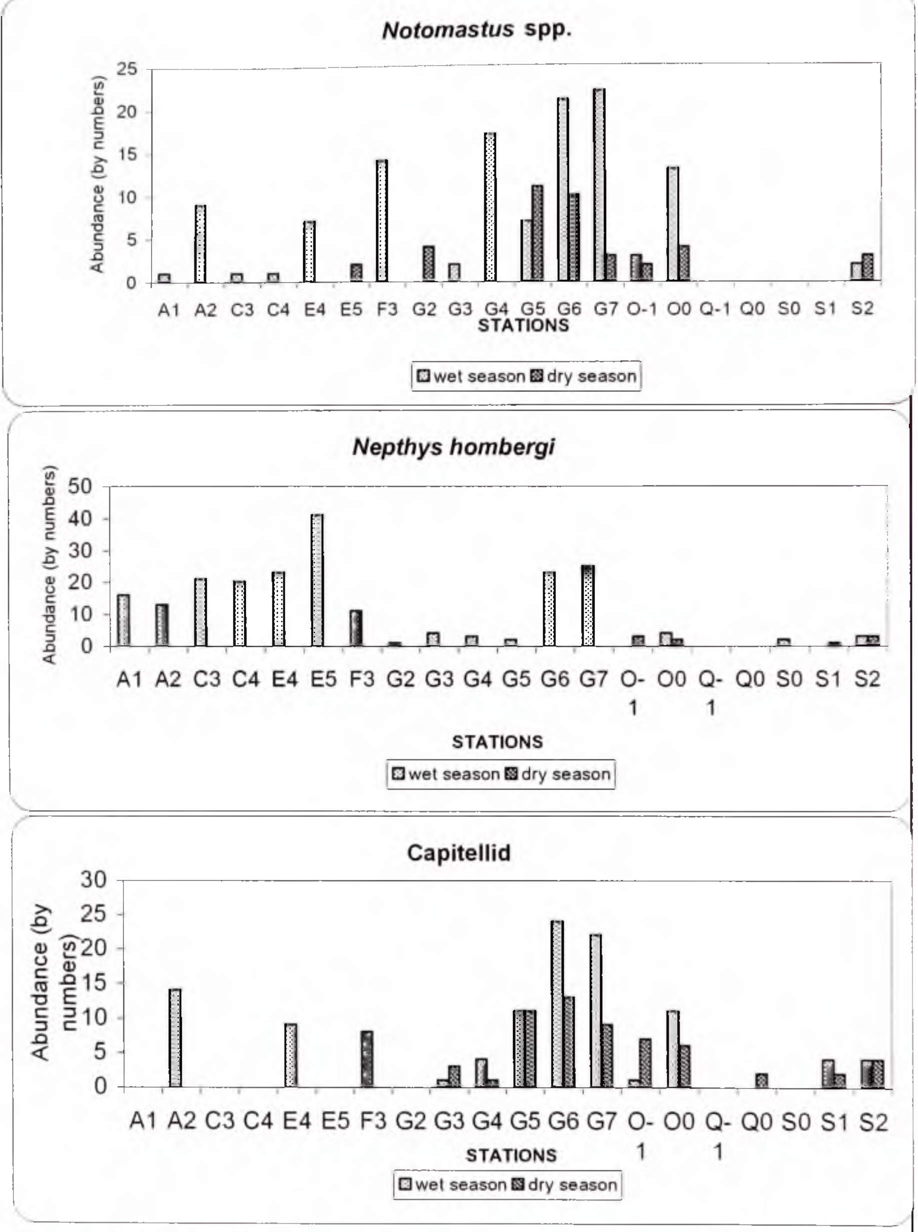
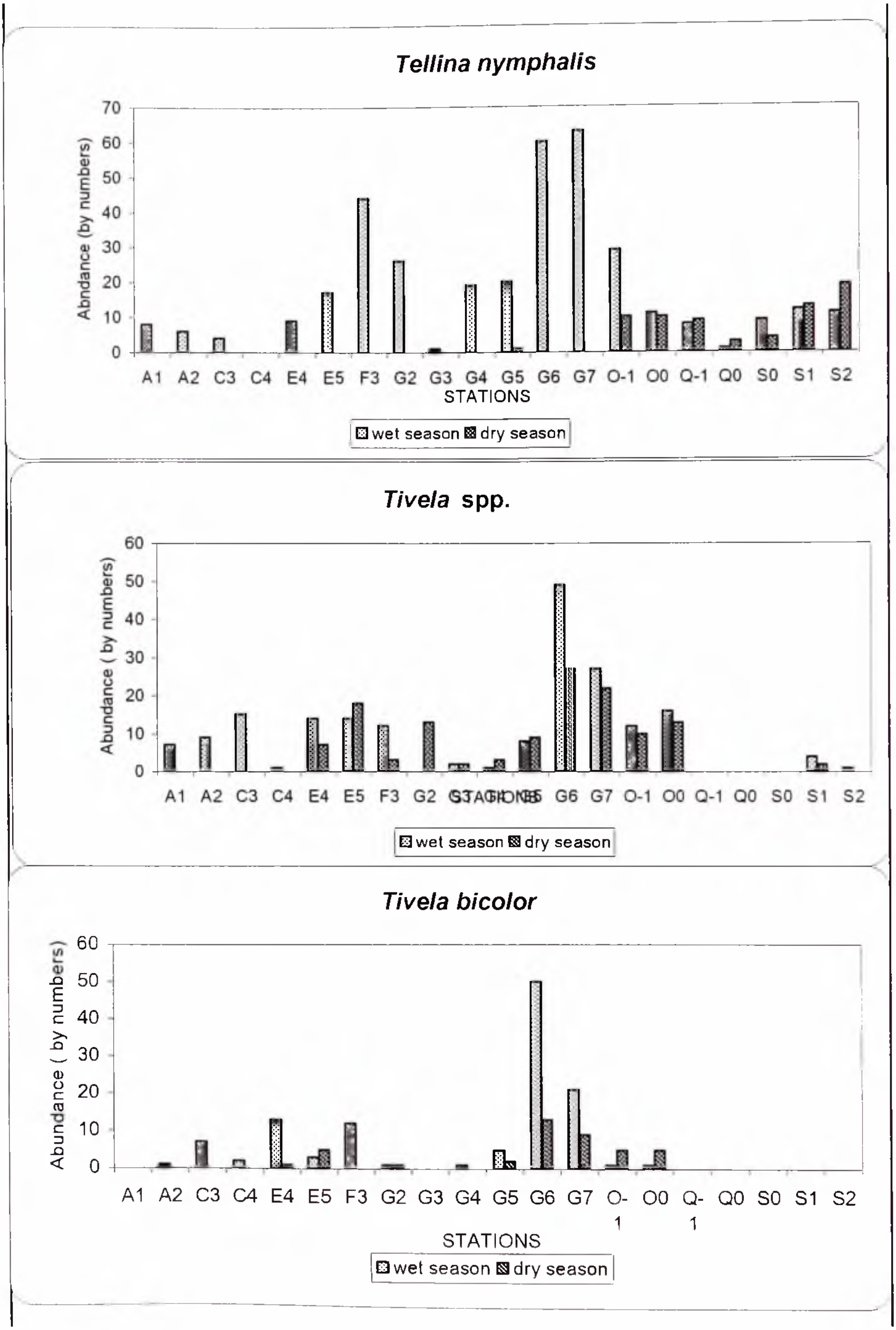


Figure 4.10 : Abundance and distribution of the dominant macrofauna of the Keta lagoc

Fig. 4.10 Abundance and distribution (Contd.)

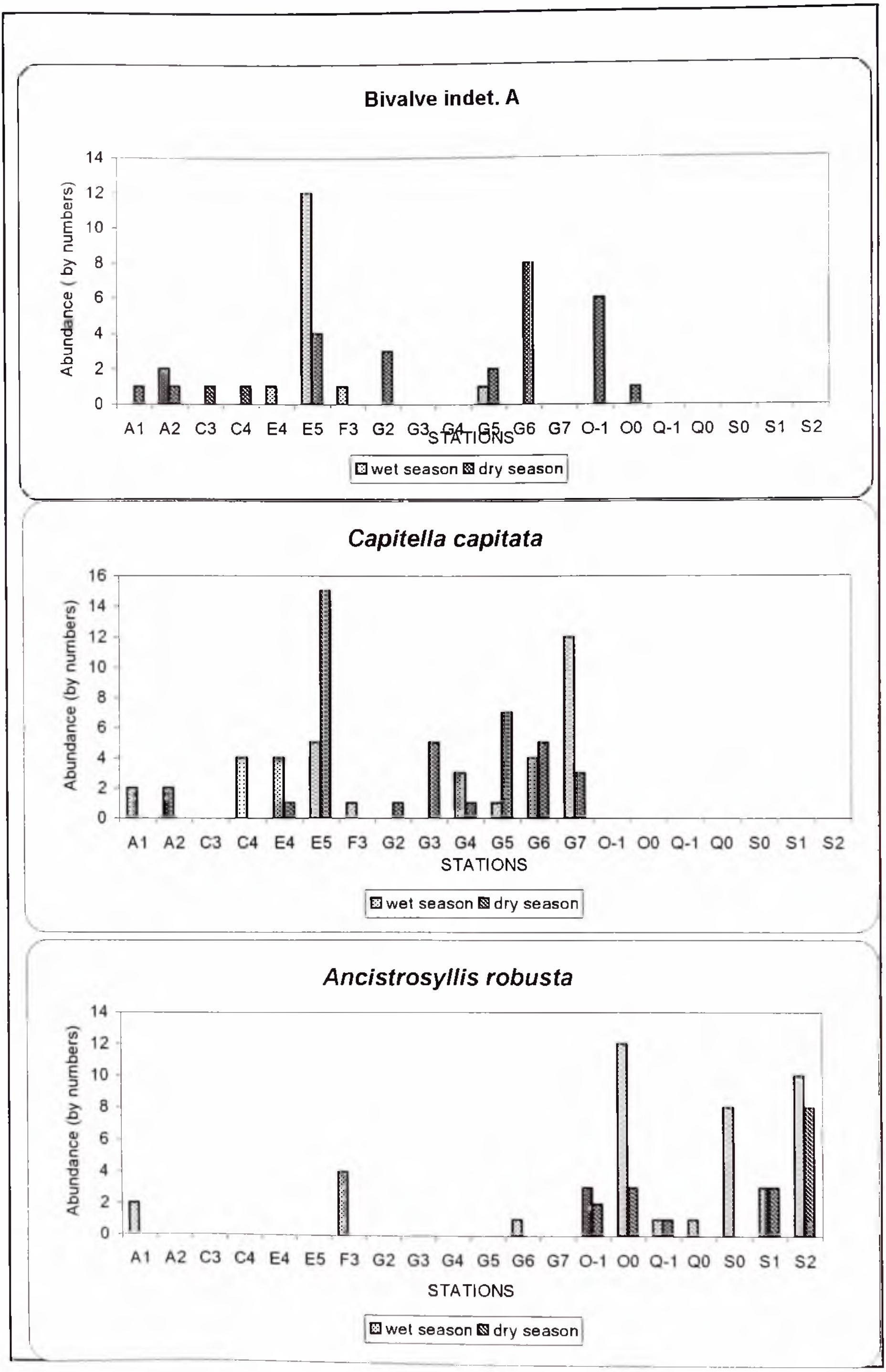


Tellina nymphalis

Tivela spp.

Tivela bicolor

Fig. 4.10 Abundance and distribution (Contd).



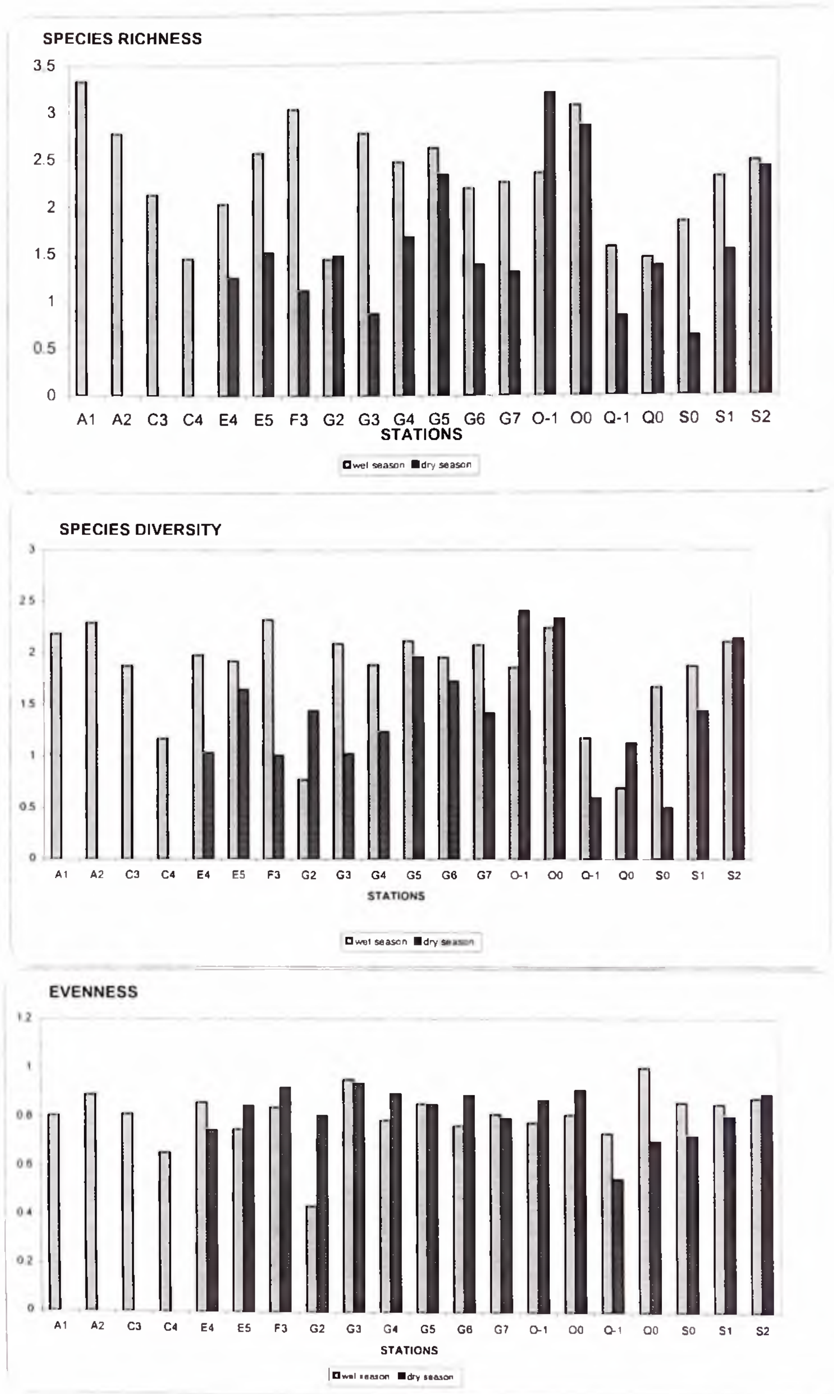


Figure 4.11 . Margalef's index for species richness, Shannon-Wiener's diversity (using Log.in base e) and Pielou's evenness at each of the stations.

Figure 4.11 demonstrates species richness, species diversity and evenness between stations for the two seasons. Species richness was relatively very high in the wet season than in the dry season exception being stations O-1 that showed a reverse trend. Species diversity was generally higher in the wet season and lower in the dry season between the stations, however stations G2, O-1, O0, Q0 and S2 (for the dry season) seem to have higher species diversity than the corresponding stations in the wet season. Species evenness was relatively the same between the two seasons. In the dry season stations A1, A2, C3 and C4 did not record any species due to stressful water conditions at those stations which perhaps was intolerable to the organisms.

4.2.2 **FINDINGS**

A total of 36 taxa species were found during the study. Seven of these taxa, namely: *Capitella capitata*, *Orbinid sp.*, *Syllid sp.*, *Ischyroceros sp.*, *Neanthes sp.*, *Polydora sp.* And *Echelus myrus* (benthic juvenile eel) are new records in the Keta lagoon. The dominant component of the taxa in terms of number of species was characterised by bivalve species: *Tellina nymphalis* (19.8%) of the total number, *Tivela tripla* (14.9%) and *Tivela bicolor* (7.38%). The dominant polychaetes were *Nepthys sp* (10.27%), *Capitellid* (7.9%) and *Notomastus latericeus* (7.38%). *Tympanotunus* sp. was under represented because they got rotten before identification despite the use of 10 % concentrated formalin. It was realized they closed their aperture tightly immediately they were sampled.

A few were handpicked and put in concentrated 40% formalin, but they were found to be rotten within a week.

Salinity preferences by macrobenthic species were evident in the lagoon, where *Tellina nymphalis* was only found at stations where salinity range was below 33ppt (stations O-1, O0, Q-1, Q0, S0, S1 and S2.. Also, organisms, notably, polychaetes re-distributed themselves following the salinity regimes prevailing in the dry season such that higher abundance occur in patches in areas where salinities are relatively lower.

Significant difference was found in species richness (one-way ANOVA, F =18.03, $p < 0.05$) between the wet season and the dry season. Species diversity also showed significant difference between the wet and the dry seasons (one-way ANOVA, F = 7.995, $p < 0.05$). However, no significant difference in species richness was found between stations for the two seasons (two-way ANOVA, F = 1.265, $p > 0.001$). In the same way, two-way ANOVA verified no significant difference in species diversity between stations (F = 1.231, $p > 0.001$).

4.2.3 **ENVIRONMENTAL PARAMETERS AFFECTING COMMUNITY PATTERN**

The results of BIO-ENV analyses revealed very strong correlations between log-transformed water parameters and fourth-root-transformed abundance of species (Tables 4.5 and 4.6).

The highest rank correlation for the wet season (r = 0.999) occurred with a group of eight environmental variables i.e. % clay, % silt, % sand, total suspended solids (TSS), turbidity, total dissolved solids (TDS) sulphate and silicate (Table 4.5). For the dry season, the

Best combinations of environmental variables from BIO-ENV programme for the wet season

ariable/Parameter	Spearman weighgted rank Correlation	
urbidity (Turb.)	0.847	
otal suspended solids (TSS)	0.846	
otal dissolved solids (TDS)	0.478	
urb. & Sulphate (Sul.)	0.957	
SS & Sul.	0.943	
urb. &TDS	0.917	
SS & TDS	0.909	
Sand, Turb. & Sul.	0.97	
Silt, Turb. & Sul.	0.969	
SS, Turb. & Sul.	0.967	
alinity (Sal.), Turb. & Sul	0.961	
Sand, TSS, Turb. & Sul.	0.987	
Silt, TSS, Turb. & Sul.	0.982	
Sand, Turb.,Silicate (Sil.) & Sul.	0.974	
Silt, % Sand, Turb., TSS & Sul.	0.991	
Clay, % Silt, Turb., TSS & Sul.	0.989	
Silt, % Sand, TSS, Turb., TDS & Sul.	0.996	
Silt, %Sand, TSS, Turb., Sul. & Sil	0.989	
Clay, % Silt, %Sand,Turb., TSS, TDS & Sul.	0.997	
Silt, % Sand, Turb., TSS, TDS, Sul. & Conductivity (Cond.)	0.996	
Clay, % Silt, %Sand,Turb., TSS, TDS, Sil. & Sil.	0.999	

Best combinations of environmental variables from BIO-ENV programme for the dry season

ariable/Parameter	Spearman weighted rank Correlation	
Sand	0.731	
onductivity (Cond.)	0.707	
H	0.706	
urb. & Sulphate (Sul.)	0.941	
urb. & TDS	0.926	
SS & TDS	0.925	
SS & Sul.	0.922	
Sand, Turb. & Sul.	0.979	
Sand, TSS & TDS	0.968	
Sand, TSS & Sul.	0.965	
Sand, Turb. & TDS	0.964	
Sand, TSS, Turb. & Sul.	0.991	
Silt, % Sand, Turb. & Sul.	0.986	
Sand, Salinity, Turb. & Sul.	0.982	
Clay, % Sand, Turb., TSS & Sul.	0.993	
% Silt, % Sand, Turb., TSS & Sul.	0.993	
Clay,% Silt, % Sand, TSS, Turb.& Sul.	0.996	
Silt, %Sand, Salinity,TSS, Turb. & Sul.	0.995	
% Clay, % Silt, %Sand, Salinity,Turb., TSS & Sul.	0.998	
bles in increasing order on complexity		

highest rank correlation (r = 0.998) occurred with a group of seven environmental variables which were: percent silt, percent sand, percent clay, salinity, turbidity, TSS and sulphate (Table 4.6). Tables 4.5 and 4.6 also show the values of the Spearman rank correlations of environmental variables in increasing level of complexity for the wet and dry seasons respectively.

Figures 4.12 and 4.13 demonstrate scatter plots of linear regression of species richness on the key environmental variables with the highest rank correlations from BIO-ENV analyses for sediment and water respectively. Species richness was chosen instead of species diversity because the correlation between them wasvery high (0.98) and also species richness is the simplest way to describe community and regional diversity (Magurran, 1988). From figure 4.12, percent clay (during the wet season) and percent silt (wet and dry seaons) correlated negatively with species richness. However, there was a positive correlation of species richness percent clay during the dry season. The maximum value of species richness will be obtained at a station with percent clay of 25% . Percent sand on the other hand correlated positively with species richness for both the wet and the seasons. There was however, higher correlation value ($R^2 = 0.3964$) in the wet season and the percent sand at which maximum species richness could be realized ranged 80% to 98%. From figure 4.13, there positive correlations between species richness and total suspended solids, turbidity, sulphate (during the wet season) and silicate for both seasons, and negative correlations for total dissolved solids, sulphate (during the dry season) and salinity (dry season).

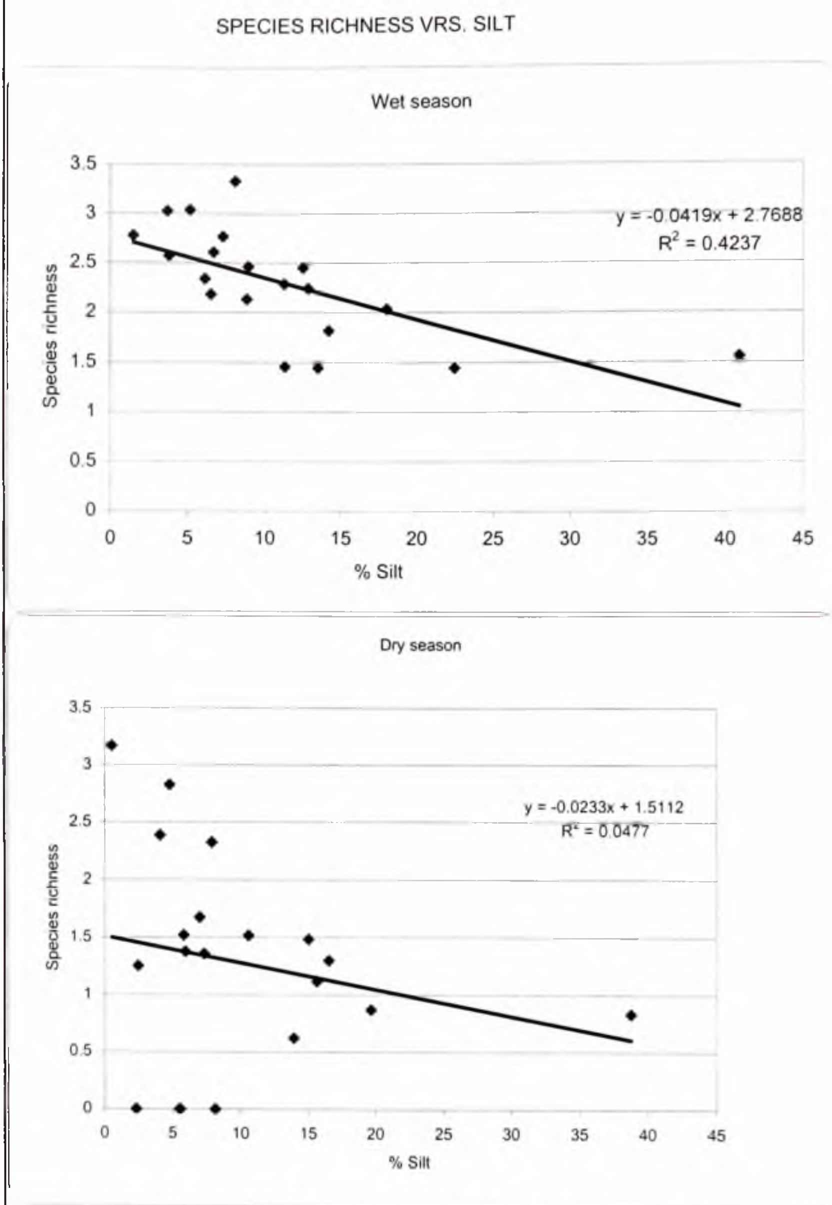


Figure 4.12 Linear regression of species richness on sediment parameters. (at 95 % confidence interval).

SPECIES RICHNESS VRS. CLAY

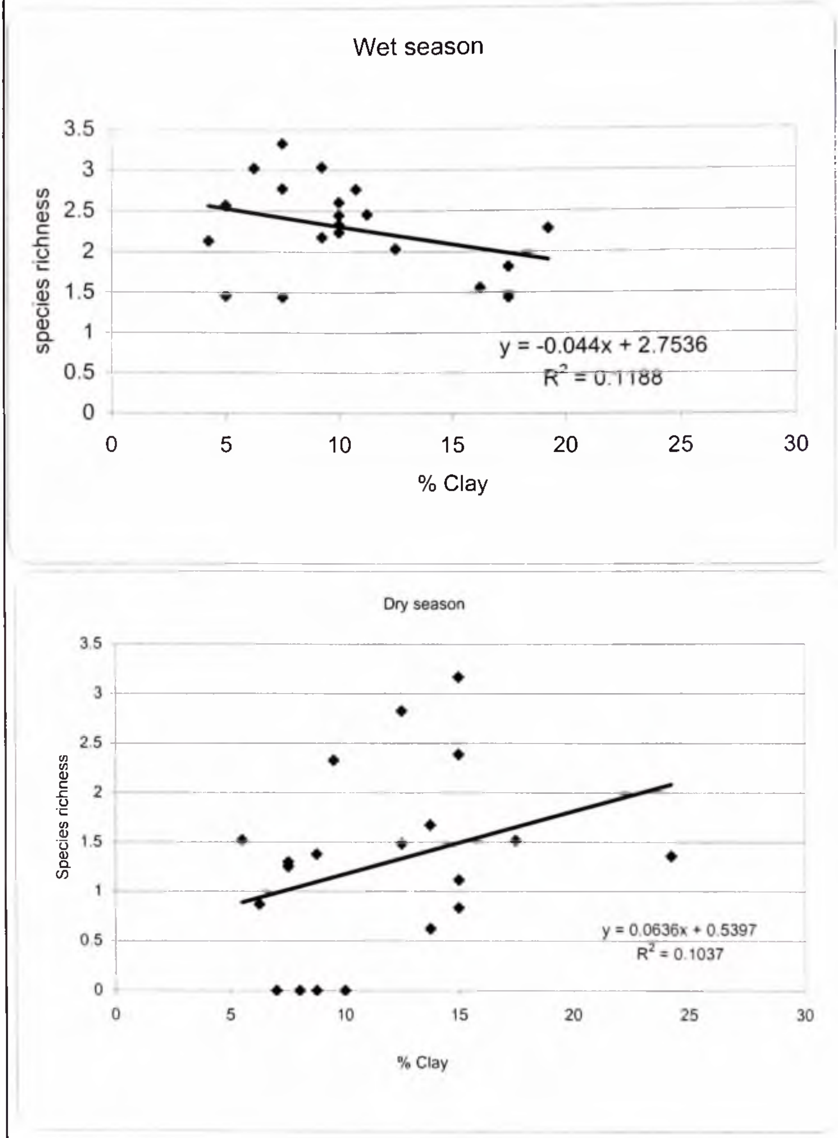


Figure 4.12 Linear regression of species richness on sediment parameters.
(at 95 % confidence interval).

Figure 4.12 Linear regression(Condt.)

SPECIES RICHNESS VRS. SAND

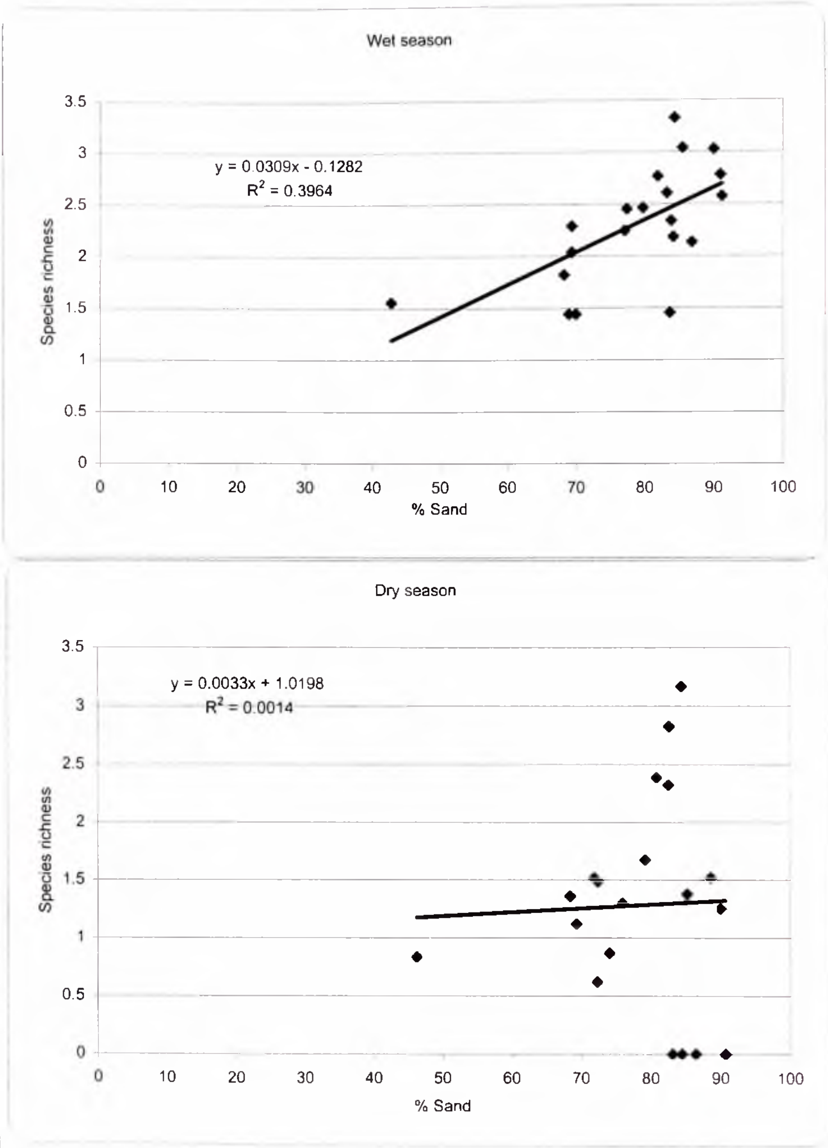


Figure 4.12 Linear regression of species richness on sediment parameters. (at 95 % confidence interval).

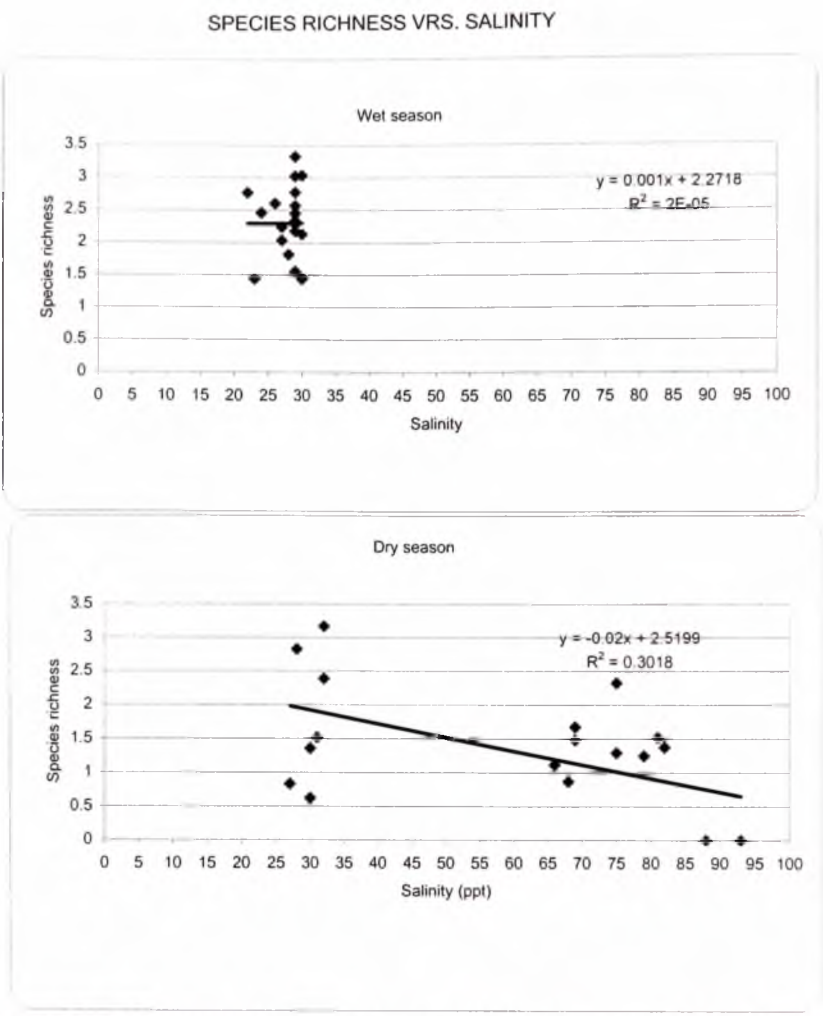


Figure 4.13 Regression of species richness against key environmental variables (at 95% confidence interval).

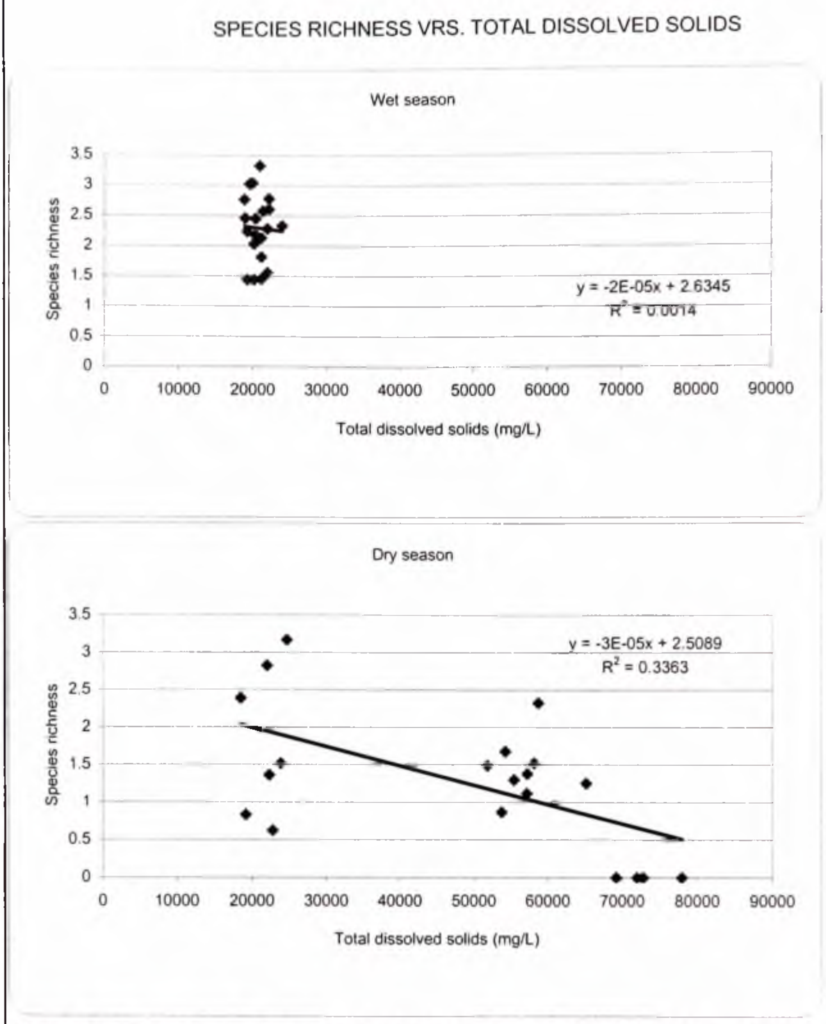


Figure 4.13 Regression of species richness against key environmental variables (at 95% confidence interval).

SPECIES RICHNESS VRS. TOTAL SUSPENDED SOLIDS

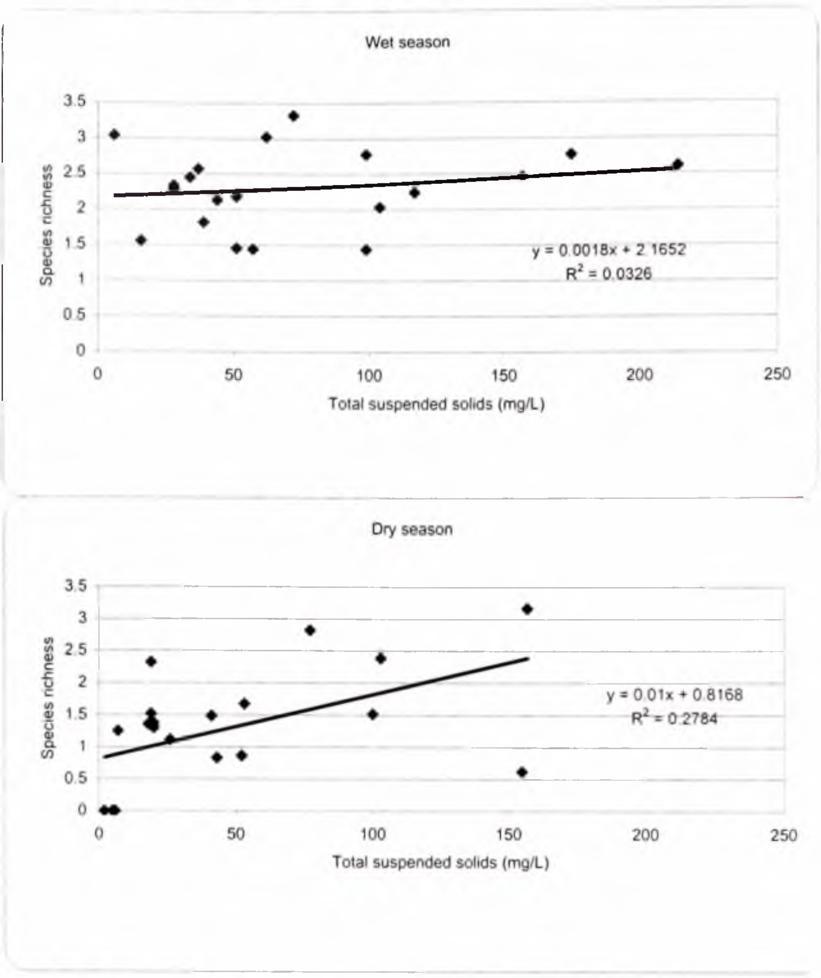


Figure 4.13 Regression of species richness against key environmental variables (at 95% confidence interval).

SPECIES RICHNESS VRS. SULPHATE

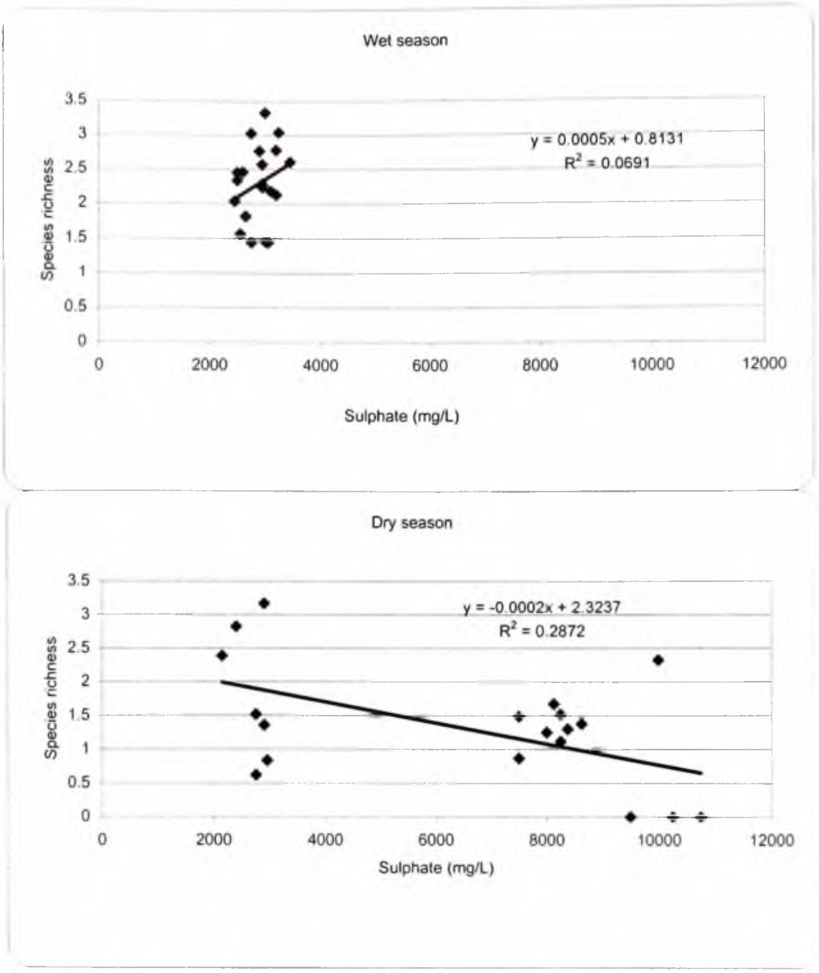


Figure 4.13 Regression of species richness against key environmental variables (at 95% confidence interval).

SPECIES RICHNESS VRS. SILICATE

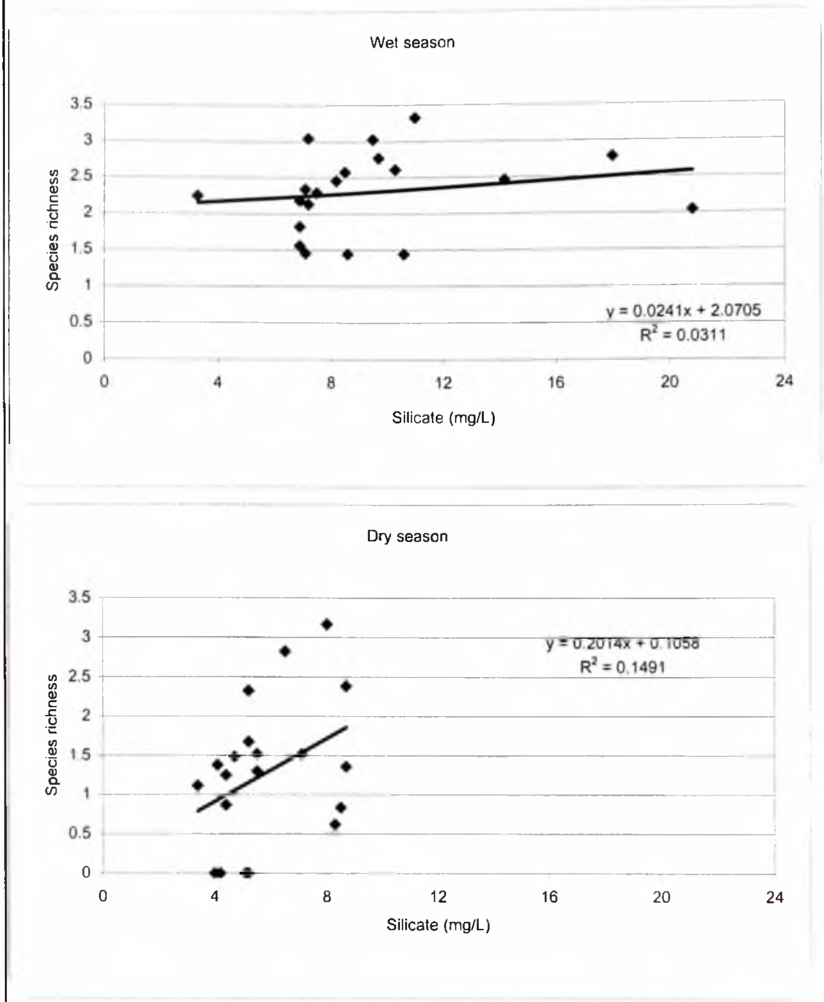


Figure 4.13 Regression of species richness against key environmental variables (at 95% confidence interval).

SPECIES RICHNESS VRS. TURBIDITY

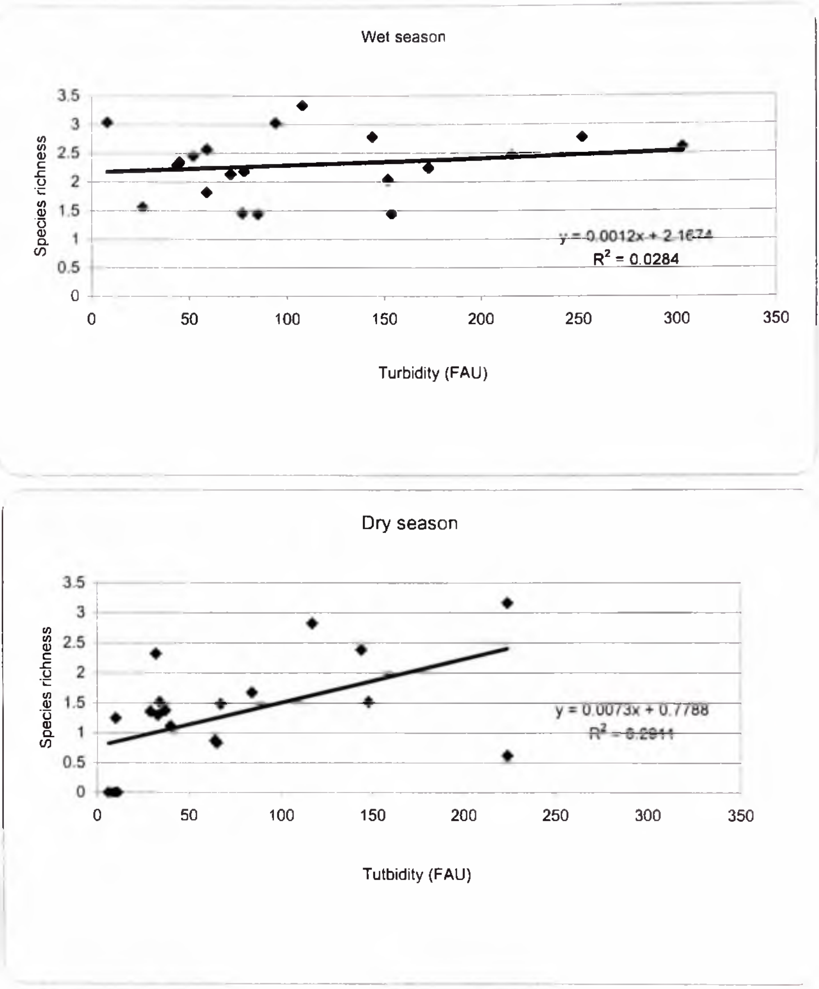


Figure 4.13 Regression of species richness against key environmental variables (at 95% confidence interval).

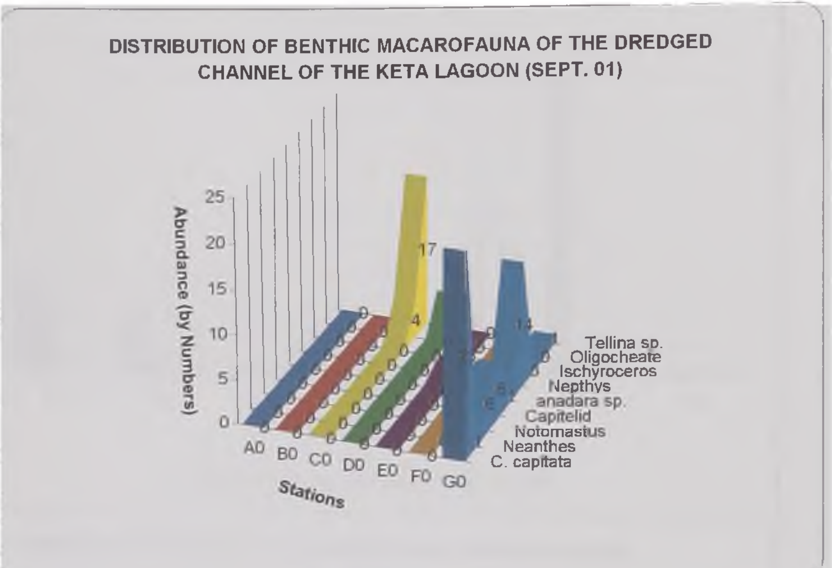
4.3 DREDGED CHANNEL

The dredged channel showed marked variability in the macrofauna during the time of dredging and periods after dredging (Figure 4. 14). During the period of dredging certain stations recorded no living organisms mainly because the dredging materials, which were peat, were considered to have smothered them. Species such as *Tellina nymphalis*, *Nephtys* sp., *Notomastus* sp. *Capitella capitata* and *Ancistrosyllis robusta* were among the species determined by the SIMPER analysis (Table 4.4) as influencing the community structure of the Keta lagoon. These species occurred in appreciable numbers at stations C0 (Tellina nymphalis) and G0 (*Nephtys* sp.*Notomastus* sp. and *Capitella capitata*) during September 200. Stations F0 and G0 were feshly dredged during this period. A notable feature was the the absence of Ancistrisyllis robusta at any of the stations during September 2001 sampling but occurred exactly a year after dredging (September 2002) at stations C0 and D0. Capitella capitata was also abundant at station D0 during September 2002. There were however, both spatial and temporal changes in abundance of the benthic macrofauna in the dredged channel.

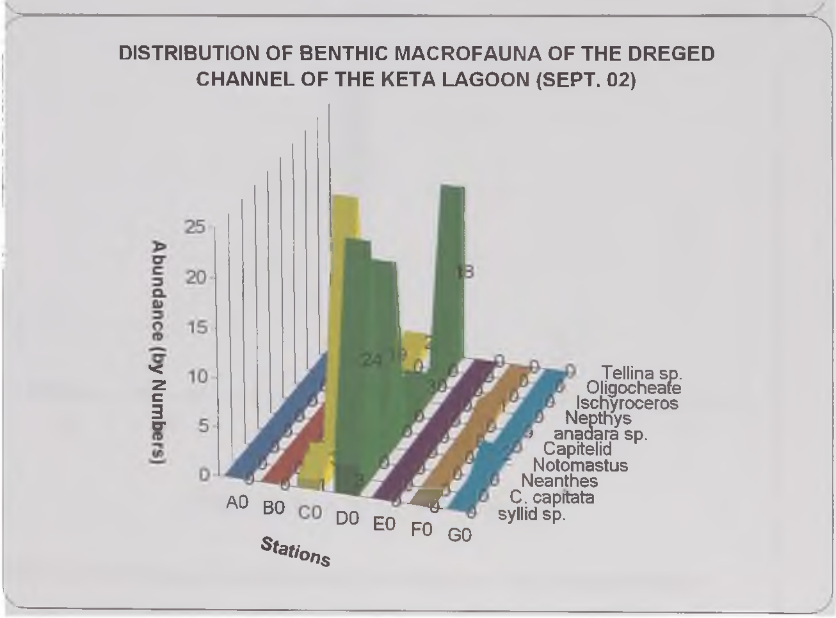
The environmental parameters showed both temporal and spatial variation during the periods of the study (Figure 4.15).

Spatio-temporally, parameters such as total dissolved solids, sulphate and salinity showed a trend. Higher values of these parameters were observed at stations E0 and F0 during May 2002. The lowest values occurred at stations A0 and D0. Turbidity did not show any trend, however higher turbidity was recorded at stations D0 during September 2001, which could possibly be due to the movement of dredged plume from stations F0 and G0 which were just completed or being dredged at period. Turbidity and total suspended solids levels were extremely low at station Go throughout the study which could possibly due to the direction of the fetch carrying the dredged plume eastward direction.

The distribution of variables such as total dissolved solids, sulphate concentrations and salinity seemed to mimic each other spatially. Stations E0 and F0 recorded the highest values of these variables. The other stations recorded values within very narrow range to each other.



DISTRIBUTION OF BENTHIC MACAROFAUNA OF THE DREDGED CHANNEL OF THE KETA LAGOON (SEPT. 01)



DISTRIBUTION OF BENTHIC MACROFAUNA OF THE DREGED CHANNEL OF THE KETA LAGOON (SEPT. 02)

Figure 4.14 Distribution and abundance of benthic macrofauna in the dredged channel during sampling period.

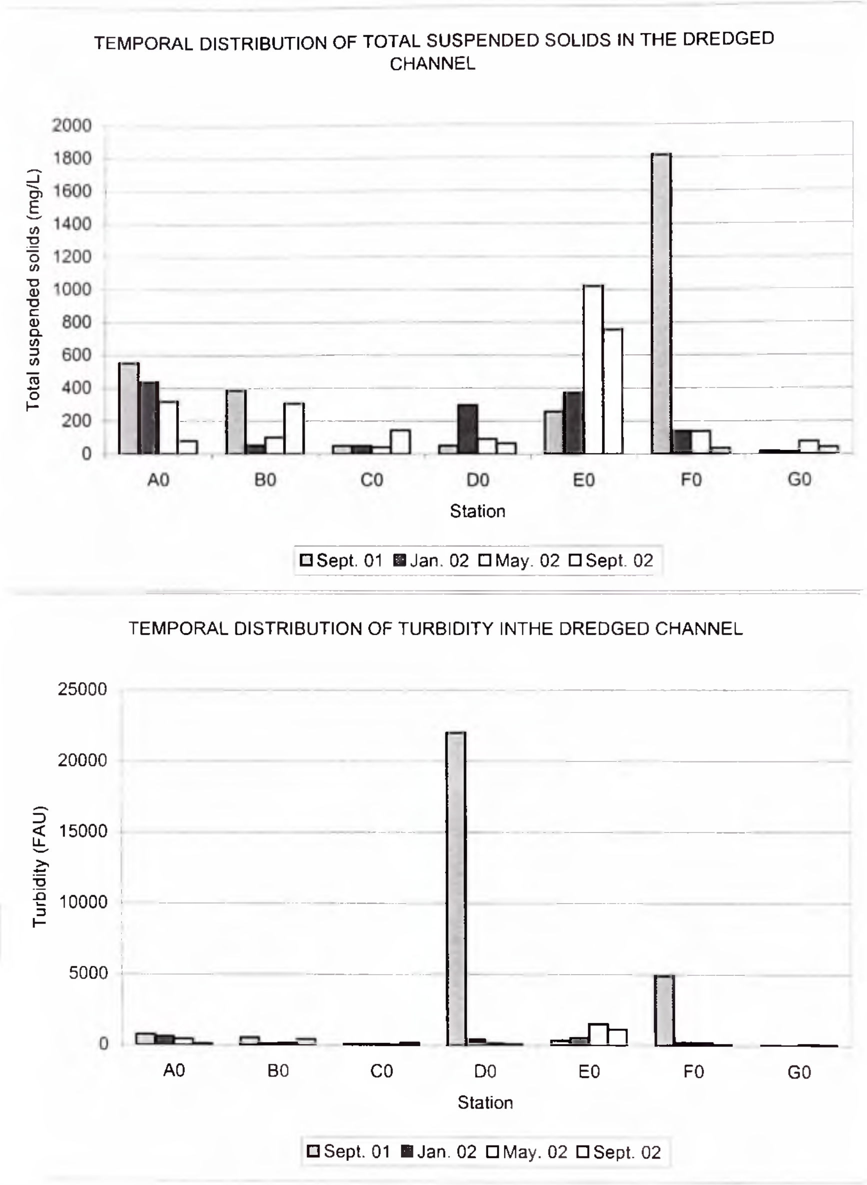
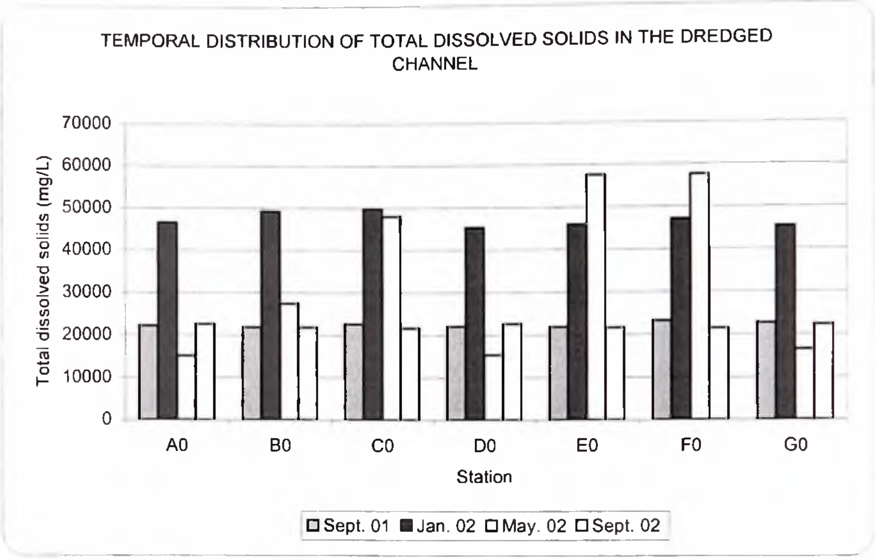


Figure 4.15 Temporal variations of environmental parameters in the dredged channel

Figure 4.15 Contd.


TEMPORAL DISTRIBUTION OF TOTAL DISSOLVED SOLIDS IN THE DREDGED CHANNEL

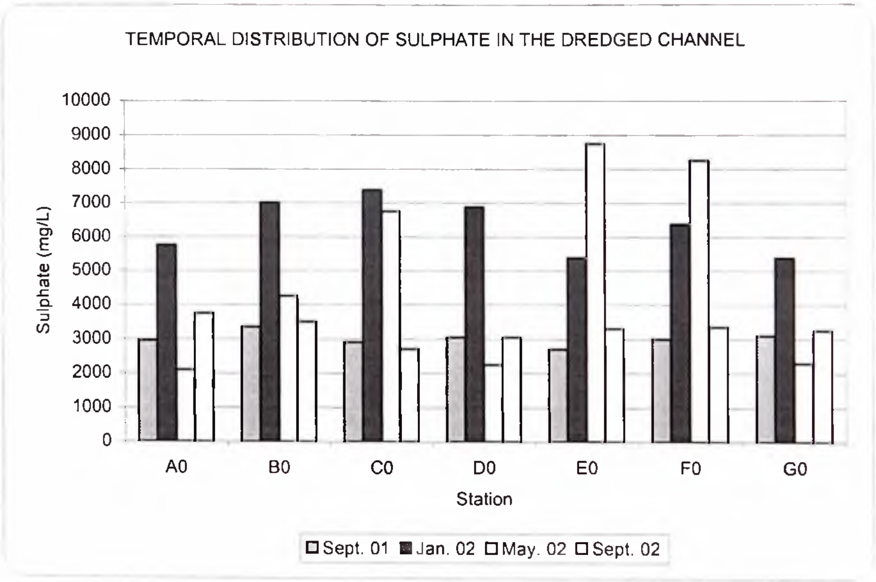
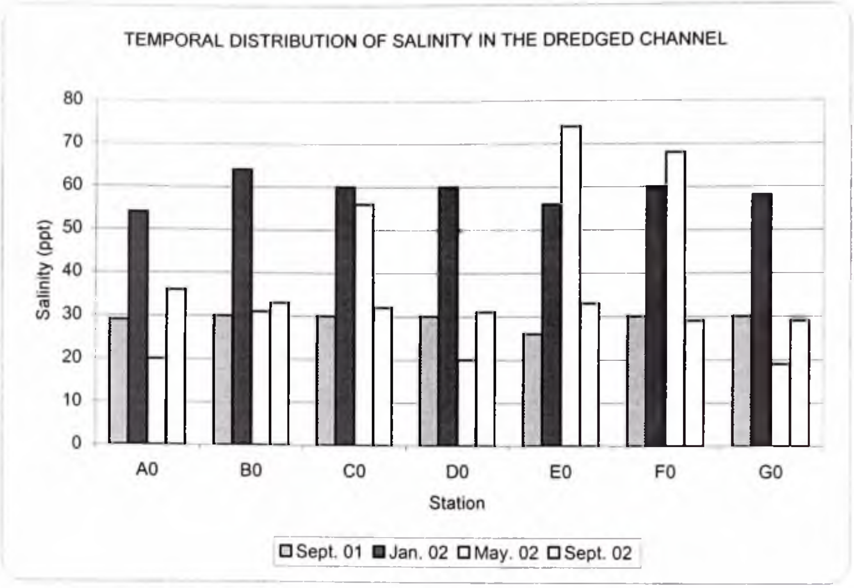

TEMPORAL DISTRIBUTION OF SULPHATE IN THE DREDGED CHANNEL

Figure 4.15 Contd.



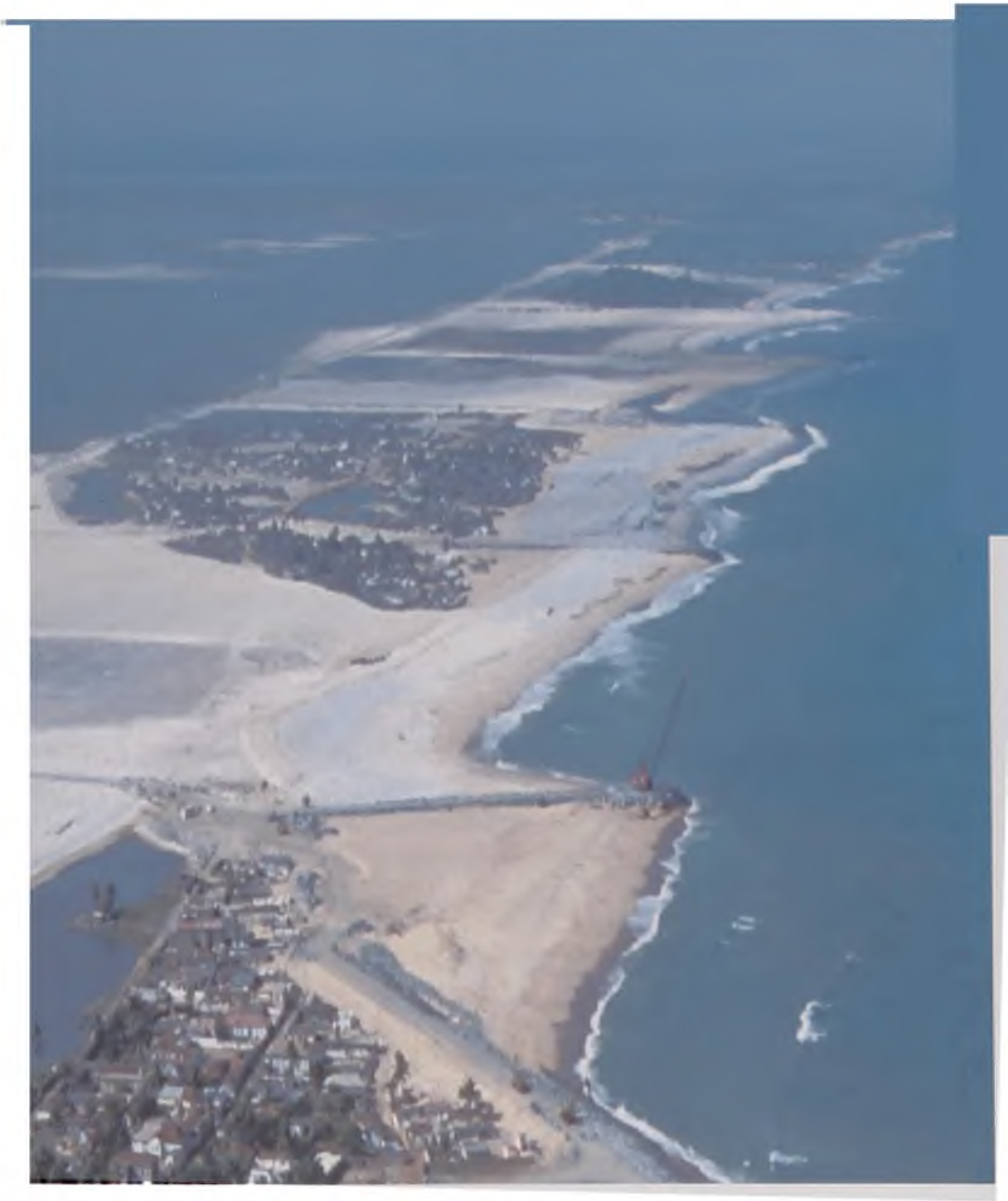


Figure 4.16 Aerial photograph of Keta showing part of the dredged channel, road, revetment, reclaimed area and the township. Photo by Great Lake Dry & Dock (GLDD).

4.4 SEDIMENT DISTRIBUTION MAP

Patterns of sediment distribution are related to sediment sources and processes at work in and around the lagoon environment (Bird, 1994). Sediment transported into a lagoon may undergo repeated cycles of erosion, transport and deposition by wave action or ebb – flood tidal current and be suspended many times prior to accumulation (Nichols and Boon, 1994). Some sediment may be sorted by wave actions, aggregated into flocs or eaten by animals, thus changing its physical form or composition (Nichols and Boon, 1994). The direction and intensity of processes of sediment in a lagoon is determined not only by the hydrodynamics but by the behaviour of the particles which varies with their size, shape, density, composition and biological processing (Nichols and Boon, 1994).

To obtain a broader picture of the sediment distribution, the entire lagoon was mapped. Figures 4.17, 4.18 and 4.19 demonstrate the spàtial distribution of sand, silt and clay respectively in the Keta lagoon. The spatial distribution of sediment in the lagoon was uneven. The peripheral stations have higher amount of finer sediment such as silt and clay. Approximately 80 % of the stations are sandy with sand percentages ranging from 70 – 98. This may possibly be areas of high energy with strong currents or much wind-induced perturbation which were characterized by coarser substrate such as sand as observed. Conversely, areas of lower energy tend to be characterized by more consolidated finer sediment as encountered in the peripheral stations. Muddy sediment accumulates in areas where disturbance from currents and storms are uncommon and sediment particles can fall out of the water.

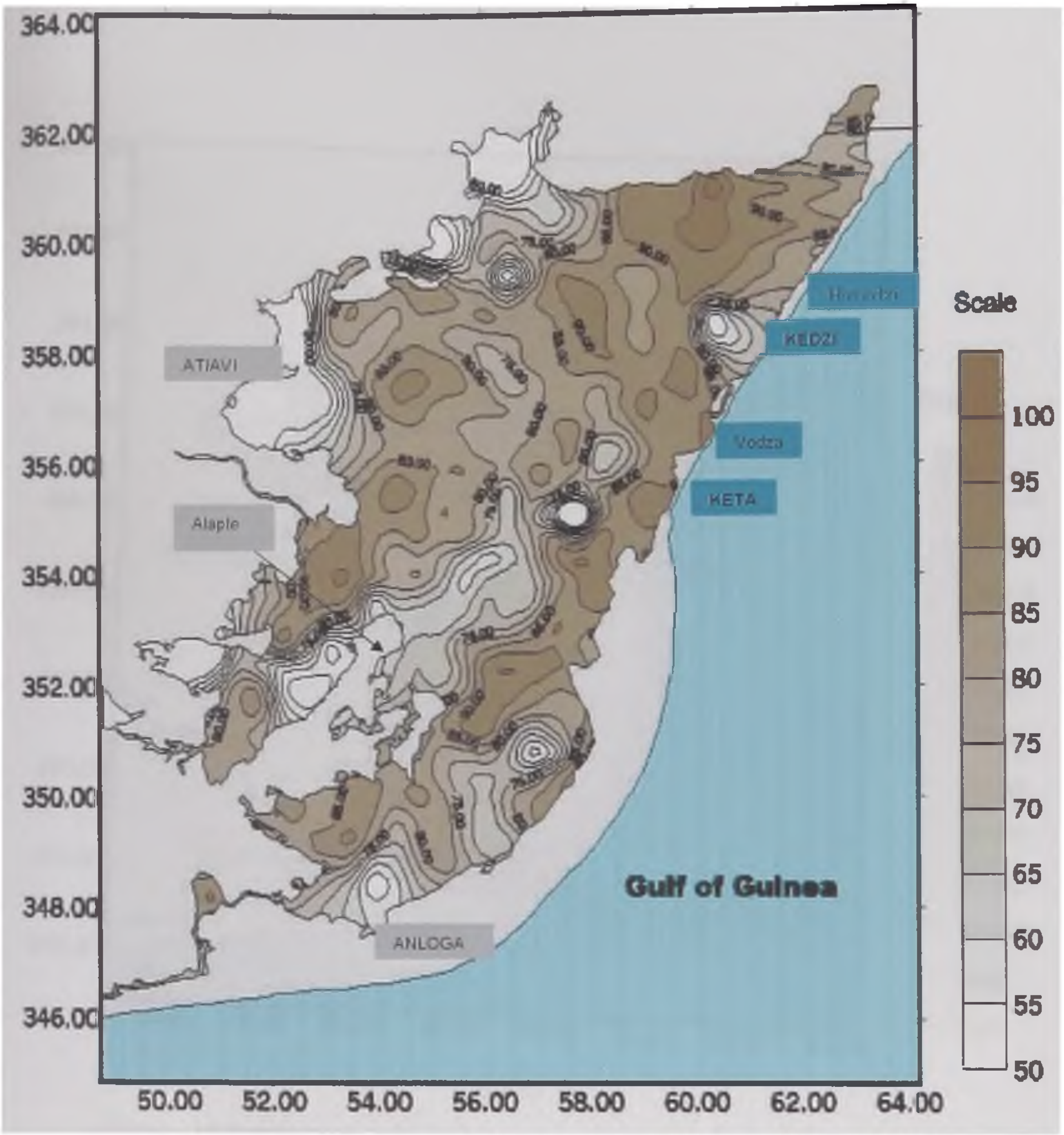


Figure 4.17 Spatial distribution of sand in the Keta lagoon (Values of scale in percent).

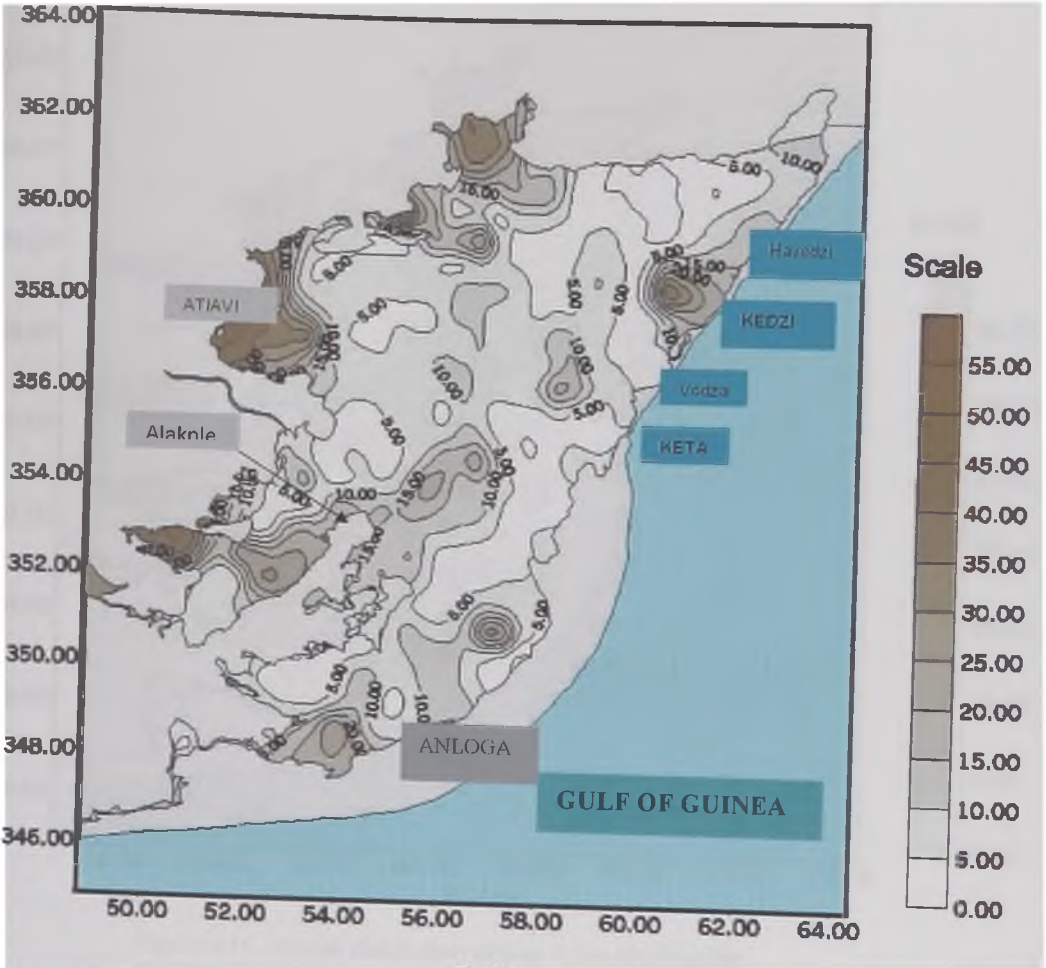


Figure 4.18 Spatial distribution of silt in the Keta lagoon (Values of scale in percent).

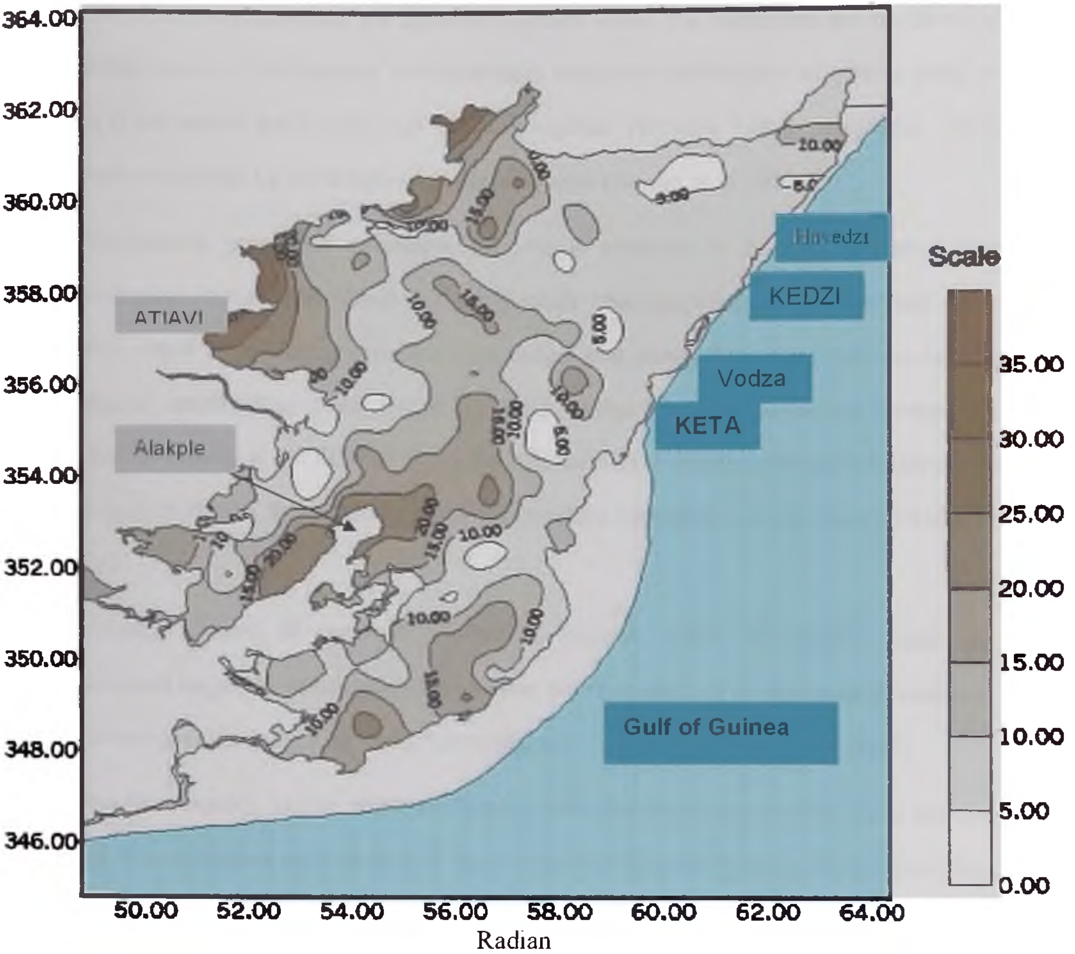


Figure 4.19. Spatial distribution of clay in the Keta lagoon. (Values of scale in percent).

SEDIMENT DISTRIBUTION

Sedimentary environments are dynamic habitats where the sediments,the fundamental building blocks of the habitats, are continually structured both by the organisms living on and in the habitat and by the local physical regimes (Woodin, 1999). Substrate type is determined laregy by the enegry of the environment (Gowen *et al.*, 2000).

Hydrodynamic processes determine the overall structure of benthic habitats. The hydrological regime determines the sedimentary characteristics of the sea floor (Hall, 1994), which largely determines the composition and distribution of the resident benthic biological communities (Duineveld et al., 1991). It has been argued that the composition of the community is not determined by the sedimentary characteristics *per se*, but by the physical conditions that produce those sedimentary conditions (Snelgrove and Butman, 1994).

Distribution pattern of individual species of shallow –water sedimentary fauna are determined largely by sediment dynamics over broad scales and by biological interactions, sediment geochemistry, near –bed flow processes ar finer scale (Snelgrove, 1999).

In the Keta lagoon, coarse sediments (sand) dominate and occur in most areas studied, while finer sediments such as silt and clay occupy the intervening areas of the lagoon floor less subjected to current and turbulence. The latter occurred mainly at the peripheral stations. This occurrence might probably due to the direction and strength of the wind and the length of fetch across which they are effective. This is because Keta lagoon is a closed ecosystem where waves and currents are often generated by wind blowing over the water. Also, the fringing vegetation in the freshwater end of the lagoon filter out the sediment depositing the finer sediments (silt and clay) in less energy impacted areas of the lagoon.

Many species have a complex relationship with the sedimentary environment. By mechanisms yet to be fully understood, the flow-, nutrition- and substrate related variables contribute to patterns in species distribution that are fairly consistent in time and space (Snelgrove, 1999). It is well known that fine sediment such as clay, which have grains tightly packed together, may exhibit the presence of rich infauna communities, since such sediments have poorly water circulation and often low oxygen tension (Gray, 1981).

In the study area benthic macrofaunal species such as *Pseudopolydora* spp. (Polychaete) and a crustacean *Ischyroceros* spp. abundance and distribution followed the distribution of clay and silt especially at the peripheral stations of the lagoon. The *Pseudopolydora* spp were found to inhabit tubes of plant materials that have been swept by the wind to the peripheral stations. These species may possibly be good ecological indicators of distribution of clay and silt and or the flow regimes, which is the basis for sediment distribution in the Keta lagoon. However, a detailed studied must be carried on such species to establish this fact.

CHAPTER FIVE

DISCUSSION

5.1 VARIABILITY OF ENVIRONMENTAL PARAMETERS

Coastal lagoons are reported as highly dynamic (Barnes, 1980) due mainly to seasonal variability in physico-chemical factors (Mistri *et al.*, 2000). They are ecosystems with strong spatial gradient concerning the chemical characteristics of the water and of the biological populations present (Guelorget and Perthuisot, 1983).

The environmental and biological factors in the study area of the Keta lagoon are clearly acting on a spatio-temporal gradient. In general, there were important differences between stations in both the wet and the dry season. All these are mainly the consequence of the lagoonal characteristics. Spatio-temporally, environmental parameters such as salinity, conductivity, total dissolved solids, total suspended solids, turbidity, sulphate, and silicate showed a very high variability between the seasons. Sediment parameters such as percent sand, percent silt and percent clay and, water parameters including phosphate, nitrate did not show much temporal variability though most stations exhibited spatial variability between the two seasons. The former may explain little sediment movement in the lagoon meaning that near-bed water current might not be strong. The low temporal variation in phosphate and nitrate values may be attributed to the non-conservative nature of it in the lagoon and/or less microbial activities (Day and Yanez-Arancibia, 1985). This is because the presence of both anaerobic and aerobic organisms makes chemical cycling very important in lagoonal ecosystem. Anaerobic conditions allow reactions like solubilization of precipitated phosphorus, denitrification (Day and Yanez-Arancibia, 1985), and there is always large storage of nitrogen and phosphorus in anaerobic sediments, which can be made available for plant uptake via mineralization.

Salinity, sulphate and total dissolved solids levels differed greatly between stations and seasons during the study periods. Seasonal changes in these parameters were possible due in great part to the combined effects of the very high evaporation and reduced run-off from land drainages. Considering the large surface area of the lagoon and strong winds which increase the rate of evaporation, such explanation are acceptable, but other factors probably played an important role in determining the variability of the physico-chemical parameters. Variables such as pH, water and air temperatures, dissolved oxygen, percent sulphur, percent organic matter, percent clay, percent silt, nitrate and phosphate showed slight variation among stations. These variables however, do not show important differences between the wet and dry seasons.

The cluster analysis showed three zones for the wet season (figure 4.4) and the dry season (figure 4.5) in the lagoon, according to variation in physical and chemical characteristics measured. Parameters such as total dissolved solids, sulphate and percent sand contributed immensely to the clustering groups realized in the two seasons. There was much variation between the clustering for the two seasons. The groupings for the dry season clustering were less than that for the wet season. Also very high similarities existed within a group and also between the major groups. However, a very strong affinity could be observed between certain stations in the two seasons. For instance, there was a very good similarity between stations S1, S0 and S2;; E5, A1, Q0, G6, C3,C4 and E4; F3, G5, G4, G3, G7, A2 and G2. These associations appear linked to similarities in the environmental parameters between these stations rather than fauna. Stations such as O-1, O0, S0, S1 and S2 in the southwestern sector of the lagoon had relatively milder changes in environmental variables (especially salinity) for the two season compared with other stations. The "milder" salinity ranged from 29ppt to 32ppt while the "strong" salinity ranged from 60ppt to 93ppt.

Spatial stratification in the lagoon was quite evident in the dry season. The southwestern part of the study area was characterized by low salinity and high turbidity. Clearly, that was the result of reduced run-off from streams that discharge into the lagoon. The southeastern part (A1, A2, C3, and C4) was characterized by high salinity regimes, which created a very stressful environment for the macrobenthic fauna. The middle zone had intermediate salinity values. However, in the wet season such spatial differences were less evident. This could probably due to dilution from direct precipitation and freshwater incursion from land drainages during such period when rainfall was higher.

The distinct station clustering of environmental variables between seasons could possible be indicated by a strong relationship between external factors (e.g. temperature, wind and riverine incursion) and internal biogeochemical processes (primary production, mineralization) though these were not assessed therein. These interactions might have favoured spatial heterogeneity within the lagoon during the dry season. The seasonal changes in the external and internal factors that may affect the relationships between physical and chemical variables were observed in the differences between the results of Principal Component Analysis (PCA) performed separately with data for each season.

The PCA explained much of the variation in the ordination of the sampling stations. On the first axis for the wet season, the environmental variables that contributed most to the ordination of the sampling stations are turbidity, salinity, silicate, percent clay, percent silt and percent sand. The dry season parameters included turbidity, salinity, pH, percent clay, and percent sand. Most of the variables (salinity, turbidity, percent clay and percent sand) that contributed to the clustering in the wet season were also operative in the dry season. The most drastically changed variables in the PC2 for the two seasons were turbidity, salinity, percent sand and pH (Appendix III).

The environmental parameters on the first principal components (PC1) for the wet season and dry season explained much of the total variance between the stations in the respective seasons. The parameters were both negatively and positively loaded on PC1 for the two seasons. These opposing relationships between these parameters demonstrated lack of correlation or inverse relationship between variables with negative scores and those with positive coefficient values. The latter could be associated more with biologically mediated processes. This means that the variables with high negative scores could be very critical in understanding the dynamics of the physico-chemical parameters of the Keta lagoon and hence their impact on the macrobenthic fauna. The observed pattern in the analysis indicated a dynamic and heterogeneous pattern of environmental variables in the different areas of the lagoon during different times of the year. This observation corroborates studies by Herrera-Silveira (1994). However, Herrera-Silveira (1994) found the difference between the seasons and groups studied to be due to the coupling of the intensity and frequency of external factors such as rainfall, winds, frontal systems, and biogeochemical processes such as primary production, mineralization, conservative and non-conservative behaviour of the nutrients, fertilization and bioturbation.

5.2 IMPACT OF ENVIRONMENTAL PARAMETERS ON COMMUNITY STRUCTURE

Many environmental variables have been reported to correlate with temporal and spatial distribution pattern and dynamics of macrobenthic faunal communities in lagoonal systems. These are either clearly physical (e.g salinity – Barnes, 1980), physico-chemical (Nicolaidou *et al*., 1988; Alongi, 1990) or variables involved with food supply (e.g. nutrients, organic material – Gray, 1981; Nixon, 1982). However, each of the species in the community responded differently to the suite of the environmental variables found to correlate with the distribution and dynamic pattern (Warwick and Clarke, 1991).

Grassle and Grassle (1974) pointed out that the adaptation of certain species to unpredictable environments is related to the degree of short-term selection possible from a range of genotype available. It seems reasonable; therefore, to presume that the more widely distributed a species is, the more likely it is to present a wide range of genotype deriving from the adaptations, which the species has to develop, in order to encounter different types of habitat. The relatively large seasonal fluctuations in environmental conditions that were observed during this study probably ensure that only species that are tolerant to broad changes in variables such as total dissolved solids, salinity, sulphate, turbidity and total suspended solids may survive in such an ecosystem.

The distribution pattern of the macrofaunal community over the seasons appear to have periodic changes, ranging from a well stratified rich community in the wet season to a relatively impoverished one in the dry season, apparently related to the intense stress from environmental variables. Such a trend had been referred to as dystrophic episode (Dounas and Koutsoubas, 1996). These episodes, however, have been considered to be a natural reaction of the lagoonal habitat to extreme environmental conditions (e.g. hypersalinity) and are of great importance in the re-establishment of the ecological balance (Guelorget and Perthuisot, 1992). For instance, benthic communities are more abundant in lagoons where salinities remain tolerable (< 40 ppt) (Alongi, 1990). This was confirmed in this study where high abundance of macrofauna were found in the salinity range of 29ppt to 32ppt at most of the stations and especially in the stations located at southwestern part of the lagoon (during the dry season). Salinities above such range were tolerable by few bivalves such as *Tivela sp.* and *Anadara sp.* etc. It must be emphasized that *Tellina sp.* did not show such a preference for such a range of salinity that other bivalves showed. However, bivalves that survive salinities above 50ppt and other variables were not found in salinities above 80ppt. This observation is supported by this study for the dry season, where zone I represented an impoverished community where salinity was > 85ppt. Zone II comprised mainly bivalves where salinity was between 56ppt to 80ppt; and zone III C consisted mainly of polychaetes interspersed with few bivalves (e.g *Tellina sp.*).(Figure 4.6)

In the study area, benthic communities fell into relatively several distinct groups when analyzed for species composition and population density (Figures 4.6 and 4.7). This indicates a high level of spatial variability in benthic community composition in the two seasons studied. This is also corroborated by the relatively lower levels of similarity of the biological communities within any one group compared with data for the physico-chemical variables. However, stations such as S1, S2, O0 and O-1 exhibited less spatial variability in macrobenthic fauna composition and abundance (Figure 4.8) which can be attributed to lesser fluctuation in the environmental variables at those stations. Certain species clustered together in both the wet and the dry seasons (Figure 4.9). This may explain an association between such groups of species in a parallel manner across sites.

Different combinations of environmental variables were considered at increasing level of complexity (on K variables where K=1,2...v) to obtain the best matches of biological and environmental similarity matrices for each K as measured by Spearman weighted rank correlation. The weighted spearman rank correlation ($\rho\omega$) lies in the range –1 (completely opposed) to 1 (complete agreement). Values close to zero indicate the absence of any match between the two patterns. Clarke and Warwick (1994) cautioned, however, that values for the weighted spearman rank correlation should not be referred to standard significance tables because the ranks are based on a large number of interdependent similarity calculations and thus are mutually dependent variables. The subset of environmental factors that best explains the observed pattern is then obtained by choosing the combination that gives the highest correlation using Spearman's test for non-parametric range. This was achieved using the BIO-ENV extension to the PRIMER package. Employing this tool; total dissolved solids and silicate were the variables that stood out between the two seasons.

The variations in environmental factors and differences in macrofaunal community composition, distribution and abundance for the two seasons are suggestive of a very high dynamic ecosystem. The dynamism of benthic macrofaunal community was also evident in the high average dissimilarity (70.35) between the wet season and the dry season

(Table 4.4). The abundance of species contributing to the average (dis) similarity was very high in the wet season than in the dry season.

Linear regression showed negative correlations between species richness against percent silt, percent clay and total dissolved solids. High amount of total dissolved solids in the water column may affect the organisms physiologically and, as such, species with less coping mechanisms might be wiped out from the environment. These variables therefore, might be very important in determining the distribution of the organisms. Environmental variables that correlated well with species richness and abundance were sulphate, salinity (in the dry season), total suspended solids, turbidity and percent sand within tolerable ranges.

The results from the SIMPER analyses showed the dominant macrofauna in the Keta lagoon namely: *Tellina nymphalis*, *Nephtys* spp., Bivalve indet. A, *Tivela tripla, Marphysa sanguinea*, Capittelid indet. A, *Ancistrosyllis robusta*, *Notomastus* spp., *Tivela bicolor* and *Capitella capitata* (Table 4.4). Abundance of such macrofauna was very high in the wet season than in the dry season but fluctuated between the stations in either season. However, stations G6 and G7 have very high abundance numbers for all the important species in the two seasons (Figure 4.10). Such stations might therefore, present unique habitat biotopes suitable for such organisms. Nevertheless, most of these dominant species showed correlations (though weak) with variables such as percent silt, salinity, water temperature, percent sand, total suspended solids, turbidity and sulphate.

Earlier work by Longhurst (1959) in West Africa and McNulty *et al., (1962)* in south Florida found that *Tellina spp.* for instance prefers sand to mud. The most abundant macrofauna in this study was *Tellina sp.* in the wet season and *Tivela sp.* in the dry season. Also the dominant sediment in the area was sand (> 80% for over 80% of the stations studied), and more so among the best matching environmental variables selected by BIO-ENV analyses included %sand. This study therefore corroborates with the earlier work that *Tellina sp* prefers sand, but in addition can tolerate other variables such as total suspended solids, turbidity total dissolved solids and salinity within reasonable levels.

5.3 COLONIZATION AND SUCCESSION IN THE DREDGED CHANNEL

Large amount of sediments were dredged from the burrowed pits for the Keta Sea Defence Work Project (KSDWP). This smothered macrofauna in area where the sediment were deposited (habitat islands). It however, exposed new area (burrow pit) for colonization. The rate and period of recovery for these macrofauna would be indicators for assessing the enormity of the impacts.

Disturbance likely leads to a non-equilibrium state in community structure where communities are continually recovering the last disturbance (Reice, 1994) as occurred during the constructional phase of the KSDWP. Disturbance of coastal macrobenthic communities induced through experimental manipulation suggest that colonization may be relatively rapid, but time to recovery is variable and depends on the timing of disturbance, nature of the habitat, reproductive periodicity of macrobenthos, and abiotic and biotic factors (e.g. Probert, 1984; Zajac and Whitlatch, 1982).

In the study area, benthic macrofaunal community showed a good deal of dominance and diversity during the time of dredging and periods after dredging. In fact, during the periods of dredging the dominant species encountered in the channel was *Tellina sp.* which survived the low oxygen at the bottom of the deeper waters as high as 9 m. Gradually, however this species disappear and could not be recorded in the subsequent samples. Exactly a year later colonization by similar species, which were recorded during the dredging and few months after dredging, were found. This probably was due to the more favourable conditions being established in the channel with time. It must be noted that the species recorded during dredging and a year after were very similar in terms of composition during the wet periods where environmental condition were in the tolerable ranges of the organisms. The abundance of the species showed both spatial and temporal variation. In the September 2001 samples, the abundance of *Tellina sp.* was high in station C and *Capitella capitata* and other Capitellids were high in station G (where highest species richness and diversity was recorded). This was due to the fact that sampling was done few days after dredging so most of the recorded species were still surviving. However, in September 2002, the abundant species occurred in stations C (though numbers and diversity varied with the previous year's results) and D. In this case the dominant species were *Notomastus* sp. *Capitella capitata* and *Tellina sp.* but station G did not record many species. It could also be realized that the dominant species in each instance were opportunistic species, able to tolerate stressful environments. This corroborates with findings by Hall, *et al.*, (1994) that a common consequence of high physical disturbance is a numerical reduction in non-opportunistic taxa

Temporal and spatial variability were observed in the physico-chemical parameters measured (e.g. salinity, total dissolved solids, total suspended solids and sulphate) in the channel (Figure 4. 18). However, these values fell within ranges measured elsewhere in the lagoon indicating that the effect of the dredging activities on the physico-chemical parameters within the study area was not significant. The only exception being the dredge spoils which created a very high turbid environment. Nevertheless, the impact on the benthos was measurably great as the substrates that served as habitats were continuously removed and obviously the first 8 months saw no colonization process in place

5.4 SEDIMENT DISTRIBUTION

The distribution of sediment in the Keta lagoon seemed to follow the hydrodynamic regimes. The effects of the wind (velocity, direction), currents, near-bottom shear stress, flow regimes, rainfall pattern, biological activities (bioturbation, vegetation) and anthropogenic activities in the lagoon may all contributed significantly to the pattern of sediment in the lagoon. These factors may help in understanding the sediment pattern in the lagoon and consequently the abundance and distribution pattern of macrofauna of the Keta lagoon.

The high amount of sand (over 80% of the area had sand with percent range of 80 to 98) observed in the Keta lagoon is indicative of high physical energy environment. This could possibly be the effect of the strong wind creeping over the shallow lagoon. This observation could also explain the high percentages of silt and clay observed at the peripheral stations of the lagoon.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATION

6.1 CONCLUSION

The analyses suggest that multiple environmental factors influence the distribution pattern of macrofauna in the Keta lagoon, depending on the season. This, further, is indicative of a high dynamic system, which is stressed especially during the dry season where organisms that could not cope were eliminated notably in the areas that dried up. The pattern was that of diversified populations with high species richness in the wet season, which changed to a more impoverished one in the dry season.

The following findings were made:

1. Significant differences were found in species richness and species diversity between the wet season and dry season.
2. Macrobenthic fauna community in the Keta lagoon was dominated by ten (10) dominant species. These were: *Tellina nymphalis, Nephthys sp.*, Bivalve indet. B, *Tivela tripla, Eunice sp.*, Capitellid indet A, *Ancistrosyllis robusta*, *Notomastus latericeus, Tivela bicolor,* and *Capitella capitata*.
3. A suite of several environmental variables appear to control the abundance and distribution of benthic macrofaunal community in the Keta lagoon (e.g. silt, clay, salinity, total dissolved solids, total suspended solids, turbidity, sulphate and silicate)..

4. In general, macrofauna assemblages in the Keta lagoon mimicked habitat heterogeneity created by the environmental conditions.

5. Sediment distribution in the Keta lagoon seems to follow the hydrodynamic regimes in the lagoon. Distribution and abundance of *Pseudopolydora* sp. and *Ischyroceros* sp. in the lagoon seemed to follow the distribution pattern of clay and silt.

6. The dredging activities did not impact much on the physico-chemical parameters in the study area, though it created a localized turbid environment that affected benthic macrofauna and fishes in general.

6.2 RECOMMENDATIONS

- Most lagoons are eco-complexes (e.g. Keta lagoon), containing more than one ecosystem: wetlands, marshes, sea grass fields, and pelagic systems. These systems are often modeled, and therefore allow prediction of the direction of future changes caused by natural processes as well as anthropogenic activities.

The sedimentary environment in a given area is, largely, the direct result of near-bed flow conditions. Factors such as larval supply and particulate flux that may be particularly important determinants of species distribution are controlled by hydrodynamic conditions. The observed sediment distribution of the Keta lagoon suggests a probable important role of hydrodynamics in the ecological functioning of the Keta lagoon. A study of the hydrodynamic conditions of the lagoon for a comprehensive understanding of the factors that structure the macrofaunal community in the Keta lagoon is therefore recommended..

- A long-term comprehensive study of the dredged channel created by the Keta Sea Defense project Work (KSDPW) and areas impacted by the work are recommended for study so as to determine the rate of colonization of the benthic macrofaunal community until reaching a stable community. However, the study must be holistic taking into consideration other biological communities.

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APPENDICES

Appendix **Page**

Appendix I

Field coordinates of the sampling stations in the Keta lagoon.

Station code	Field coordinates	
	Latitudes	Longitudes
A1	01^{0}00’39”	05^{0}58’55”
A2	01^{0}00’13”	05^{0}59’13”
A3	00^{0}59’48”	05^{0}59’34”
A4	00^{0}59’22”	05^{0}59’54”
A6	00^{0}58’30”	06^{0}00’33”
A7	00^{0}58’05”	06^{0}00’54”
A8	00^{0}57’39”	06^{0}01’14”
B1	01^{0}00’24”	05^{0}58’30”
B2	01^{0}00’00”	05^{0}58’50”
B3	00^{0}59’35”	05^{0}59’11”
B4	00^{0}59’12”	05^{0}59’32”
B5	00^{0}58’48”	05^{0}59’53”
B7	00^{0}57’58”	06^{0}00’33”
B8	00^{0}57’35”	06^{0}00’53”
B9	00^{0}57’09”	06^{0}01’14”
B10	00^{0}56’45”	06^{0}01’34”
B11	00^{0}56’18”	06^{0}01’55”
C1	01^{0}00’08”	05^{0}58’00”
C2	00^{0}59’44”	05^{0}58’22”
C3	00^{0}59’21”	05^{0}58’43”
C4	00^{0}58’55”	05^{0}59’06”
C5	00^{0}58’31”	05^{0}59’28”
C8	00^{0}57’15”	06^{0}00’30”
C9	00^{0}56’52”	06^{0}00’48”
C10	00^{0}56’29”	06^{0}01’09”
C11	00^{0}56’03”	06^{0}01’28”
D1	00^{0}59’51”	05^{0}57’29”
D2	00^{0}59’25”	05^{0}57’51”
D3	00^{0}59’00”	05^{0}58’10”
D4	00^{0}58’35”	05^{0}58’31”
D5	00^{0}58’10”	05^{0}58’51”
D6	00^{0}57’45”	05^{0}59’12”
D7	00^{0}57’19”	05^{0}59’32”
D8	00^{0}56’54”	05^{0}59’52”
D9	00^{0}56’28”	06^{0}00’12”
D10	00^{0}56’03”	06^{0}00’32”
E1	00^{0}59’30”	05^{0}57’05”
E2	00^{0}59’06”	05^{0}57’24”
E3	00^{0}58’40 “	05^{0}57’44”
E4	00^{0}58’15”	05^{0}58’04”
E5	00^{0}57’50”	05^{0}58’23”
E6*	00^{0}57’24”	05^{0}58’43”
E7	00^{0}56’58”	05^{0}59’02”
E8	00^{0}56’33”	05^{0}59’23”
E9	00^{0}56’08”	05^{0}59’42”
E10	00^{0}55’42”	06^{0}00’03”
E11	00^{0}55’15”	06^{0}00’24

F1	DREDGING	
F2	00^{0}58’48“	05^{0}56’55”
F3	00^{0}58’22”	05^{0}57’14”
F4	00^{0}57’56”	05^{0}57’34”
F5	00^{0}57’31”	05^{0}57’53”
F6	00^{0}57’05”	05^{0}58’11”
F7	00^{0}56’40”	05^{0}58’32”
F8	00^{0}56’14”	05^{0}58’53”
F9	00^{0}55’48”	05^{0}59’13”
F11	00^{0}54’57”	05^{0}59’54”
G1	DREDGING	
G2	00^{0}58’34”	05^{0}56’31”
G3	00^{0}58’11”	05^{0}56’53”
G4	00^{0}57’39”	05^{0}57’18”
G5	00^{0}57’13”	05^{0}57’37”
G6	00^{0}56’47”	05^{0}57’56”
G7	00^{0}56’23”	05^{0}58’16”
G8	00^{0}56’00”	05^{0}58’36”
G9	00^{0}55’35”	05^{0}58’57”
G10	00^{0}55’10”	05^{0}59’18”
G11	00^{0}54’44”	05^{0}59’38”
H0	00^{0}59’05”	05^{0}55’21”
H1	00^{0}58’41”	05^{0}55’40”
H2	00^{0}58’17”	05^{0}56’03”
H3	00^{0}57’52”	05^{0}56’24”
H4	00^{0}57’27”	05^{0}56’46”
H5	00^{0}57’03”	05^{0}57’05”
H6	00^{0}56’37”	05^{0}57’25”
H7	00^{0}56’10”	05^{0}57’46”
H8	00^{0}55’43”	05^{0}58’06”
H9	00^{0}55’15”	05^{0}58’27”
H10	00^{0}54’48”	05^{0}58’48”
H11	00^{0}54’20”	05^{0}59’10”
I0	00^{0}58’47”	05^{0}54’52”
I1	00^{0}58’23 “	05^{0}55’15”
I2	00^{0}58’00”	05^{0}55’36”
I3	00^{0}57’35”	05^{0}55’57 “
I4	00^{0}57’12”	05^{0}56’21”
I5	00^{0}56’48”	05^{0}56’44”
I6	00^{0}56’23”	05^{0}57’05”
I7	00^{0}55’57”	05^{0}57’28”
I8	00^{0}55’32”	05^{0}57’49”
I9	00^{0}55’07”	05^{0}58’10”
I10	00^{0}54’42”	05^{0}58’32”
I11	00^{0}54’17”	05^{0}58’53”
I12	00^{0}53’51”	05^{0}59’14”
J0	00^{0}58’30 “	05^{0}54’24”
J1	00^{0}58’04”	05^{0}54’45”
J2	00^{0}57’39”	05^{0}55’05”
J3	00^{0}57’14”	05^{0}55’26”
J4	00^{0}56’48”	05^{0}55’46”
J5	00^{0}56’22”	05^{0}56’07”

J6	00^{0}55’55”	05^{0}56’27”
J7	00^{0}55’30”	05^{0}56’48”
J8	00^{0}55’05”	05^{0}57’08”
J9	00^{0}54’40”	05^{0}57’29”
J10	00^{0}54’15”	05^{0}57’48”
J11	00^{0}53’51”	05^{0}58’09”
J12	00^{0}53’26”	05^{0}58’29”
J13*	00^{0}53’02”	05^{0}58’45”
K0	00^{0}58’12”	05^{0}53’57”
K1	00^{0}57’46”	05^{0}54’17”
K2	00^{0}57’20”	05^{0}54’39”
K3	00^{0}56’53”	05^{0}55’00”
K4	00^{0}56’29”	05^{0}55’21”
K5	00^{0}55’58”	05^{0}55’42”
K6	00^{0}55’31”	05^{0}56’03”
K7	00^{0}55’04”	05^{0}56’24”
K8	00^{0}54’38”	05^{0}56’45”
K9	00^{0}54’12”	05^{0}57’06”
K10	00^{0}53’45”	05^{0}57’27”
K11	00^{0}53’20”	05^{0}57’47”
K12	00^{0}52’53”	05^{0}58’06”
K13	00^{0}52’28”	05^{0}58’26”
L0	00^{0}57’56”	05^{0}53’26”
L1	00^{0}57’32”	05^{0}53’46”
L2	00^{0}57’06”	05^{0}54’05”
L3	00^{0}56’39”	05^{0}54’26”
L4	00^{0}56’12”	05^{0}54’48”
L5	00^{0}55’48”	05^{0}55’07”
L6	00^{0}55’23”	05^{0}55’26”
L7	00^{0}54’56”	05^{0}55’47”
L8	00^{0}54’30”	05^{0}56’09”
L9	00^{0}54’04”	05^{0}56’30”
L10	00^{0}53’36”	05^{0}56’51”
L11	00^{0}53’12”	5^{0}57’14”
L12	00^{0}52’44”	5^{0}57’33”
M-1*	00^{0}58’02”	05^{0}52’43”
M0	00^{0}57’41”	05^{0}52’59”
M1	00^{0}57’15”	05^{0}53’20”
M2	00^{0}56’48”	05^{0}53’41”
M3	00^{0}56’23”	05^{0}54’02”
M4	00^{0}55’58”	05^{0}54’23”
M5	00^{0}55’35”	05^{0}54’42”
M6	00^{0}55’08”	05^{0}55’03”
M7	00^{0}54’39”	05^{0}55’24”
M8	00^{0}54’13”	05^{0}55’44”
M9	00^{0}53’47”	05^{0}56’04”
N0	00^{0}57’35”	05^{0}52’28”
N1	00^{0}57’00”	05^{0}52’50”
N2	00^{0}56’34”	05^{0}53’12”
N3	00^{0}56’08”	05^{0}53’33”
N4	00^{0}55’41”	05^{0}53’54”
N5	00^{0}55’16”	05^{0}54’14”

N6	00^{0}54’48”	05^{0}54’36”
N7	00^{0}54’23”	05^{0}54’57”
N8	00^{0}53’57”	05^{0}55’18”
O-1	00^{0}57’39”	05^{0}51’42”
O0	00^{0}57’12”	05^{0}52’03”
O1	00^{0}56’43”	05^{0}52’25”
O3	00^{0}55’54”	05^{0}53’07”
O4	00^{0}55’20”	05^{0}53’28”
O5	00^{0}54’54”	05^{0}53’49”
O6	00^{0}54’30”	05^{0}54’10”
O7	00^{0}54’04”	05^{0}54’30”
O8	00^{0}53’39”	05^{0}54’51”
P-2*	00^{0}57’49”	05^{0}50’53”
P-1	00^{0}57’23”	05^{0}51’12”
P0	00^{0}56’56”	05^{0}51’32”
P1	00^{0}56’28”	05^{0}51’54”
P2	00^{0}56’03”	05^{0}52’16”
P3	00^{0}55’38”	05^{0}52’38”
P4	00^{0}55’09”	05^{0}53’00”
P5	00^{0}54’43”	05^{0}53’24”
P6	00^{0}54’15”	05^{0}53’45”
P7	00^{0}53’50”	05^{0}54’07”
P8	00^{0}53’23”	05^{0}54’26”
Q-2*	00^{0}57’28”	05^{0}50’24”
Q-1	00^{0}57’07”	05^{0}50’46”
Q0	00^{0}56’39”	05^{0}51’07”
Q1	00^{0}56’12”	05^{0}51’28”
Q2	00^{0}55’47”	00^{0}51’50”
Q3	00^{0}55’21”	05^{0}52’13”
Q4	00^{0}54’53”	05^{0}52’35”
Q6*	00^{0}53’54”	05^{0}53’29”
Q7	00^{0}53’35”	05^{0}53’45”
Q8*	00^{0}53’09”	05^{0}54’05”
R-1	00^{0}56’50”	05^{0}50’19”
R0	00^{0}56’23”	05^{0}50’38”
R1	00^{0}55’58”	05^{0}51’01”
R2	00^{0}55’33”	05^{0}51’22”
R7	00^{0}53’17”	05^{0}53’18”
R8	00^{0}52’50”	05^{0}53’40”
R9	00^{0}52’25”	05^{0}53’59”
S-1	00^{0}56’35”	05^{0}49’47”
S0	00^{0}56’09”	05^{0}50’10”
S1	00^{0}55’43”	05^{0}50’32”
S2	00^{0}55’17”	05^{0}50’54”
S3*	00^{0}54’51”	05^{0}51’12”
S7	00^{0}53’01”	05^{0}52’49”
S8	00^{0}52’32”	05^{0}53’13”
S9	00^{0}52’07”	05^{0}53’34”
T-1	00^{0}56’19”	05^{0}49’18”
T0	00^{0}55’54”	05^{0}49’40”
T1	00^{0}55’27”	05^{0}50’02”
T2	00^{0}55’00”	05^{0}50’25”
T3*	00^{0}54’44”	05^{0}50’45”

T8	00^{0}52’17”	05^{0}52’43”
U0	00^{0}55’39”	05^{0}49’12”
U1	00^{0}55’12”	05^{0}49’34”
U2	00^{0}54’45”	05^{0}49’55”
U3	00^{0}54’18”	05^{0}50’17”
U8	00^{0}52’00”	05^{0}52’16”
U9	00^{0}51’31”	05^{0}52’38”
V0*	00^{0}55’18”	05^{0}48’49”
V1	00^{0}54’57”	05^{0}49’09”
V2	00^{0}54’29”	05^{0}49’28”
V3	00^{0}54’00”	05^{0}49’49”
V4	00^{0}53’33”	05^{0}50’15”
V7*	00^{0}52’05”	05^{0}51’31”
V8	00^{0}51’47”	05^{0}51’47”
V9	00^{0}51’18”	05^{0}52’11”
V10	00^{0}50’51”	05^{0}52’34”
W1	00^{0}54’41”	05^{0}48’40”
W2	00^{0}54’09”	05^{0}49’01”
W3	00^{0}53’42”	05^{0}49’22”
W4	00^{0}53’15”	05^{0}49’44”
W5	00^{0}52’48”	05^{0}50’05”
W8	00^{0}51’31”	05^{0}51’22”
W9	00^{0}51’04”	05^{0}51’44”
X2	05^{0}53’56”	05^{0}48’36”
X3	05^{0}53’29”	05^{0}49’00”
X4*	05^{0}53’03”	05^{0}49’33”
X6*	00^{0}52’18”	05^{0}50’08”
X8	00^{0}51’13”	05^{0}50’54”

* Station less than 1 km before or after the next station on the transect.

STATION COORDINATES OF THE DREDGED CHANNEL

Station code	Field coordinates	
	Latitudes	Longitudes
A0	001^{0}00’58”	05^{0}58’35”
B0	001^{0}00’46”	05^{0}58’16”
C0	001^{0}00’28”	05^{0}57’46”
D0	001^{0}00’10”	05^{0}57’16”
E0	00^{0}59’49”	05^{0}56’46”
F0	00^{0}59’32”	05^{0}56’17”
G0	00^{0}59’17”	05^{0}55’54”

Appendix II

The Main Characteristics of Environmental Parameters For the Seasons

WET SEASON

arameters **arameter**	Mean MMean	Standard dev.	Range	
			Minimum	Maximum
epth (m)	0.72	0.13	0.47	0.94
alinity (ppt)	27.9	2.38	22.0	30.0
ater temperature (°C)	27.71	1.67	25.0	30.8
ir temperature (°C)	29.83	3.15	25.9	35.4
issolved oxygen (mgl^{-1})	6.34	0.39	5.81	7.25
H	8.15	0.10	7.95	8.30
onductivity (mS)	35.86	1.29	33.4	38.0
urbidity (FAU)	110.0	78.33	8.0	303
otal suspended solids (mgl^{-1})	74.50	55.95	6.0	214
otal dissolved solids (mgl^{-1})	20786	1304.37	18900	24000
ransparency (m)	0.42	0.15	0.23	0.68
itrate (mgl^{-1})	0.33	0.13	0.1	0.6
Phosphate (mgl^{-1})	0.27	0.12	0.06	0.56
ulphate (mgl^{-1})	2887.50	284.17	2450	3450
ilicate (mgl^{-1})	9.47	4.06	3.3	20.8
Clay (%)	10.32	4.35	4.25	19.25
ilt (%)	11.21	8.64	1.50	40.92
Sand (%)	78.46	11.32	42.82	91.17
Sulphur (%)	0.0923	0.0744	0.0008	0.2404
rganic matter (%)	0.7680	0.5366	0.3008	2.6160

DRY SEASON

Parameters **Parameter**	Mean Mean	Standard dev. dedeviation	Range	
			Minimum	Minimum
Depth (m)	0.30	0.12	0.05	0.5
Salinity (ppt)	61.8	25.13	27.0	93.0
Water temperature (°C)	30.93	1.85	28.20	33.9
Air temperature (°C)	29.96	6.54	26.0	33.01
Dissolved oxygen (mgl^{-1})	6.09	0.45	4.94	6.76
PH	8.42	0.13	8.2	8.64
Conductivity (mS)	67.87	24.56	32.8	101.3
Turbidity (FAU)	69.20	68.14	6.0	224.0
Total suspended solids (mgl^{-1})	46.25	48.18	2.0	157.0
Total dissolved solids (mgl^{-1})	47879	20734.3	18500	78000
Transparency (m)	0.26	0.10	0.05	0.50
Nitrate (mgl^{-1})	1.07	0.26	0.30	1.3
Phosphate (mgl^{-1})	0.20	0.07	0.11	0.34
Sulphate (mgl^{-1})	6948.68	3162.21	2150	10750
Silicate (mgl^{-1})	5.83	1.75	3.4	8.7
Clay (%)	11.65	4.63	5.50	24.25
Silt (%)	9.86	8.58	0.52	38.77
Sand (%)	78.48	10.25	46.22	90.67
Sulphur (%)	0.0825	0.0739	0.0074	0.2923
Organic matter (%)	0.4445	0.2366	0.1839	1.0495

Appendix III

PCA scores for the first three axes for the wet season and the dry season

Wet season

Sample	**SCORE1**	**SCORE2**	**SCORE3**
%CLAY	-0.357	-0.629	0.231
%SILT	-0.256	-0.975	1.232
%SAND	-6.043	-0.381	-0.772
DEPTH	4.815	0.255	0.027
pH	0.063	-0.139	-0.265
SALINITY	-3.206	-0.529	-0.459
TURBIDITY	-6.144	1.476	0.643
NITRATE	5.555	0.231	-0.266
PHOSPHATE	5.691	0.375	-0.080
SILICATE	-0.118	0.316	-0.292

Dry season

Sample	**SCORE1**	**SCORE2**	**SCORE3**
%CLAY	-0.758	-0.275	-0.172
%SILT	0.135	-0.247	1.737
%SAND	-6.113	0.723	-0.332
DEPTH	5.510	0.000	-0.109
pH	-0.106	0.356	-0.141
SALINITY	-5.240	1.596	0.044
TURBIDITY	-4.271	-2.481	-0.274
NITRATE	4.199	0.427	-0.240
PHOSPHATE	5.738	0.072	-0.263
SILICATE	0.907	-0.171	-0.252

Appendix IV

SIMPER analysis showing the similarities for the wet season and dry season and the contributions of each species to the average similarities.

Average similarity within the wet season: 46.10

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Tellina nymphalis	17.90	11.10	1.95	24.08	24.08
Nephthys hombergi	10.60	5.97	1.21	12.95	37.04
Tivela spp.	9.60	5.67	1.24	12.29	49.33
Notomastus spp.	6.00	3.83	0.92	8.31	57.63
Tivela bicolor	5.90	3.05	0.78	6.62	64.25
Capitellid	5.65	2.93	0.71	6.36	70.61
Marphysa sanguinea	2.70	2.60	0.60	5.65	76.25
Ancistrosyllis robusta	2.25	2.18	0.48	4.74	80.99
Capitella capitata	1.90	1.58	0.53	3.43	84.42
Hirudinean	1.20	1.39	0.54	3.02	87.44
Heteromastus spp.	1.85	1.38	0.48	3.00	90.44
Nereis sp. B	1.70	1.27	0.39	2.75	93.19
Diplodonta spp.	2.85	1.12	0.46	2.44	95.63
Bivalve indet C	0.60	0.69	0.33	1.50	97.13
Bivalve indet. B	0.85	0.28	0.23	0.60	97.73
Tympanotonus spp.	0.45	0.27	0.23	0.58	98.32
Polydora sp.	1.75	0.19	0.18	0.40	98.72
Ischyroceros sp.	0.25	0.16	0.18	0.34	99.06
Anadara senilis	1.25	0.14	0.13	0.29	99.36
Neanthes spp.	0.70	0.10	0.12	0.22	99.57
Polychaete A	0.10	0.05	0.07	0.12	99.69
Bivalve indet. A	0.25	0.04	0.07	0.09	99.78
Crustacean indet.	0.10	0.04	0.07	0.08	99.87
Mysid sp.	0.10	0.04	0.07	0.08	99.95
Nereis indet. A	0.25	0.02	0.07	0.05	100.00

Average similarity within the dry season: 27.47

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Tivela spp.	6.45	6.31	0.66	22.96	22.96
Bivalve indet. B	1.40	6.03	0.33	21.96	44.93
Capitellid	2.90	3.20	0.52	11.65	56.58
Tellina nymphalis	3.45	2.32	0.34	8.44	65.01
Capitella capitata	1.90	2.26	0.40	8.21	73.23
Tivela bicolor	2.05	1.62	0.40	5.89	79.12
Notomastus spp.	1.95	1.42	0.40	5.16	84.27
Marphysa sanguinea	2.00	1.30	0.31	4.73	89.00
Anadara senilis	0.85	0.83	0.23	3.03	92.02
Bivalve indet. C	0.45	0.58	0.20	2.10	94.13
Ancistrosyllis rubosta	0.85	0.53	0.21	1.91	96.04
Nereis indet. A	1.45	0.29	0.18	1.06	97.09
Heteromastus spp	0.25	0.27	0.17	0.97	98.07
Nephthys hombergi	0.45	0.23	0.18	0.85	98.92

Nereis indet. B	1.95	0.12	0.13	0.45	99.37
Neanthes spp.	0.55	0.09	0.13	0.33	99.70
Hirudinean	0.40	0.06	0.07	0.22	99.92
Diplodonta sp.	0.55	0.02	0.07	0.08	100.00

Appendix V

SIMPER analysis results: species contributing to the average Bray-Curtis dissimilarity between the wet season and dry season.

Average dissimilarity between the wet season and the dry season = 70.35

Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Tellina	17.90	3.45	6.71	1.21	9.54	9.54
Nephthys hombergi	10.60	0.45	5.45	1.33	7.75	17.29
Bivalve indet. B	0.85	1.40	5.02	0.74	7.14	24.43
Tivela	9.60	6.45	4.82	1.16	6.85	31.28
Marphysa sanguinea	2.70	2.00	4.00	1.01	5.68	36.96
Capitellid	5.65	2.90	3.95	1.06	5.61	42.58
Ancistrosyllis rubosta	2.25	0.85	3.94	0.77	5.60	48.17
Notomastus spp.	6.00	1.95	3.92	1.18	5.57	53.74
Tivela bicolor	5.90	2.05	3.72	1.12	5.28	59.02
Capitella capitata	1.90	1.90	3.61	1.00	5.13	64.15
Nereis indet. B	1.70	1.95	2.86	0.81	4.07	68.22
Heteromastus spp.	1.85	0.25	2.61	0.91	3.71	71.94
Bivalve indet.. C	0.60	0.45	2.60	0.77	3.69	75.63
Hirudinean	1.20	0.40	2.53	0.94	3.59	79.22
Diplodonta spp.	2.85	0.55	2.32	0.85	3.30	82.52
Anadara senilis	1.25	0.85	2.32	0.66	3.30	85.82
Nereis indet. A	0.25	1.45	1.36	0.57	1.93	87.75
Neanthes sp.	0.70	0.55	1.23	0.55	1.75	89.50
Polydora sp.	1.75	0.00	1.03	0.47	1.47	90.96
Tympanotonus spp.	0.45	0.00	1.02	0.55	1.45	92.41
Ischyroceros spp.	0.25	0.00	0.75	0.48	1.06	93.47
Polychaete indet. A	0.10	0.00	0.66	0.32	0.94	94.42
Bivalve indet. A	0.25	0.00	0.66	0.30	0.94	95.36
Mysid sp.	0.10	0.00	0.63	0.29	0.90	96.26
Crustacean indet.	0.10	0.00	0.53	0.32	0.76	97.02
Orbinid	0.05	0.30	0.39	0.32	0.55	97.57
Echelus myrus	0.10	0.00	0.38	0.22	0.54	98.11
Anemone sp.	0.15	0.00	0.19	0.23	0.26	98.37
Pseudopolydora spp.	0.05	0.00	0.18	0.23	0.25	98.63
Malacoceros spp.	0.05	0.00	0.18	0.23	0.25	98.88
Nemertine	0.05	0.00	0.18	0.23	0.25	99.14
Dispio spp.	0.10	0.00	0.17	0.23	0.24	99.37
Pachymelania sp.	0.05	0.00	0.15	0.23	0.21	99.58
Polychate indet. B	0.05	0.00	0.15	0.23	0.21	99.79
Polychate indet. D	0.05	0.00	0.15	0.23	0.21	100.00

Appendix VI

Summary of results of ANOVA

Species richness

Source of variation	SS	df	MS	F	P-value	Fcrit.
Station x Seasons	12.20655	19	0.64245	1.266414	0.306512	3.027367
Season x Season	10.35909	1	10.35909	20.40397	0.000236	8.184998
Error	9.646293	19	0.5077			
Total	32.21193	39				

Significant level 99%

Species diversity

Source of variation	SS	df	MS	F	P-value	Fcrit.
Station x Seasons	8.165583	18	0.453643	1.231961	0.331406	3.128008
Season x Season	4.607549	1	4.607549	12.51273	0.002353	8.285497
Error	6.628119	18	0.368229			
Total	19.40125	37				

Significant level 99%

Species richness

Source of variation	SS	df	MS	F	P-value	Fcrit.
Between season	10.35909	1	10.35909	18.01347	0.000136	4.098169
Within station	21.85284	38	0.57075			
Total	32.21193	39				

Significant level 95%

Species diversity

Source of variation	SS	df	MS	F	P-value	Fcrit.
Between season	3.189461	1	3.189461	7.995442	0.007612	4.113161
Within station	14.36076	36	0.39891			
Total	17.55022	37				

Significant level 95%

Appendix VII

Benthic macrofauna Data of Keta Lagoon

WET SEASON

SPECIES	A1	A2	C3	C4	E4	E5	F3	G2	G3	G4	G5	G6	G7	O-1	O0	Q-1	Q0	S0	S1	S2
Notomastus	1	9	1	1	7	0	14	0	2	17	7	21	22	3	13	0	0	0	0	2
Heteromastus	0	3	2	0	2	0	0	0	0	3	5	8	8	0	5	0	0	0	1	0
Capitella capitata	2	2	0	4	4	5	1	0	0	3	1	4	12	0	0	0	0	0	0	0
Capitellid	0	14	0	0	9	0	8	0	1	4	11	24	22	1	11	0	0	0	4	4
Nepthys	16	13	21	20	23	41	11	1	4	3	2	23	25	0	4	0	0	2	0	3
Orbinid	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Nereis A	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	0	0
Nereis B	0	0	0	0	0	0	2	2	2	0	0	0	0	10	3	0	0	3	1	11
Neanthes sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	9
Syllid	2	0	0	0	0	0	4	0	0	0	0	1	0	3	12	1	1	8	3	10
Hirudinean	5	3	1	0	0	2	6	0	2	1	0	1	0	0	1	0	0	0	2	0
Polydora sp.	16	0	0	0	0	1	11	0	0	0	0	0	7	0	0	0	0	0	0	0
Pseudopolydora	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dispio sp	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Malacoceros	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertine	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poly. A	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Poly. B	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Poly. D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Eunice	1	0	0	0	0	0	6	0	3	3	4	0	0	5	17	2	0	2	5	6
Tellina	8	6	4	0	9	17	44	26	1	19	20	60	63	29	11	8	1	9	12	11
Tivela	7	9	15	1	14	14	12	0	2	1	8	49	27	12	16	0	0	0	4	1
Tivela bicolor	0	1	7	2	13	3	12	1	0	1	5	50	21	1	1	0	0	0	0	0
Anadara senilis	0	8	12	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corbula	0	0	0	0	1	1	5	1	0	3	3	2	1	0	40	0	0	0	0	0
Bivalve A	0	0	0	3	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalve B	0	2	0	0	1	12	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Bivalve C	4	0	3	0	0	0	0	0	0	0	1	1	0	0	1	1	0	0	1	0
Tympanolonus	1	4	2	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Pachymelania sp	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Mysid sp.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Ischyroceros sp	1	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Crustacean indet.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Echelus myrus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Anemone sp.	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix VII

Benthic macrofauna Data of Keta Lagoon

DRT SEASON

SPECIES	AA1	AA2	CC3	CC4	EE4	EE5	FF3	GG2	GG3	GG4	GG5	GG6	GG7	OO-1	OO0	QQ-1	QQ0	SS0	SS1	SS2
Nolomastus	0	0	0	0	0	2	0	4	0	0	11	10	3	2	4	0	0	0	0	3
Heteromastus	0	0	0	0	0	0	1	0	0	0	2	0	1	1	0	0	0	0	0	0
Capitella capitata	0	0	0	0	1	15	0	1	5	1	7	5	3	0	0	0	0	0	0	0
Capitellid	0	0	0	0	0	0	0	0	3	1	11	13	9	7	6	0	2	0	2	4
Nepthys	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	1	3
Orbinid	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0
Nereis A	0	0	0	0	0	0	0	0	0	0	0	0	0	14	4	0	1	0	0	10
Nereis B	0	0	0	0	0	0	0	0	0	0	0	0	0	28	3	0	0	0	0	8
Neanthes sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	8	1	0	0	0	0	2
Sylid	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	1	0	0	3	8
Hirudinean	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	7
Polydora sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudopolydora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dispio sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Malacoceros	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nemertine	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poly. A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poly. B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poly. D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eunice	0	0	0	0	0	0	0	0	0	0	1	0	0	10	8	0	12	1	6	2
Tellina	0	0	0	0	0	0	0	0	0	0	1	0	0	10	10	9	3	4	13	19
Tivela	0	0	0	0	7	18	3	13	2	3	9	27	22	10	13	0	0	0	2	0
Tivela bicolor	0	0	0	0	1	5	0	1	0	0	2	13	9	5	5	0	0	0	0	0
Anadara senilis	0	0	0	0	0	6	0	7	0	1	0	2	0	0	0	1	0	0	0	0
Corbula	0	0	0	0	0	0	0	0	0	0	0	0	0	1	10	0	0	0	0	0
Bivalve A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bivalve B	1	1	1	1	0	4	0	3	0	0	2	8	0	6	1	0	0	0	0	0