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SPATIAL DISTRIBUTION OF SUSPENDED PARTICULATE MATTER (SPM) IN MTWAPA CREEK AND FUNZI BAY - KENYA

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Abstract

Surface water concentrations of inorganic nutrients and suspended particulate matter (SPM) components were examined and compared between Mtwapa and Shirazi creeks in Kenya. This was aimed at assesing the ecological situation of the two creeks and determine the influence of sewage discharge. The results obtained were further compared with those from Ramisi, an estuarine system. Mtwapa recorded higher nutrient, chlorophyll *a* and phytoplankton carbon concentrations than Shirazi. The two creeks also recorded different phytoplankton stocks and groups. Dinoflagellates dominated Mtwapa in the stations within the vicinity of sewage discharge points whereas Shirazi was dominated by pennate and centric diatoms, though at lower concentrations. Shirazi recorded the highest particulate organic carbon (POC) / phytoplankton carbon ratio. The Ramisi estuarine stations were characterised by high concentrations of dry weight (DW), centric diatoms, phytoplankton carbon, detritus and POC. Cluster analysis revealed three main clusters; the first cluster of pure estuarine stations, a second cluster comprised of stations from Mtwapa and Shirazi and a third cluster of two Mtwapa stations which were located within the vicinity of sewage discharge points. A PCA sites scatter plot produced similar clusters. A PCA species-sites biplot showed that stations in the first cluster were characterised by high concentrations of phytoplankton carbon, centric diatoms, DW, POC and detritus, 'species' which were highly correlated with axis 2; stations in the second cluster were characterised by high concentrations of POC / phytoplankton carbon ratio whereas stations in the third cluster were characterised by high concentrations of dinoflagellates, a 'species' which was highly correlated with axis 1. The three systems however had detritus as the main POC component contributing above 60% of the total POC.

Dedication

To my lovely parents and
all my teachers.

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CHAPTER ONE
INTRODUCTION

1.1. The Kenyan coastal zone

The Kenyan coastal zone is characterised by mangrove forests along creeks, bays and estuaries, seagrass beds, lagoons and coral reefs (UNEP, 1998). These three ecosystems ecologically interact for they are interlinked by tidal water movements. Like most coastal and marine environments, the coastal zone is endowed with abudant natural resources and is rich in biodiversity. These resources have been skillfully and at other times unskillfully exploited by the communities around. Increased human economic and recreational development activities as well as demographic changes have led to increasing environmental stresses such as pollution, eutrophication and erosion.

Kenyan coastal economy is primarily dependent on marine based industries, commerce, harbours, maritime activities and most importantly, on the vibrant tourism industry. As a result of the rapid growth of the tourist industry, the coastal area has experienced a tremendous increase in human population, partly due to immigration for employment opportunities.

The coastal zone has also experienced a lot of physical developments. Due to increase in population and holiday makers, there has been a lot of investment in hotel establishments and residential quarters. This has resulted in increased volume of solid and liquid waste. Unfortunately, there has been no commensurate increase in provision of social ammenities such as a centralised sewage treatment system and disposal. Thus most of the establishments rely on septic tanks/soakage pits. Consequently, sewage from these establishments find its way into the marine environment directly through discharge or indirectly through seepage especially where disposal systems are close to the shore.

Oil pollution, dredging and dredge-spoil dumping have also been reported along the Kenyan coast (Mwangi *et al.*, 1998).

There is a conspicous scarcity of scientific information on the extent of contamination of the coastal waters and any available information is sporadic and somehow inadequate. Some earlier studies include:

- Munga *et al.,* (1994) showed that 18% of [1]BOD_5 load to Mombasa coastal waters was contributed by domestic sewage from both the town and beach hotels. It was also shown that storm runoff contributed 30% of all nitrogenous wastes.

- Mwangi (unpublished) found faecal coliforms and *E. coli* in the inshore waters of Tudor creek and Port Reitz indicating direct or indirect sewage disposal.

- Norconsult (1975) is a pollution overview around Mombasa town which considered deep sea outfall hydrodynamic dispersal mechanisms. However it only considers floatables from sewage and the possibility of their dispersion and dilution by nearshore wind induced currents if the sewage is disposed of at the deep sea outfalls.

- Mwangi *et al.,* (1998) did some work on the status of marine pollution in Mombasa Marine Park and Reserve and Mtwapa Creek. They found that due to the hydrodynamic regime (flushing time of 30 hrs and of 60% of the lagoon water), spatial and temporal concentration of nutrients, chlorophyll *a* and BOD in the lagoon (Marine Park) do not reach eutrophic levels. However, during the rainy season, the concentrations of nutrients, biologically oxidizable material, faecal contamination and phytoplankton were high in Nyali and Shanzu surrounding areas due to hyrodynamic influence from adjacent creeks. Mtwapa creek was found to be eutrophied as a result of point sources of raw sewage discharge, underground seepage and surface water runoff. Occasionally bacteria levels in the lagoon water reached 1800/100ml and 1600/100ml for feacal coliforms and *Escherichia coli* respectively. The EEC guide limit for recreational water is 100/100ml. This is a clear indication of anthropogenic discharge of raw sewage. Furthermore the ratio of faecal coliform to faecal *Streptococci* (FC/FS) is

[1] BOD_5 (Biological Oxygen Demand) oxygen consumed during bacterial oxidation of organic matter.

commonly used to evaluate the origin of faecal pollution whether from domestic or industrial sewage. A ratio of 4.0 or higher indicates domestic waste (human faecal pollution) whereas ratios of 0.6 or lower are typical for stormwater runoff or discharges from farm animals (Mwangi *et al*., 1998).

It is this limited literature on marine pollution of Kenyan coastal waters which influenced this study. It is intended to add on the existing information on the effect of eutrophication on Mtwapa creek by considering the levels of particulate organic carbon and its main constituents. By comparing Mtwapa creek with the relatively natural Shirazi creek, some information on the effects sewage discharge has on the ecological situation of the creek will at least be elucidated. This will be achieved by measurement of suspended matter as dry weights, particulate organic carbon (POC), phytoplankton carbon, chlorophyll *a* and nutrients. It is expected that both creeks will exhibit different levels of these variables since they are impacted differently by human activities.

1.2. Literature Review

Suspended in all natural waters and at the interface of the water with the bottom are assemblages of small particles of different sizes and shapes making up what is called seston or suspended particulate matter (SPM). These are derived directly or indirectly from the production of living populations (Pomeroy, 1980). There is no definition which adequately describes the real nature of this mixed particles (Parsons *et al.*, 1973) (figure. 1.21). However this particulate mixture is the basis of life in aquatic ecosystems. Considering a simplified model of a pelagic food web (figure. 1.22), there is clear evidence that these small particles are the main players in the pelagic carbon cycling of aquatic ecosystems (Billiones, 1998).

1.2.1. The different components of SPM

In order to understand the trophodynamics of aquatic ecosystems, it is important to classify SPM based on the role it plays in the system. Different SPM components occupy different niches and functions. The living components act as producers or consumers, prey or predator and decomposers. The non-living fraction serves as food, substrate and habitats.

The living components of SPM are the planktonic organisms. Plankton refers to those organisms which drift passively with the water movement (Mann *et al*, 1980). The phytoplankton are the most common autotrophs in the aquatic ecosystem. They contribute to a large portion of primary production. They are arbitrarily categorised according to size. Net plankton are those retained by a 20 µm mesh size whereas those which pass through the net are called nanoplankton. There also exists ultrananoplankton < 5µm (Mann *et al*, 1980).

Primary production in the ocean is mainly by living particles within the size range of 1 - 20 µm. Moreover, microorganisms less than 100 µm account for majority of the biological activity in the water column, hence making big organisms of less importance in the energy cycling of aquatic systems. (Billiones, 1998).

The zooplankton are organisms in the size range of 20 µm to 20 mm. Also based on size they are grouped into several categories. Microzooplankton have a size range

between 20 - 200 µm and the mesozooplankton ranges between 200 µm to 1 mm. These are considered as part of SPM. The zooplankton is an important link between the primary producers and the higher trophic levels in marine and fresh water ecosystems (Billiones, 1998).

In the lower size range of the living SPM component are the bacteria whose size range is less than or 1 µm. These are important actors in the microbial food web. Also part of SPM are cyanobacteria which contribute to primary production.

The majority of non living portion of SPM is composed of detritus. In many ecosystems both terrestrial and aquatic, as much as 90% of primary plant production goes to the detritus food web (Mann *et al.,* 1980). In aquatic environments, 20-80% of SPM mass are detritus.

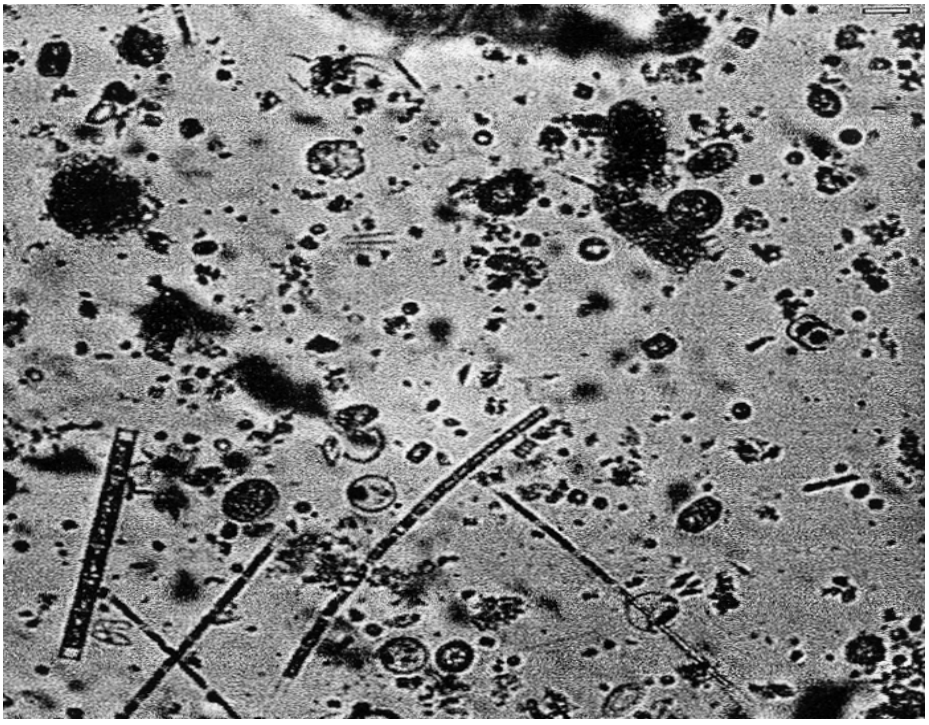


Fig. 1.21: A microscopic view of suspended particulate matter (SPM). Calibration bar = 20 µm (Billiones, 1998)

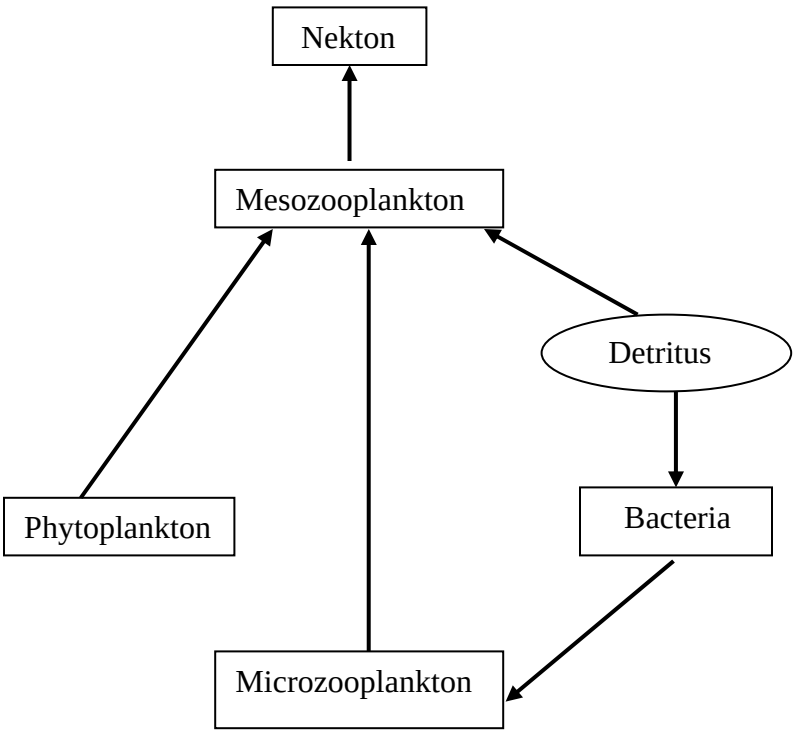


Fig. 1.22: A simplified model of the pelagic foodweb. All compartments except nekton are components of SPM (Billiones, 1998).

It is estimated that there is 10^{13} kg of detritus in the ocean which is about five times the mass of phytoplankton (Billiones, 1998). This does not however go into waste since detritus is a very important energy source for the pelagic and microbial food webs and a source of food for benthic communities. It has been shown that detritus does interconnect the microbial food web with the grazing food web and that a substantial flow of energy and materials from detritus to higher level consumers does exist (Mann *et al.,* 1980).

Detritus can be categorised into two functional groups; primary detritus derived from plant material and secondary detritus which is a product of consumption processes of aquatic fauna. Primary detritus are those which have not yet been ingested whereas secondary detritus are the by-products of ingestion and include feacal pellets, molts, as well as leftovers from sloppy feeding and regurgitation (Mann *et al.*, 1980).

1.2.2. Sources of detritus

The great bulk of detritus originates directly or indirectly from plant biomass. Animal biomass is also included though its contribution is minimal. In large water bodies, most of the detritus is derived from aquatic plants. However, since all water bodies have a water shed, a terrestrial component exists in aquatic detritus. In some cases like small forest streams, this terrestrial component accounts for about 99% of the detritus (Pomeroy, 1980). Terrestrial dust, effluents of manufacturing processes and discarding of manufactured products into aquatic systems also form part of the terrestrial detritus component (Wangersky, 1977).

In the larger water bodies such as oceans (mainly in the coastal zone), the major source of detritus is the vegetation growing in the water. These include attached macrophytes, algae and higher plants and the phytoplankton floating in the water. In lakes having regions of shallow water, in slowly flowing rivers and in estuaries, attached macrophytes make the major contribution of detritus since they are the major producers of plant biomass. Emergent, floating freshwater plants, due to their rapid growth, are a major source of detritus in freshwater ecosystems. The process of detritus formation from living macrophytes is a continuous one since as growth takes place, some vegetative parts die and disintergrate (Pomeroy, 1980).

The process of detritus formation in aquatic environments is accelerated by the physical processes of waves and the biological processes of grazing. Waves break parts of or entire plants. Grazers in aquatic systems are as inefficient as other animals, oftening wasting more than they consume, but contributing to the supply of detritus. As grazers, zooplankton are messy and finicky thus phytoplankton cells break during grazing and are lost as detritus (Pomeroy, 1980).

Due to size specificity of zooplankton grazers, larger cells are ussually crumbled and partially wasted. Moreover some phytoplankton species are noxious hence they are selectively avoided. They grow till depleted of nutrients, die and are degraded to detritus by microorganisms (Pomeroy, 1980).

Apart from death, some zooplankton such as appendicularians and pteropods produce gelatinous materials into the surface water as part of their normal activities.

These materials can account for extremely high local particulate organic carbon in the surface waters (Wangersky, 1977).

Dissolved organic compounds from plants also indirectly contribute to detritus production. Growth and death of macrophytes and phytoplankton is accompanied by loss of dissolved organic compounds like glycollate, glucose, other monosaccharides and amino acids (Pomeroy, 1980). These dissolved or colloidal materials are not lost but are scavenged by bacteria which are attached to detritus. They can also become adsorbed on free surfaces like bubbles, solid objects and probably existing aggregates in seawater and get transformed by bacterial activity into various forms of detritus (Gordon, 1963; Gordon *et al.,* 1964; Menzel *et al.,* 1966; Wangersky, 1977). This adsorption of dissolved organic matter and the subsequent colonization by bacteria increases the nutritive value of detritus. Thus detritus particles serving as substratum for bacteria forms a means by which dissolved organic substances re-enter the food chain. Therefore, the ingestion of detritus by grazers is instrumental in increasing the effectiveness of energy transfer along the aquatic food chain (Lenz, 1977). Even in areas where phytoplankton is scarce, there is sufficient residue of older dissolved organic matter to promote significant quantities of aggregates (Gordon *et al.,* 1964). Dissolved organic matter (DOM) affects the character and functioning of aquatic ecosystems and is a major resevoir of organic carbon. DOM originates from terrestrial input (allochthonous material) as well as from indegenous primary production (autochthonous material) (Stefan *et al.*, 2000).

Faeces production especially from grazers is a secondary source of detritus. About 10 to 50 % of plant material consumed by grazers is usually not digested but is voided as faeces or pseudofaeces. Pseudofaeces are those materials deliberately sorted out and rejected either during feeding or in the stomach (Pomeroy, 1980). The faeces being partially digested are a rich source of both dissolved and particulate matter mixed with an innoculum of bacteria. Since many organisms encase or compact faecal matter, the faeces tend to sink relatively rapidly taking detritus to the bottom. The accumulated faeces at the bottom are a major source of nutrition to benthic communities (Pomeroy, 1980).

Tidal wetlands like mangrove swamps and saltmarshes also contribute to detritus production. Their contribution however depends on whether they are net exporters or importers of particulate matter. Their export or import is dictated by factors such as the

geomorphology of the wetland drainage basin, the tidal amplitude and the magnitude of freshwater input to the drainage basin (Odum *et al.,* 1978). The presence of mangrove swamps influences water circulation through the maintenance of self scouring deep drainage channels (Kitheka, 1997; Furukawa *et al*., 1997). These drainage channels if characterized by tidal asymetry i.e stronger ebb flows than flood flows, coupled with the occurrence of dense mangrove vegetation, tend to promote the seaward transport of organic matter and nutrients. The flow of water from the mangroves into sea grass zone and eventually into the coral reef promotes the interchange of nutrients and organic matter and also promotes the ecological interaction between the three ecosystems which can therefore be considered to be interlinked. The degree of interlinkage depends however on hydrodynamic processes operating in the coastal waters (Kitheka, 1997).

Mangrove forests are among the most productive natural ecosystems. Due to their location, in river estuaries and along the coast, mangrove trees can be said to be links between terrestrial and marine ecosystems. Through litter fall, and subsequent decomposition, nutrients are returned into the aquatic system and utilised by primary producers. The rates of decomposition of mangrove leaf litter depends on the leaching of water soluble substances, microbial action and the breakdown by macro-invertebrates (Chale, 1992).

A fraction of SPM also exists as a mixture of unidentifiable particles occuring singly or as part of aggregates. Mel'nikov (1976) classified particles as flocs, aggregates and fragments. *In situ*, particulate matter occur as macroflocs, microflocs (fragmented macroflocs), and single grains. Aggregates consist of two or more individual particles bound by strong chemical bonds thus they remain structurally stable during handling (Billiones, 1998). Aggregates are the most widespread group of particles in detritus occuring in the entire water collumn from surface to the greatest depths. Flocs are formed by loosely bound particles which break up on shaking or stirring but which reform immediately on standing. They are mostly large particles which are distributed mainly in the top layers of the euphotic zone (Mel'nikov, 1976). Resuspended sediments also form part of SPM in shallow areas like estuaries and coastal zones where turbulence is high.

Anthropogenic activities can influence the levels of suspended particulate matter in aquatic ecosystems through waste dumping and sewage discharge. These activities lead

to elevated particulate matter and nutrient levels which promote phytoplankton growth or inhibit their growth if the particulate matter leads to increased turbidity. Increased turbidity reduces light penetration which reduces primary production. Increased phytoplankton growth increases the phytoplankton carbon and consequently the particulate organic carbon (POC) of the affected system.

1.2.3. Ecological significance of SPM

Apart from its role in the trophic relations of aquatic ecosystems, SPM has other ecological significance. SPM can be an important environmental factor affecting biological and physico-chemical processes. High levels of SPM is a limiting factor to primary production in turbulent turbid areas due to its impedance of light transmission. In many water masses, a very good correlation exists between the amounts of suspended organic and inorganic matter and the extinction coefficients, if the material involved is of a uniform quality. For different types of water, these correlations may be different and in this way extinction measurements can be a useful tool for the distinction and classification of water bodies (Postma, 1961).

Suspended particle concentration effect (PCE) is an important factor influencing the bioconcentration and bioaccumulation of organic pollutants in aquatic systems. When a contaminant becomes associated with SPM or sediment, the particle dynamics becomes more important in determining the fate of the contaminant than water movement. Large scale transport patterns of these particles may concentrate contaminants in specific areas remote from their point of introduction (Lindsay *et al*., 1996).

SPM may be a source or sink of carbon. Labile fractions of detritus from terrestrial plants and from dead planktonic organisms are easily degraded by microorganisms and may be an important source of dissolved organic carbon (DOC). Contrally, the refractory portion (portion not degraded) stays in the system and accumulates. These can be exported in dynamic systems like estuaries and rivers (Billiones, 1998).

A correlation exists between the productivity of a water mass in the open ocean and its content of particulate matter. Except in cases of upwelling and the spring blooms in temperate and boreal waters, the productivity of the open oceans is largely governed by the rate of nutrient regeneration in surface waters. This regeneration is a function of the

number of actively metabolizing bacteria present, which inturn is a function of the particle content of the water. Thus particle concentration may be the basic control on the productivity of open oceans (Wangersky, 1977).

Given that small auto- and heterotrophic organisms are prevalent in the small water samples filtered at sea, these organisms generally dominate the sestonic particulate organic carbon. Consequently aquatic ecologists have used the measure of this sestonic organic carbon as corresponding to the food that can be ingested by mesozooplankton (Lengendre *et al*, 1999).

1.2.4. SPM from different viewpoints

Different study fields have different definitions of SPM producing different classifications. For operational purposes, particles in aquatic ecosystems can be classified based on sizes. Particles retained by a 0.45 µm filter are considered as particulate whereas those which pass through are said to be dissolved. There however exists no clear cut demarcation of particle sizes but a continuum of sizes. Particles sizes ranging from 0.45 µm to a few millimetres covering unicellular organisms and mesozooplankton, the major players in carbon cycling, are considered in seston studies (Billiones, 1998).

Considering sources, SPM can be classified as either autochthonous or allochthonous. Autochthonous particulate matter is derived from within a system whereas allochthonous originates from outside a system. Autochthonous sources include planktonic organisms , their remains and faeces (Lenz, 1977) whereas the allochthonous component is from land, air or if considering estuaries, from the sea or the river and consists of transported plankton and detritus.

SPM can also be viewed as living or non-living. The living component consists of bacteria, protists, phytoplankton and zooplankton. The non-living component consists mainly of detritus derived directly or indirectly from the living organisms (Billiones, 1998). The different components show variations in concentration and proportions in different systems. In estuaries and coastal zones, the bulk of the organic particulate matter is detritus, commonly with a mass hundred times that of the living component (Pomeroy, 1980). In the open ocean however, the living component dominates (Sheldon

et al., 1972). Sediment resuspension also contributes to the non-living component in shallow turbulent systems.

SPM can also be classified as being organic or inorganic, labile or refractory (Parsons and Takahashi, 1973). A large part of detritus is said to be refractory since it is very resistant to degradation. This does not however mean that there is inefficient utilization of detritus since there exists an equilibrium between detritus production and degradation (Wangersky, 1977). Pomeroy (1980) argued that there is a need for the high standing stock of detritus due to its function as food and habitat for the living component in the assemblage. If the food disappears, the habitat also disappears. Thus it can be said that nonliving particulate organic matter in the sea is an ecologically active "population" in all aspects except the endowment of life rather than a mere assemblage of broken corpses (Gordon, 1963).

Geologists classify particulate matter as biogenic or minerological while sedimentologists view particulate matter from the aspects of sedimentation and flocculation processes (Billiones, 1998).

1.3. Study sites

Two study sites ; Funzi bay in the south and Mtwapa creek in the north of the town of Mombasa were considered in this work (Figure 1.3 a and b). Funzi bay connects to Shirazi creek and Ramisi estuary. The selection of the sites was based on differences in eutrophication levels. Mtwapa creek system receives raw sewage from nearby beach hotels, residential quarters and a government prison which directly discharge waste into the creek, and underground seepage from septic tanks. Poor drainage systems within the neighbouring Mtwapa municipality leads to storm run-off waters flowing into the creek. It is also strongly influenced by seasonal river discharge (Mwangi *et al.*, 1998).

On the other hand, Shirazi creek and Ramisi estuary are relatively unpolluted. They are located far from Mombasa town and there is no urban centre within this locality. Tourism industry and urbanization have picked up slowly in this area and there is no much economic activity which can attract human migration. Thus population density is low in the neighbouring areas and there are no serious human related activities which are a threat to the coastal ecosystems. The three systems are however bordered by mangrove

forests which may export organic matter into the estuary and creek systems with the tides. This work compares the SPM components in Mtwapa and Shirazi creeks as representing different eutrophication levels. Results obtained will also be used to check how these two creek systems compare with Ramisi estuary, a natural system experiencing immense terrigeneous influence from freshwater input.

Anthropogenic activities can influence the levels of suspended particulate matter in aquatic ecosystems through waste dumping and sewage discharge. These activities lead to elevated nutrient and particulate matter levels which promote phytoplankton growth. Eleanor *et al.,* (1998) reported that anthropogenic nitrogen inputs have the potential to enhance primary production in nitrogen limited coastal systems. Increased phytoplankton growth (production) increases the phytoplankton carbon and consequently the particulate organic carbon (POC) of the affected system. The responses of coastal areas to nutrient inputs varies. Some show pure phytoplankton dominated response whereas others appear to be dominated by macrophyte growth (Eleanor *et al*., 1998). Whatever the response, the end result is an increase in particulate matter content of the affected systems when the primary producers die or during grazing.

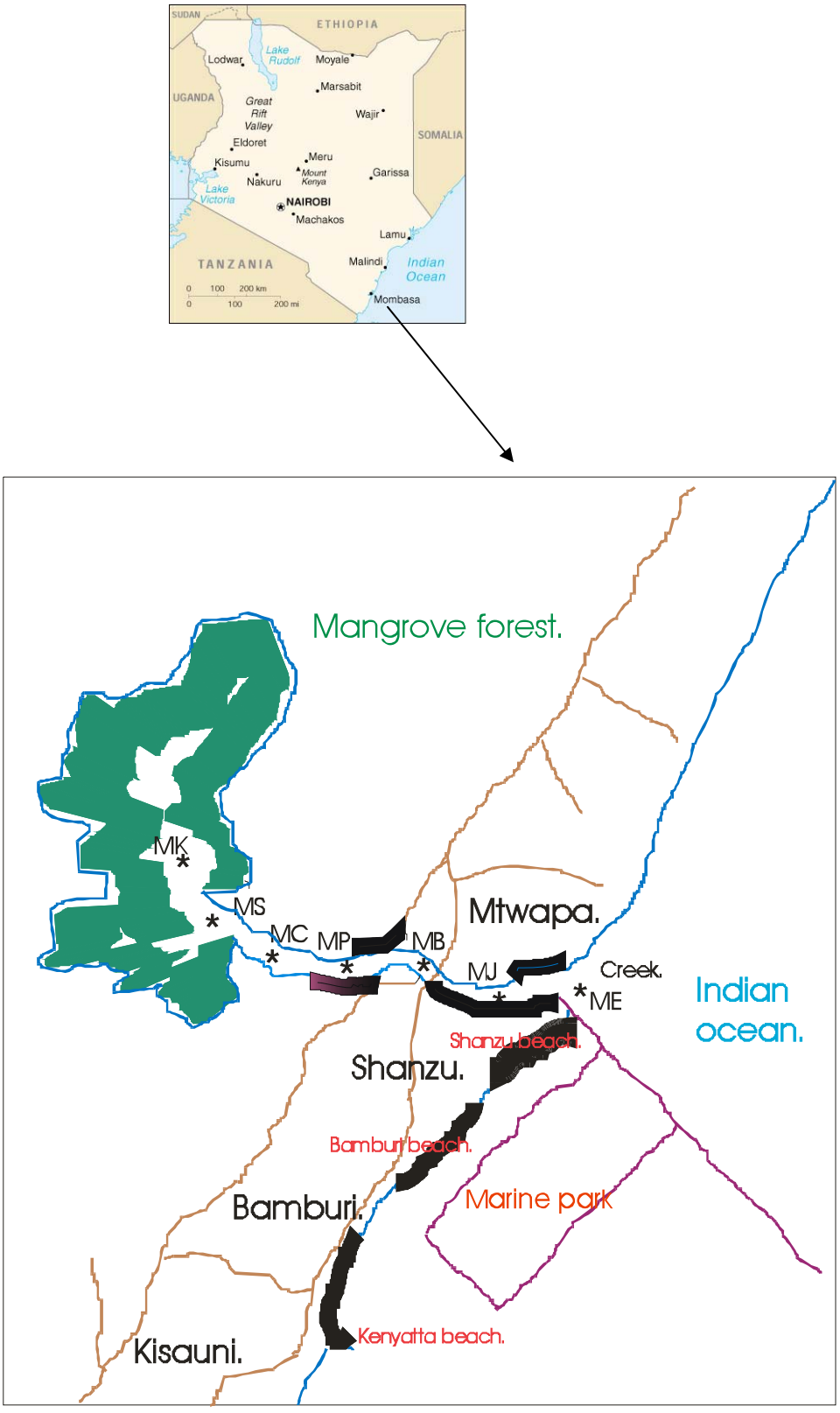


Figure.1.3 (a): Map of Mtwapa showing the sampling sites.

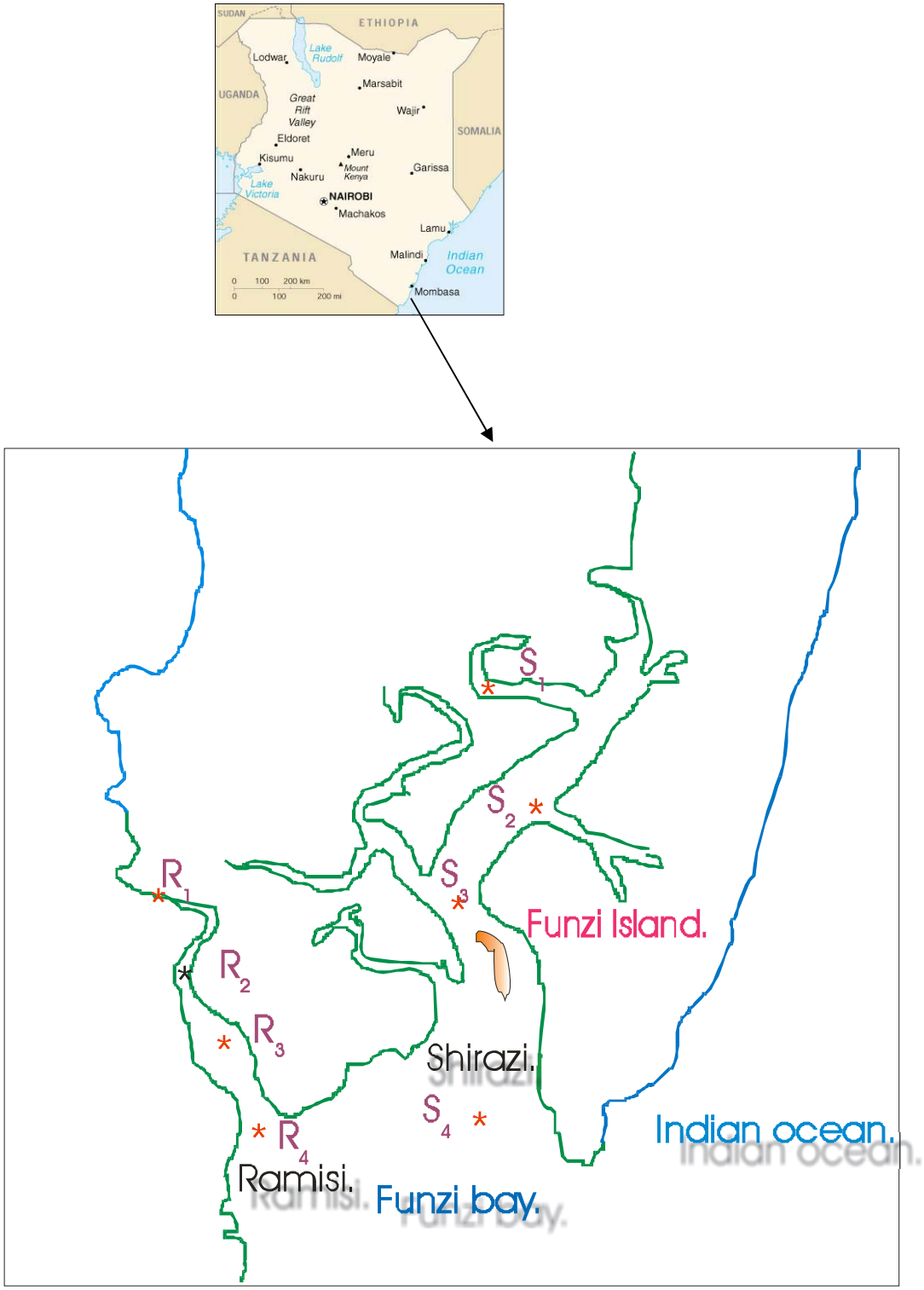


Figure. 1.3 (b): Map of Funzi showing the sampling sites.

1.4. Aim and objective

The overall aim of this study was to asses the ecological status of the two creek systems in terms of nutrient levels and concentrations and composition of particulate organic carbon.

The specific objective was to determine the influence of sewage discharge on the levels of particulate organic carbon (POC). This was achieved by comparing the following factors between the two creeks;

- Concentrations of suspended particulate matter (SPM) as dry weights.
- Concentrations of particulate organic carbon (POC).
- Concentrations of inorganic nutrients (Ammonia, Nitrates and Phosphates).
- Determination of most abudant phytoplankton genera and their contribution to particulate organic carbon.
- Chlorophyll *a* levels.

CHAPTER TWO
MATERIALS AND METHODS

2.1. Sampling

Sampling was done during slack waters in the months of August, September and October (24th and 26 th August, 9 th, 16 th, 28 th and 29 th September and 6 th October 1999). This was not meant to include temporal variation but one time sampling within the study period. The spreading of the sampling within three months was imposed by logistical possibilities and limitations. Four sampling stations were established in Shirazi creek and Ramisi estuary and seven in Mtwapa creek. During each sampling the following environmental factors were measured; temperature, salinity, pH and secchi depth. Water samples for nutrient analysis were collected in 100 ml plastic bottles, brought to the lab and stored for one day in a freezer until analysis. Water samples for chlorophyll *a* determination were collected in 1 L opaque plastic containers and brought to the lab for further processing. 5 L water samples for microscopic analysis of phytoplankton were collected in plastic containers and fixed with lugol's solution in the lab. Water samples for particulate organic carbon analysis were collected in 1 L plastic bottles and stored for a maximum of two days in in a freezer before filtration. Replicate samples were collected for each variable.

2.2. Sample analysis

2.2.1. Enviromental factors

Temperature and pH were determined using a pH meter. pH readings were corrected for the water temperature. Salinity was measured using a refractometer whereas secchi depth measurements were done with a Secchi disc. A Secchi disc depth gives the depth at which a white disc of about 30 cm diameter disappears from a viewer at the surface. The disc was lowered into the water down to a depth at which it just disapeared from view

(Postma, 1961). The corresponding depth was read from a calibrated rope attached to the disc.

2.2.2. Dissolved inorganic nutrients

The methods described by Grasshoff (1976) were used with some modifications to analyse the concentrations of ammonia (NH_4^+), Nitrate (NO_3^-) and Phosphates (PO_4^{3-}) in the water samples. All chemicals used were of analytical grade and all glassware was acid washed and rinsed with purified water to avoid contamination.

2.2.2.1.Ammonia

In this study, the method used for ammonia determination is based on the reaction of dissolved ammonia with hypochlorite in the presence of phenol to produce a blue indofenol compound which can be quantitatively determined with a spectrophotometer. To 50 ml of the sample was added two reagents assigned R1 and R2. R1 contained 17.5 g of phenol and 0.2 g of sodiumnitroprusside dissolved in distilled water and diluted to 500 ml. R2 contained 140 g of *tri*-sodiumcitrate and 11 g of sodium hydroxide dissolved in distilled water. After complete dissolution, 20 ml of sodium hypochlorite were added and the mixture diluted to 500 ml with distilled water (Ecomama practical syllabus, 1999). Both reagents were stored in a refrigerator prior to use. After adding the reagents, samples were allowed to stand overnight. The absorbance of each sample was read at a wavelength of 480 nm using Shimadzu UV-150-02 double beam spectrophotometer.

2.2.2.2. Nitrate

A cadmium collumn reductor was used. This method relies on the reduction of nitrate to nitrite and the subsequent formation of an azo dye whose absorbance can be determined spectrophotometrically. Cadmium (Cd) granules vigorously shaken with copper sulphate solution were filled in a U-shaped glass tube containing ammonium chloride solution acting as a buffer. The pH of the reductor was adjusted to 8.5. This was to ensure that all nitrate was reduced to nitrite as too alkaline solution results in partial reduction whereas too acidic solution leads to reduction beyond the nitrite step. To 50 ml

of sample in a 100 ml erlenmeyer flask was added 50 ml ammonium chloride (buffer). After thorough mixing, 40 ml of the sample was passed through the reductor, collected in the flask and discarded. This was mainly to rinse the reductor and adjust the time of passage (25 ml in 2-3 minutes). Another 40 ml was then passed through the reductor and collected in the erlemeyer flask. To 25 ml of the collected sample was added sulphanilamide solution followed six minutes later by napthyl ethylenediamine solution. The mixture was allowed to react for 45 minutes (Grasshoff, 1976). The extinction of the coloured azo dye formed was measured at a wavelength of 543 nm using Shimadzu UV-150-02 double beam spectrophotometer.

2.2.2.3. Phosphate

The method used is based on the reaction of phosphate ions with an acidified molybdate reagent to yield a phosphomolybdate complex which is then reduced to a highly coloured blue compound which can be quantified spectrophotometrically. To 50 ml sample was added 5 ml mixed reagent containing ammonium molybdate, sulphiric acid, ascorbic acid and potassium antimonyl-tartrate solution. Ammonium molybdate was prepared by dissolving 15 g of ammonium paramolybdate in 500 ml of distilled water. For sulphiric acid, 140 ml of sulphiric acid were added to 900 ml distilled water. Ascorbic acid solution was made by dissolving 27 g of ascorbic acid (powder) in 500 ml distilled water whereas potassium antimonyl-tartrate solution prepared by dissolving 0.34 g potassium antimonyl tartrate in 250 ml of distilled water (Ecomama practical syllabus, 1999). In the reaction, ascorbic acid acts as a reductor of the phosphorous molybdate complex to a highly coloured compound whereas the potassium antimonyl-tartrate acts as a catalyst (Grasshoff, 1976; Ecomama practical syllabus, 1999). The absorbance of the phosphorous molybdate complex was measured at a wavelength of 885 nm using Shimadzu UV-150-02 double beam spectrophotometer.

Note:

Only one calibration plot was made for each of the nutrients and used for the subsequent nutrient concentration calculations.

2.2.3. Chlorophyll *a*

Depending on the turbidity, between 0.5 L and 1 L sea water samples were filtered using a filter pump through 0.45 µm pore Whatman GF/F filters (47 mm) diameter. During filtration two drops of $MgCO_3$ were added to prevent acidification of the filters. Chlorophyll extraction was done using ANALAR grade 90% acetone (overnight in a fridge at 4^0C). Light extinction of the extract was measured in a Shimadzu UV-150-02 double beam spectrophotometer at wavelengths of 664, 647 and 630 nm. The extinctions were corrected for turbidity by subtracting the coresponding reading at 750 nm. Chlorophyll *a* concentration was calculated from the corrected values following the Parsons and Strickland (1963) formulae given as;

$$\textbf{(Chl } \textit{a}\textbf{)} = 11.6E_{664} - 1.31\ E_{647} - 0.14\ E_{630}.$$

The results obtained from this formula were multiplied by a factor **f**, so as to obtain chlorophyll concentrations in $mg.m^{-3}$. ($\mathbf{f = v/LxV}$ where **L** is the length of the cuvette used in cm, **v** is the volume of acetone used and **V** is the volume of sea water filtered (Ecomama practical syllabus, 1999).

2.2.4. Particulate organic carbon (POC)

Known volumes of water samples were filtered through pre-combusted (450^0C for 3 hours) 0.45 µm pore Whatman GF/F filters. The filters were then dried at 60^0C overnight and stored in a dessicator for later analysis. Particulate total carbon (PTC) and particulate inorganic carbon (PIC) measurements were done by automatic coulometric titration with Strohlein Coulomat 702. Coulometry measures the quantity of electricity required to convert a chemical substance. Thus it's an application of Faradays Law which states that, "the electrolytic separation or conversion of an equivalent requires a quantity of electricity of 1 Faraday".

In coulometric analysis of carbon, Barium Perchlorate $Ba(CLO_4)_2$ is used as the eletrolyte with a pH of 9. Combustion of the filters and acid oxidation (phosphoric acid and silver nitrate solution) for PTC and PIC respectively produces carbon dioxide which changes the pH of the electrolyte to acidic. Back titration to the original pH is done automatically by barium hydroxide $Ba(OH)_2$ produced through electrolysis. The amount

of electricity used for this back titration represents an absolute measure of the carbon in the sample. This amount of electricity is transformed into counts by a built-in electronic unit. 1 count represents 2 x 10^{-7} gC. POC is then calculated as; PTC - PIC.

2.2.5. Total suspended particulate matter (Dry weights)

Known volumes of water samples were filtered through pre-weighed 0.45 µm GF/F filters (47 mm diameter). Filters were then dried at 60^0C overnight and cooled in a dessicator before weighing. The difference in weight corrected for filter weight was taken to represent organic and inorganic matter greater than 0.45 µm in the samlpes.

2.2.6. Phytoplankton

The 5 L water samples preserved with lugols solution were allowed to settle for 2 days. They were then serially decanted to 500 ml and finally to 50 ml. After each decantation, the sample was allowed to settle for 1 day. A subsample of 5 ml was analysed for generic composition using an inverted microscope. For tintinnids, cells as well as lorica were counted since it was assumed that the presence of a lorica meant the presence of an organism. Standing stocks were calculated using the formula;

N = n.x / Nv.V2.cf where;

N = concentration of cells in the sample (cells/ litre).

x = number of viewing fields in the cuvette at x200 magnification (surface area of cuvette / surface area of the viewing field).

V2 = volume of sample in the cuvette.

n = number of cells counted at Nv viewing fields.

Nv = number of viewing fields counted.

cf = concentration factor (volume of collected sample / volume of sample in the cuvette) (Ecomama practical syllabus, 1999).

Size measurements were taken for the most abudant group in each station. Prior to sizing, the occular scale was calibrated using a micrometer scale. Phytoplankton cell volume was calculated assuming the cells to be spherical or ellipsoidal (Mullin *et al.*,

1966; Smayda, 1978; Verity *et al.*, 1992; Montagnes *et al*., 1994). Phytoplankton carbon content for diatoms and non-diatoms was calculated using the Eppley formula given as;

$$\log_{10} C = 0.76 \log_{10} V - 0.352 \text{ (for diatoms)}$$

$$\log_{10} C = 0.94 \log_{10} V - 0.6 \text{ (for non diatoms)}$$

with V: cell volume in μm^3 and C: cell carbon content (Smayda, 1978). Estimation of phytoplankton carbon from cell volume rather than chlorophyll is prefered since chlorophyll content is influenced by several environmental conditions like temperature, past light intensity and nutrient deficiency (Mullin *et al.,* 1966).

Reference books used for the identification were Newell (1963); Drebes (1974); Fogged (1975); Tregouboff (1957) and Kofoid (1974).

2.2.7. Detritus

The detrital component of POC was estimated as the difference between particulate organic carbon and phytoplankton carbon (POC - Phyto. C).

CHAPTER THREE

RESULTS

3.1. Physico-chemical factors

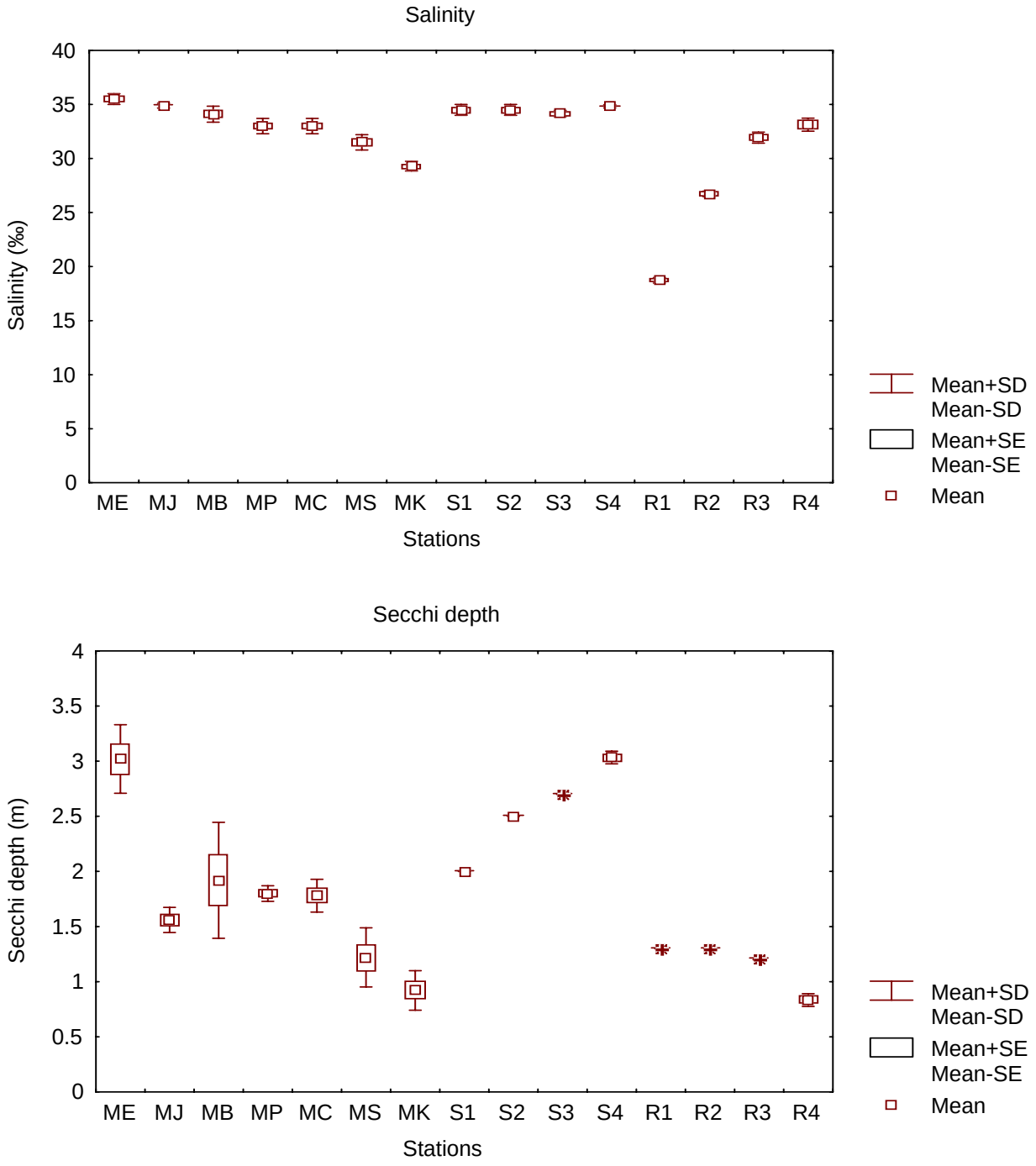


Fig. 3.11. Spatial variations in salinity and secchi depth.

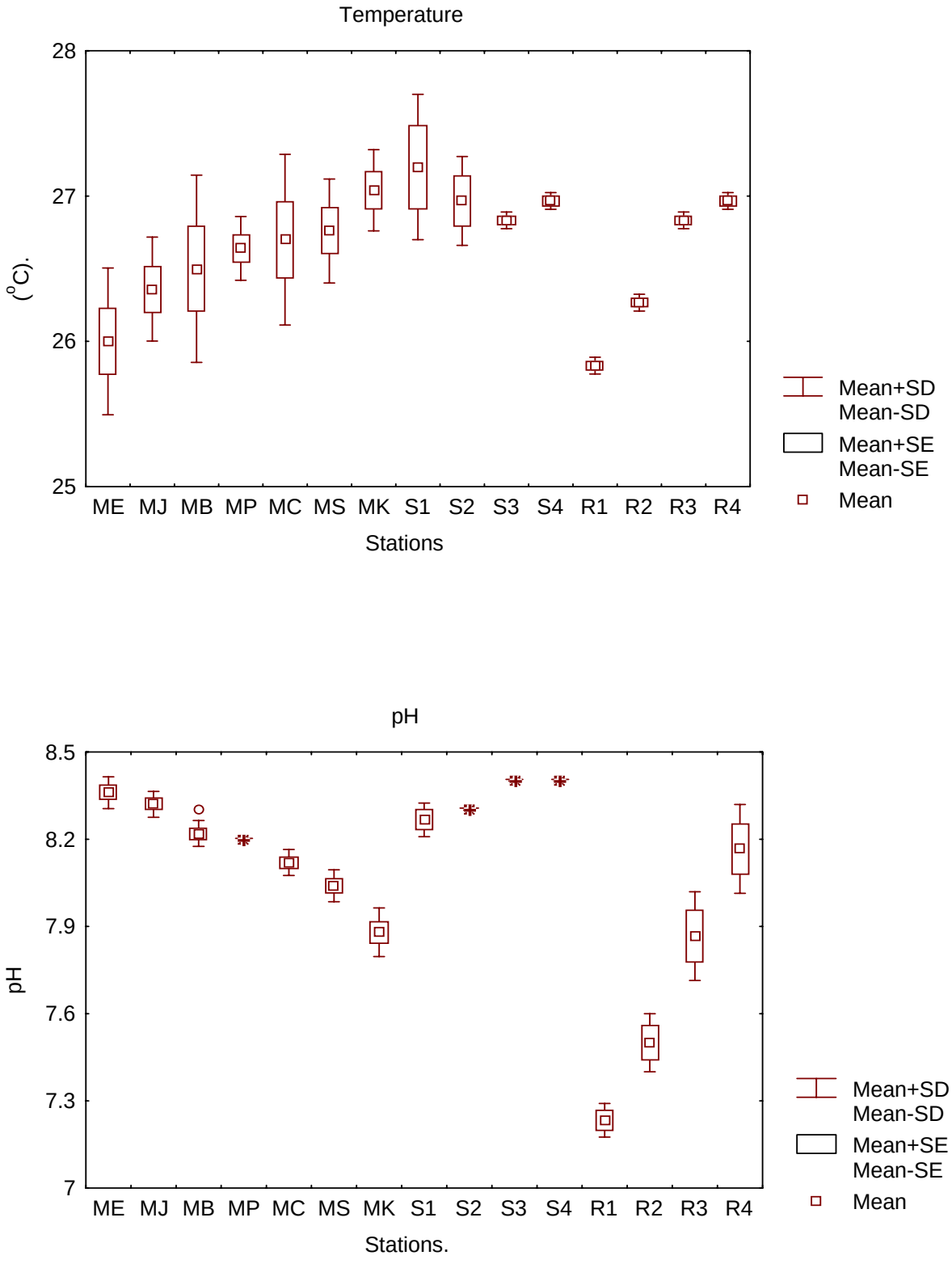


Fig. 3.12. Spatial variation in temperature and pH.

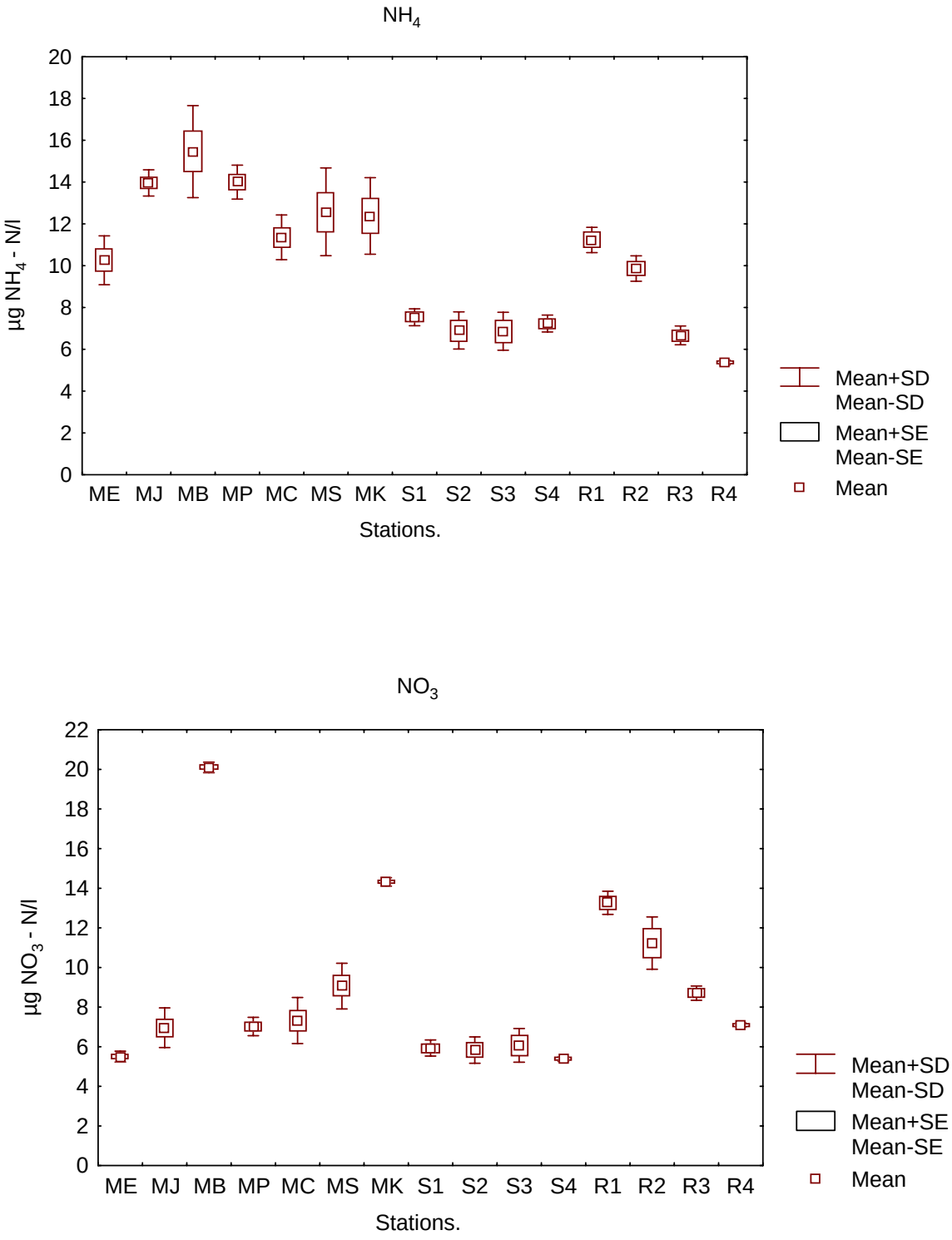


Figure. 3.13. Spatial variations in ammonia and nitrate concentrations.

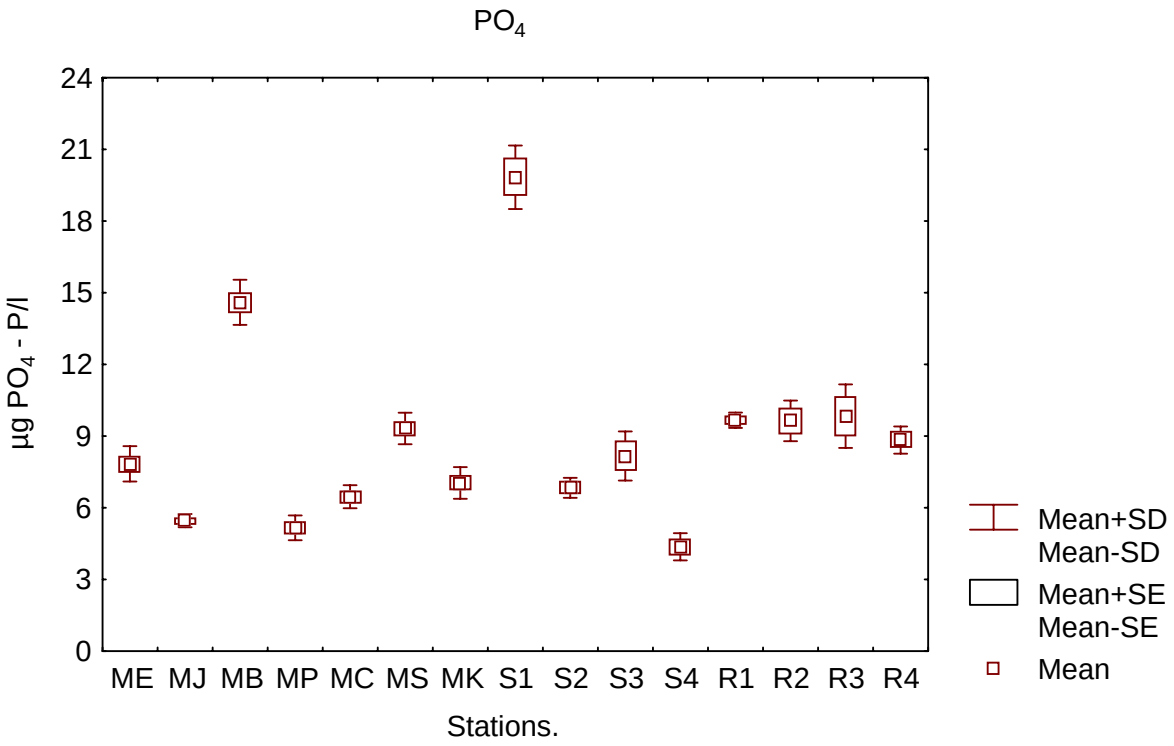


Figure. 3.14. Spatial variations in phosphate concentrations.

The spatial distributions of physico-chemical factors for all stations in the respective sites are shown in figures 3.11, 3.12, 3.13 and 3.14 .

Salinity (‰) (Figure 3.11) ranged from 35.4±0.44 to 29.3±0.4 in Mtwapa, 34.8±0.3 to 34.4±0.5 in Shirazi and 33.1±0.9 to 18.8±0.5 in Ramisi. The highest value (35.4±0.4) was recorded in Mtwapa (ME) at the creek mouth. The lowest (18.8±0.5) was recorded in Ramisi (R1), the innermost station. Multiple comparisons using Tukey's HSD test showed that all sites were significantly different ($p < 0.05$). Within site variations were significant except for Shirazi (Tukey's HSD test, $P< 0.05$ and $p > 0.05$) respectively. Salinity decreased along Mtwapa creek and Ramisi estuary from the seaside stations ME and R4 as seen in figure 3.11.

Secchi depth (Figure 3.11) ranged from 3.0±0.3 to 0.8±0.1. The highest value was recorded in Mtwapa and Shirazi (ME and S4) , stations at the mouth of the creeks and in the open ocean. The difference was significant between these stations and all the others

(Tukey's HSD test, $p < 0.05$). The lowest value was recorded in Ramisi (R4) a station at the mouth of the estuary and all the values in Ramisi were not significantly different (Tukey's HSD test, $p > 0.05$). There were significant differences between sites (ANOVA, $p < 0.05$) and overall, Shirazi recorded the highest values ranging from 2m to 3m.

Temperature (^oC) (Figure 3.12) ranged from 27.0±0.3 to 26.0±0.5 in Mtwapa, 27.2±0.6 to 26.8±0.1 in Shirazi and 27.0±0.17 to 25.8±0.1 in Ramisi. The highest temperature was recorded in Shirazi station S1 and the lowest in Ramisi station R1. Between site differences were significant except for Mtwapa and Ramisi (Tukey's, HSD test, $p< 0.05$ and $p> 0.05$ respectively). Within site differences were also significant except for Shirazi (Tukey's HSD test, $p< 0.05$ and $p> 0.05$). A similar test showed that only stations ME and MK in Mtwapa had significantly different temperatures ($p< 0.05$). In Ramisi, only stations R1 and R4 had different temperatures (25.8^oC and 27^oC) from each other and from the rest (Tukey's HSD test, $p< 0.05$). Temperature decreased from R4 to R1 in Ramisi and from MK to ME in Mtwapa as seen in figure 3.12. Stations ME, R4 and MK, R1 were located at the mouth and extreme upper ends respectively, of the creek and estuary.

pH variations are shown in figure 3.12. All values were slightly alkaline. The values ranged from 8.4±0.01 to 7.2±0.1. The highest value was recorded in Shirazi station S4 and the lowest in Ramisi station R1. There were significant differences between sites and between stations (ANOVA, $p< 0.05$). Within site variations were significant except for Shirazi (Tukey's HSD test, $p< 0.05$ and $p> 0.05$).

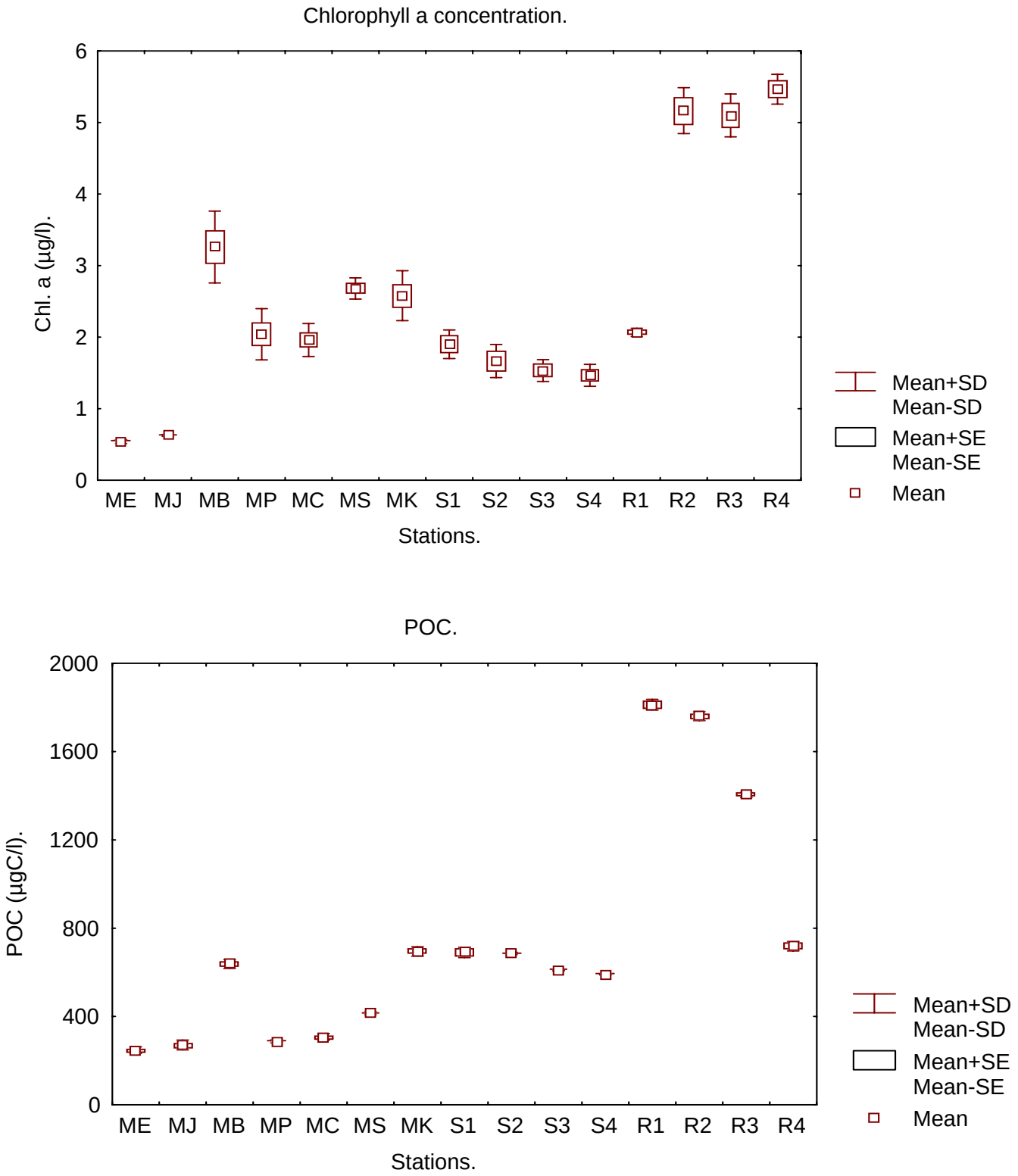
Figures 3.13 and 3.14 show the spatial distributions of inorganic nutrients ammonia, nitrates and phoshates.The highest concentration of ammonia (15.5±0.8 µg NH_4-N/l) was recorded in Mtwapa station MB and the lowest (5.4±0.1 µg NH_4-N /l) in Ramisi station R4 (Figure 3.13). Between sites differences were significant except for Shirazi and Ramisi (Tukey's HSD test, $p< 0.05$ and $p> 0.05$) respectively. Stations MB and MP in Mtwapa recorded the highest concentrations of ammonia. These stations were located within the vicinity of sewage discharge points. The lowest concentration was recorded in

Ramisi at station (R4) located at the estuary mouth. The concentrations were similar for all stations in Shirazi (Tukey's HSD test, $p > 0.05$).

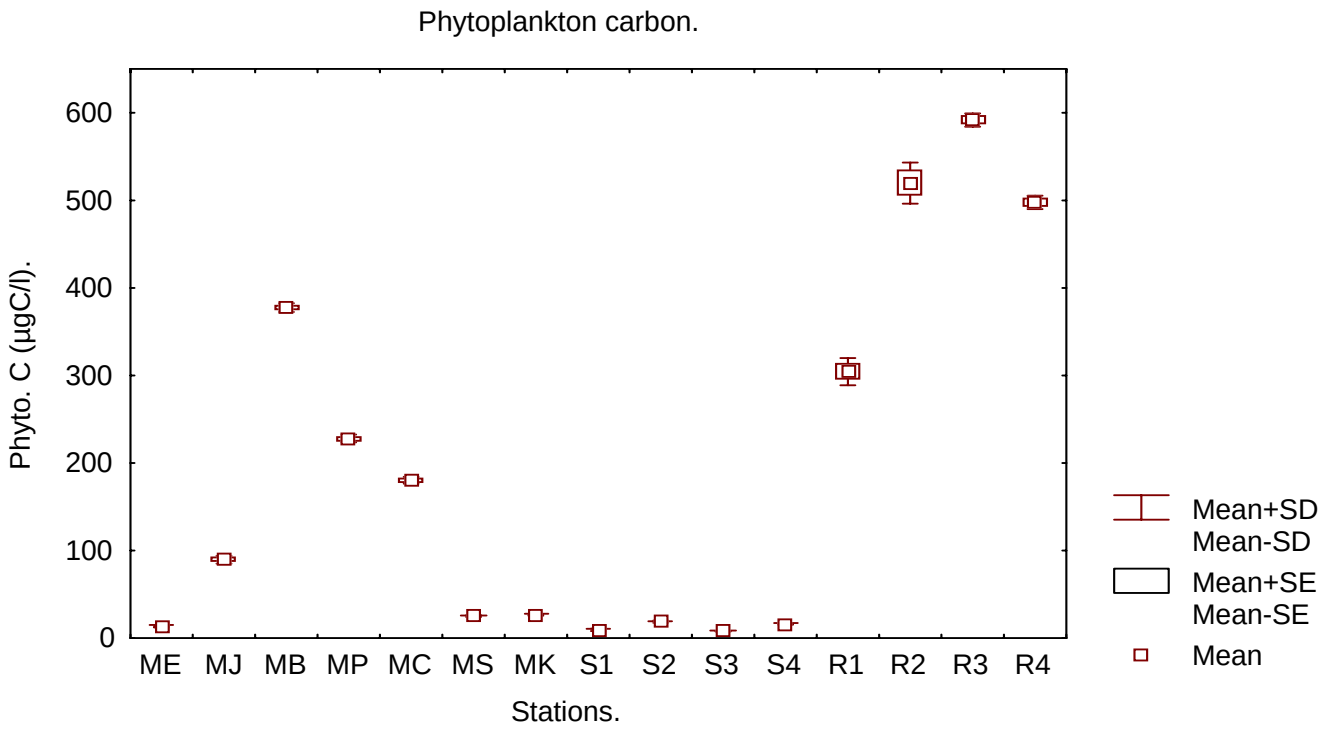
Nitrate (Figure 3.13) concentrations (µg NO_3-N/l) ranged from 20.1±1 to 7±0.45 in Mtwapa, 6±1 to 5.4±0.3 in Shirazi and 13.3±0.6 to 7.1±0.1 in Ramisi. Between sites differences were significant except for Mtwapa and Ramisi (Tukey's test, $p < 0.05$ and $p > 0.05$) respectively. Within site nitrate concentrations were significantly different except in Shirazi (Tukey's HSD test, $p > 0.05$). Shirazi recorded the lowest concentrations. Like ammonia, the highest nitrate concentration (20.1±1) was recorded in Mtwapa at station MB located near a major point source of sewage. This station was significantly different from all the other stations in the creeks (Tukey's HSD test, $p < 0.05$).

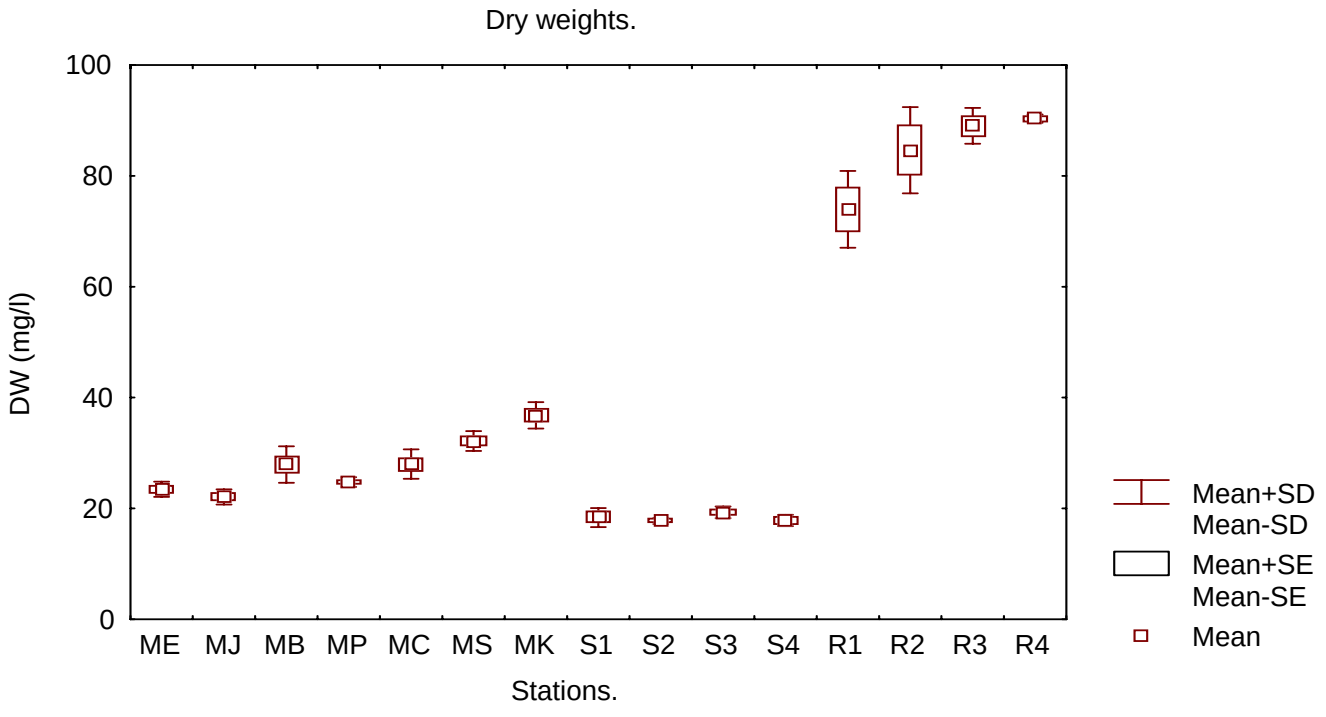
Phosphte concentrations (µg PO_4-P/l) ranged from 14.6±1 to 5.5±0.5 in Mtwapa, 19.8±2 to 4.3±0.8 in Shirazi and 9.7±0.5 to 8.8±0.6 in Ramisi (Figure 3.14). Between sites differences were significant except for Ramisi and Shirazi (Tukey's HSD test, $p < 0.05$ and $p > 0.05$) respectively. The highest value in Mtwapa was recorded at station MB near a major point source of sewage discharge. Within site variations were significant except in Ramisi (Tukey's HSD test, $p < 0.05$ and $p > 0.05$) respectively.

3.2. SPM components



3.21. Spatial variation in Chlorophyll *a* and POC concentrations.





3.22. Spatial variation in Phytoplankton carbon and dry weights.

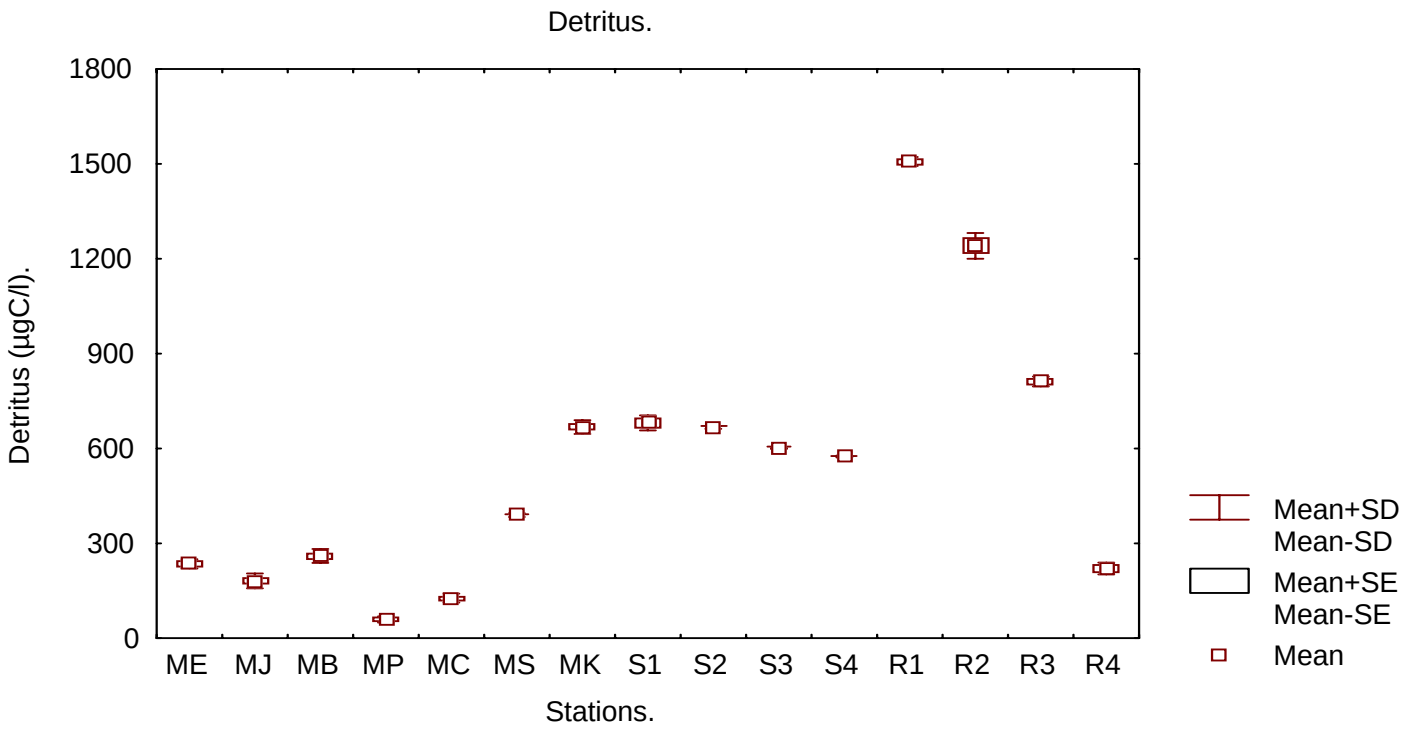


Fig. 3.23. Spatial distribution of detritus.

The spatial distributions of chlorophyll *a*, POC, phytoplankton carbon and dry weights are shown in figures 3.21 and 3.22. Each of the sites recorded significantly different values of dry weight (Figure 3.22) (ANOVA, $p < 0.05$). In Mtwapa, the range was from 20.5±2 mg/l to 36.1±4 mg/l, 17.7±0.8 mg/l to 19.3±1.4 mg/l in Shirazi and 74±6.4 mg/l to 90.3±1.3 mg/l for Ramisi. The highest values recorded were from the estuarine system (Ramisi) and the lowest from Shirazi. All values recorded in Shirazi were not significantly different (Tukey's HSD test, $p > 0.05$) and multiple comparisons showed that all stations in Ramisi were significantly different from all stations in Mtwapa and Shirazi (Tukey's HSD test, $p < 0.05$). There was an increasing trend in Mtwapa from the creek mouth (seaward) to the extreme upper stations. In Ramisi the increase was towards the estuary mouth. The minimum value recorded at Ramisi was more than twice the maximum values recorded in Mtwapa and Shirazi (Figure 3.22). Mtwapa and Shirazi have little riverine influence hence the allochthonous component of their particulate

matter could be lower than that of Ramisi. All the sites have their banks vegetated by extensive mangrove forests which may influence their particulate matter content.

POC (µgC/l) showed significant differences between sites (ANOVA, $p< 0.05$) and multiple comparisons indicated that each site recorded different concentrations from each other (Tukey's HSD test, $p< 0.05$). Ramisi recorded the highest values ranging from 712.3±18.6 to 1851.2±97. The values for Mtwapa ranged from 247.7±16.8 to 694.4±21.8 whereas those for Shirazi ranged from 582.9±12.6 to 699.2±30.2 (Figure 3.21). Generally the values were higher in Ramisi followed by Shirazi and lowest in Mtwapa. Apart from the peak value observed at station MB, the general trend in Mtwapa was an increase from the mouth of the creek to the extreme upper stations (Figure 3.21). Within site variations were significant in Mtwapa suggesting that different factors could be influencing POC concentrations along the creek. Within site variatiations were not significant in Shirazi (Tukey's test, $p> 0.05$). In Ramisi, the trend was a general decrease from the extreme upper station (R1) to the mouth (R4) (Figure 3.21). This pattern was opposite to that observed for dry weights.

The overall range for chlorophyll *a* (µg/l) was from 0.54±0.04 to 5.46±0.3 (Figure 3.21). Between sites differences were significant (ANOVA, $p< 0.05$). The highest concentration was recorded in Ramisi at station R4, the mouth of the estuary whereas the lowest in Mtwapa at station ME, the mouth of the creek near the open sea. Shirazi recorded the smallest range between 1.5±0.3 to 1.7±0.4. All values recorded in Shirazi were not significantly different (Tukey's HSD test, $p> 0.05$) and lower than the peak values in Mtwapa and Ramisi. Mtwapa recorded the biggest range from 0.5±0.04 to 3.3±0.5 with a peak at station MB. This peak concided with the peaks for ammonia, nitrate and phosphate concentrations. In Ramisi, the lowest value was recorded at station R1, the extreme upper station. The concentrations recorded at stations R2, R3 and R4 were not significantly different but were higher than in the other stations (Tukey's HSD test, $p> 0.05$ and $p< 0.05$) respectively.

The concentration ranges of phytoplankton carbon (µgC/l) were; 12.4±2.2 to 376±36.5 in Mtwapa, 7.8±1.9 to 18.9±3.5 in Shirazi and 304.3±53.8 to 591.7±63.1 in

Ramisi (Figure 3.22). Between sites and between stations variations were significant (ANOVA, $p< 0.05$). Shirazi recorded the lowest concentrations and all the values were not significantly different (Tukey's HSD test, $p> 0.05$) whereas Ramisi recorded the highest with all stations having significantly different values (Tukey's HSD test, $p< 0.05$). Within site differences in Mtwapa were also significant for the above test. The different stations recorded different phytoplankton groups and stocks (Figure 3.41) and this could explain the differences in phytoplankton carbon. The peak value for Mtwapa was recorded at station MB (Figure 3.22), the station with the peak values for ammonia, nitrate, phosphate and chlorophyll *a* concentrations. This station also recorded the highest stocks of dinoflagellates.

Detritus values (µg/l) were obtained from the difference between POC and phytoplankton carbon. These values ranged from 59.2±9.9 to 667.8±21.8 in Mtwapa, 574.9±3 to 680.7±23.9 in Shirazi and from 220.6±18.9 to 1507.9±14 in Ramisi (Figure 3.23). Thus Ramisi recorded the highest values whereas Mtwapa recorded the lowest values. The pattern of variation of detritus in the three sites was similar to that of POC. Indeed detritus contributed between 17-96%, 97-99% and 29-84% of total POC in Mtwapa, Shirazi and Ramisi respectively. These values show that detritus is a very important component of POC in these systems.

3.3. Carbon ratios

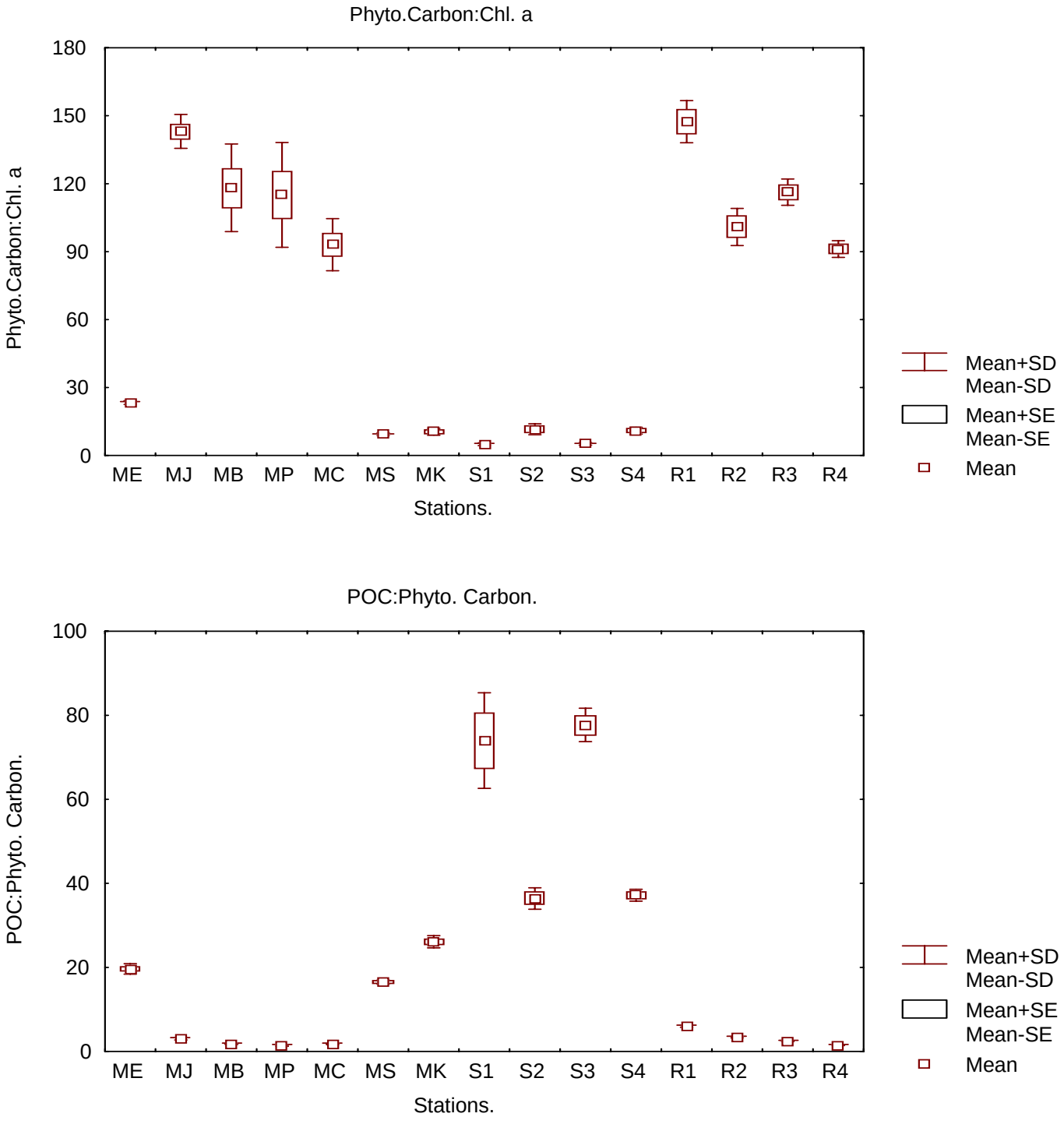


Fig. 3.31. Spatial variations in phytoplankton carbon / chlorophyll *a* and POC / phytoplankton carbon ratios respectively.

Two carbon ratios were calculated; phytoplankton carbon to Chl *a* and POC to phytoplankton carbon (Figure 3.31). POC / phytoplankton carbon ratio gives an idea of the contribution of living phytoplankton biomass to the particulate organic carbon and can be used as an index to show whether the bulk of POC is of detrital or living phytoplanton origin (Navarro et *al.*, 1993). Its values ranged from 1.3±0.1 to 26±5.2 in Mtwapa, 36.6±8.4 to 83.2±17.5 in Shirazi and 1.4±0.4 to 6.1±1.1 in Ramisi. Between sites and between stations variations were significant (ANOVA, $p< 0.05$). Tukey's HSD post hoc test showed that each of the sites had a significantly different ratio ($p< 0.05$). However a similar test showed that all stations in Ramisi had similar values and were not significantly different from those of stations MJ, MB, MP and MC in Mtwapa ($p> 0.05$). These stations recorded high values of phytoplankton carbon hence their similarity in low POC to phytoplankton carbon ratio. Stations in Shirazi recorded higher values than in Mtwapa.

Phytoplankton carbon to chlorophyll *a* ratio ranged from 9.1±1.6 to 141.6±15.2 in Mtwapa, 5.4±1.5 to 11.5±2.7 in Shirazi and 91.2±21.8 to 148.4±27.2 in Ramisi. The ratio was highest in Ramisi and lowest in Shirazi. All stations in Shirazi were not significantly different (Tukey's HSD test, $p> 0.05$). Between sites differences were significant (ANOVA, $p< 0.05$). There was a general decrease towards the estuary mouth in Ramisi. In Mtwapa the ratio was high at stations MJ, MB, MP and MC and low at the creek mouth and the extreme upper stations (ME, MS, and MK). These high values in Mtwapa were not different from those recorded in Ramisi estuarine stations (Tukey's HSD test, $p> 0.05$). Phytoplankton carbon / chlorophyll *a* ratio gives an idea of the type of phytoplankton in a system since different phytoplankton groups have different levels of chlorophyll *a*.

3.4. Phytoplankton stocks

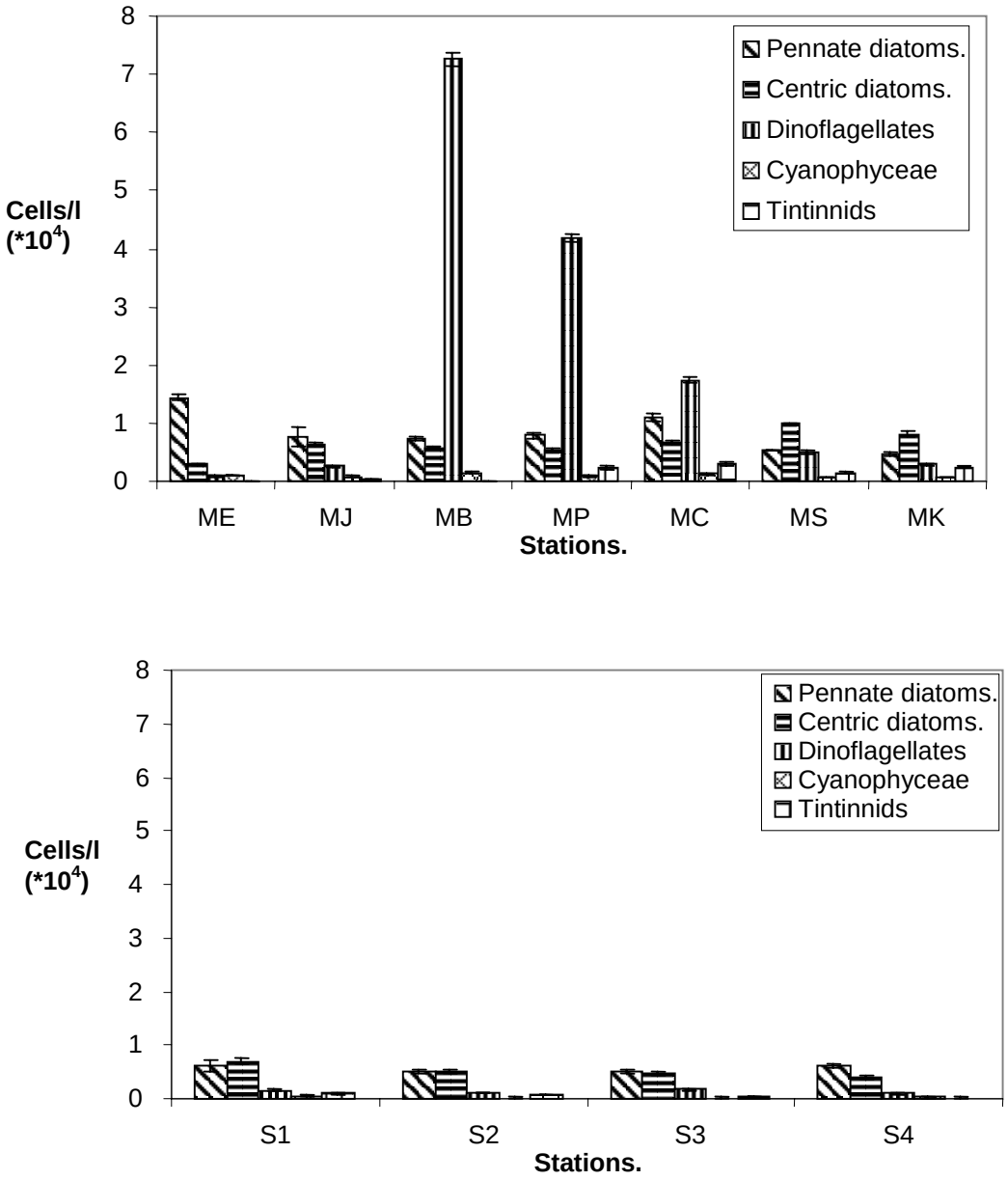


Fig. 3.41. Abundance of dominant phytoplankton groups in Mtwapa (M) and Shirazi (S).

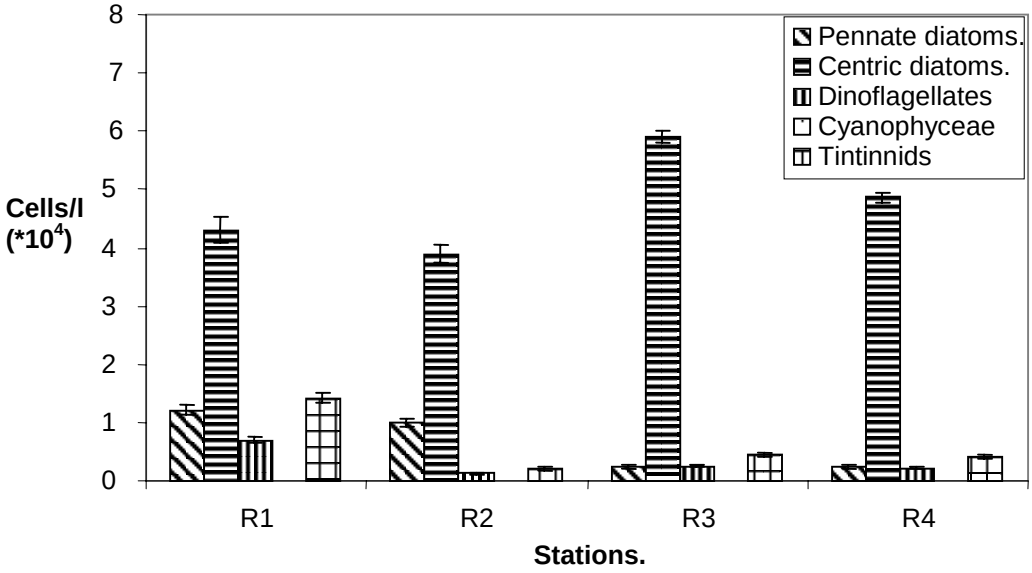


Fig. 3.42. Abundance of dominant phytoplankton groups in Ramisi.

The abundance of the various phytoplankton groups found in the three sites are shown in figures 3.41 and 3.42. Centric diatoms, mainly *Coscinodiscus* dominated all the stations in Ramisi. These stations recorded significantly different stocks of centric diatoms from each other (Tukey's HSD test, $p < 0.05$). In Mtwapa, dinoflagellates mainly *Goniodoma* dominated stations MB, MP and MC. Stations MS and MK were dominated by *Coscinodiscus* whereas stations ME and MJ had Pennate diatoms as the dominant group. Though having similar dominant groups, the stocks were significantly different (Tukey's HSD test, $p < 0.05$). Pennate diatoms and *Coscinodiscus* dominated all stations in Shirazi and the concentrations at the different stations were not significantly different (Tukeys HSD test, $p > 0.05$).

3.5. Statistical analysis

Cluster analysis was used to allocate stations into clusters of closely related stations based on similarities in SPM components (Figure 3.51). Three clear clusters emerged; one cluster was purely composed of the estuarine stations R1, R2, R3, and R4, a second cluster comprised a combination of stations from both Mtwapa and Shirazi creeks (MS, MK, SA, MJ, SC, SB, SD, MC and ME) and a third cluster comprised of sations MB and MP all from Mtwapa.

Principle components analysis, an indirect ordination method was used to rank the species along the axes. A species scatter plot based on species scores resulted in the spreading of the species along the axes based purely on the 'species' (SPM components) data (Figure 3.52).

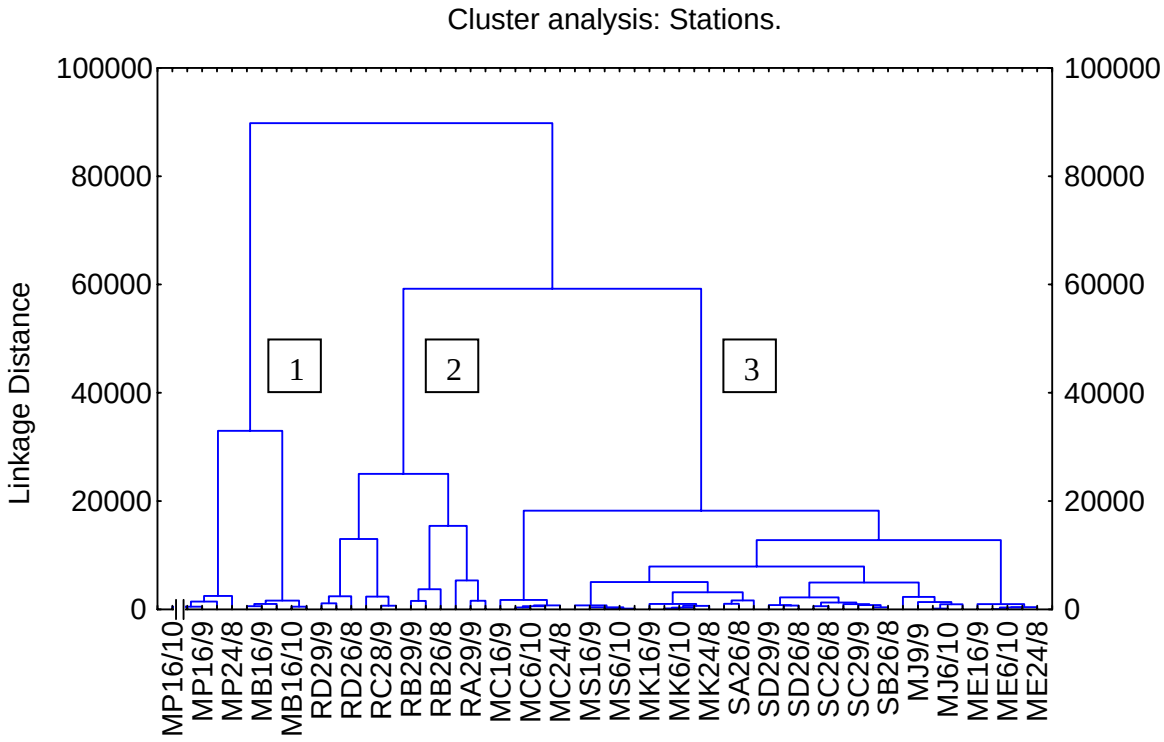


Fig.3.51. Cluster analysis showing tree clustering of stations.

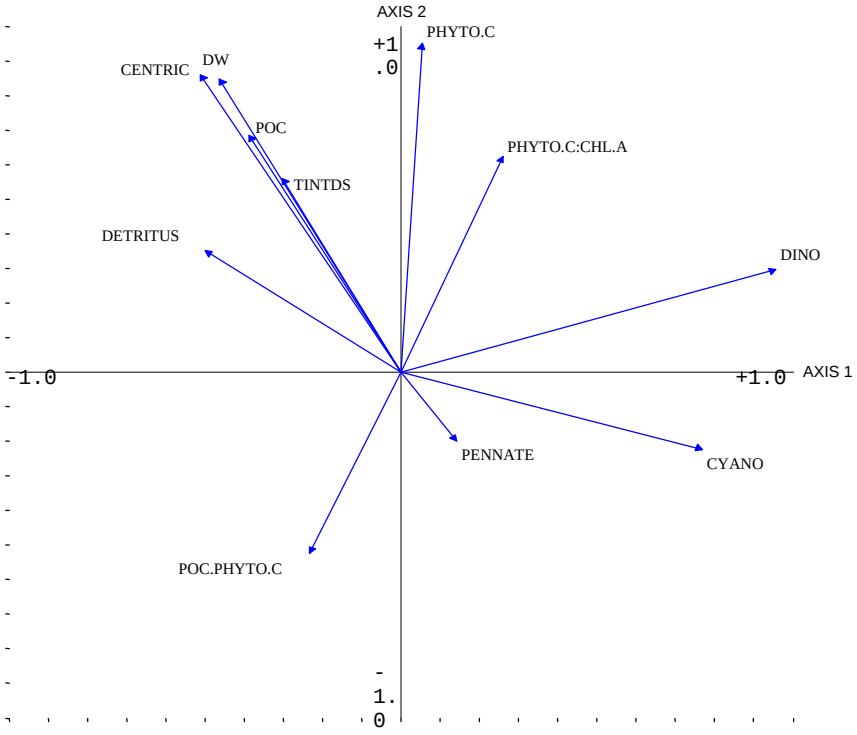


Figure. 3.52. PCA scatter plot showing the ranking of SPM components along the axes.

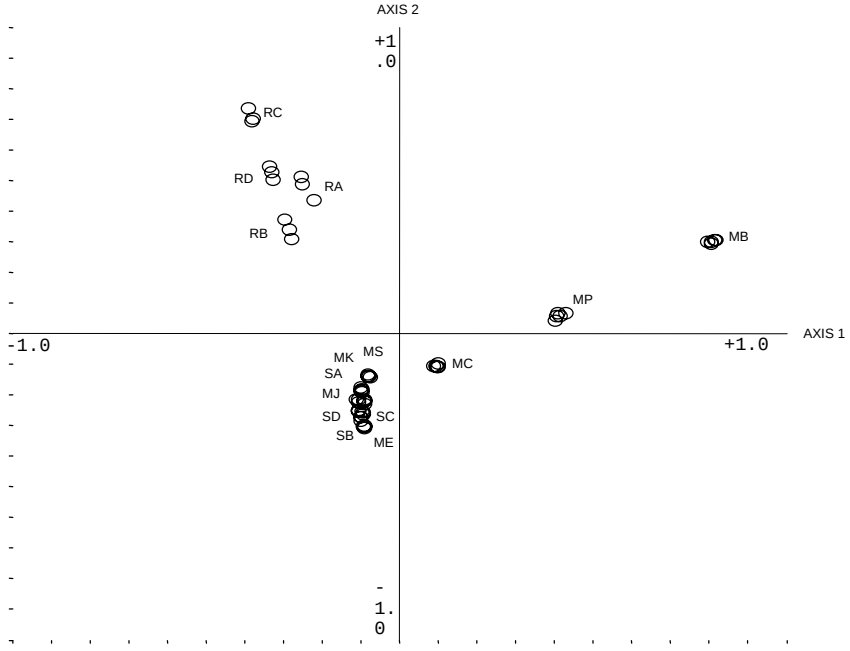


Figure. 3.53. PCA scatter plot showing the grouping of the stations.

A Principle Component Analysis (PCA) stations scatter plot showed similar clustering in accordance with the cluster analysis (Figure 3.53).

Spec: Species scores (adjusted for species variance)			
N	Name	AX1	AX2
	Eigenvalue	0.6425	0.3359
1	CHL	-0.129	0.8016
2	DW	-0.4642	0.8477
3	POC	-0.3868	0.6828
4	Phyto. Carbon	0.0532	0.9508
5	Pennate diatoms	0.1412	-0.2001
6	Centric diatoms	-0.5121	0.8588
7	Dinoflagellates	0.9547	0.2975
8	Cyanophyta	0.7689	-0.2224
9	Tintinnids	-0.3035	0.5593
10	POC:Chl *a*	-0.3825	-0.0403
11	Phyto.C:Chl *a*	0.2596	0.6236
12	POC:Phyto.Carbon	-0.2321	-0.5233
13	Detritus.	-0.4981	0.3507

Table. 3.51. Species scores used to draw the PCA species scatter plot

A 'species' scatter plot (Figure 3.52) showed that axis 2 was highly correlated with phytoplankton carbon, centric diatoms, dry weight and POC. Axis 1 was highly correlated with dinoflagellates and cyanophyta. These deductions were based on species scores provided in the output file (Table 3.51) which shows the relationships between species and axes interms of species scores. The higher the species score, the stronger the relationship between that species and the axis. The eigen values show the relative importance of each axis.

Regr: Regression/canonical coefficients for standardized variables			
N	Name	AX1	AX2
	Eigenvalue	0.6425	0.3359
1	NH4	0.4877	-0.4101
2	NO3	0.5175	0.3883
3	PO4	0.0516	0.0536
4	Salinity	0.1008	0.3791
5	pH	0.2608	-0.515
6	Temperature	0.1162	-0.2526
7	Secchi depth	0.2866	-0.3757

Table. 3.52. Canonical coefficients of environmental factors with respect to the axes.

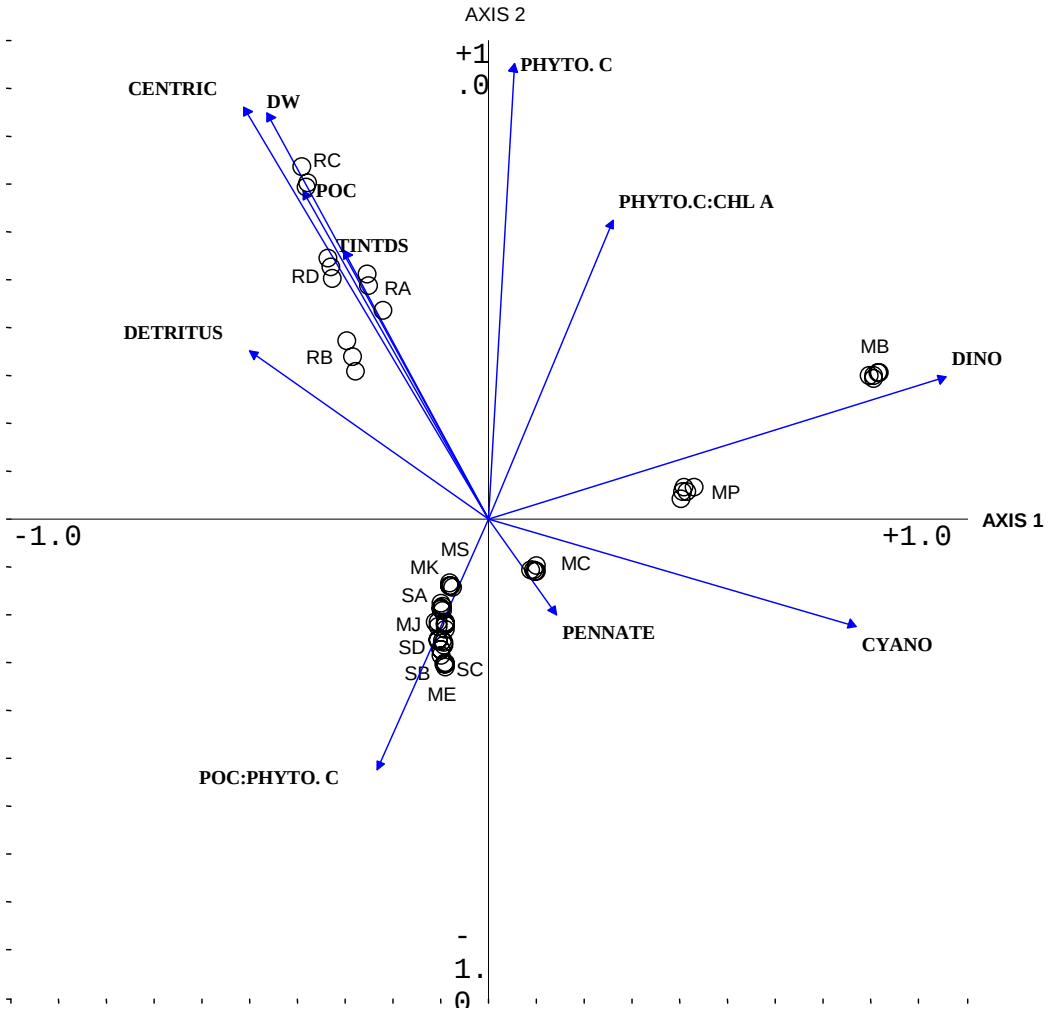


Fig. 3.54. A PCA biplot of 'species' (SPM components) and sites. Arrows represent SPM components and points represent stations.

Figure 3.54 is a species -sites biplot. Sites close together have similar characteristics whereas positively correlated species have small angles between their arrows. The value of a species changes linearly across the biplot in the direction of the arrow and this is the direction of the largest increase in the value of that species. The length of the arrow represents the rate of variation. Thus longer arrows have a higher rate of variation than small arrows. The relative importance of a species to a site is obtained by plotting the site point on to the species arrow. The shorter the distance, the more important the species is to that site.

Based on the above description, it can be seen that stations R1, R2, R3 and R4 are characterised by high concentrations of phytoplankton carbon, centric diatoms, dry weight, POC and detritus (Figure 3.54). This can further be supported by the species scores in table 3.51 which shows that the above mentioned factors are highly correlated with axis 2. Hence it can be said that these factors explain the ranking of the sites along axis 2.

Stations ME, SD, SB, SC, MJ, SA, MK, MC and MS are characterised by low values of the above factors and their clustering is based mainly on POC / phtoplankton carbon ratio. Stations MB and MP are characterised by high numbers of dinoflagellates. Dinoflagellates are highly correlated with axis one hence it can be said that they explain most of the variation (stations ranking) along axis 1.

The correlation between the environmental factors and the axes also serves to explain the clustering of the stations. From the PCA output correlation matrix (Table 3.52), ammonia and nitrate concentrations are highly correlated with axes 1. Thus it can be said that the variation along axis 1 is also influenced by these nutrients. Salinity may also explain some the variation along axis 2 based on the coefficients in table 3.52.

CHAPTER FOUR

DISCUSSION AND CONCLUSIONS

4.1. Discussion

The decrease in salinity along Mtwapa creek and Ramisi estuary (figure 3.11) can be explained by tidal effects and freshwater influence. Station ME recorded a salinity (35.4‰) close to that of ocean waters. This station was located at the creek mouth hence it was highly influenced by tides which bring in high salinity ocean waters during flood tides. Salinity decreased towards the extreme upper stations probably due to decreased tidal effects. The salinity decrease could also be linked to freshwater influence or to surface runoff which may form a brackish water plume when freshwater entrains denser sea water. A salinity decrease along Mtwapa creek was also reported by Mwangi et *al*., (1998) who recorded salinities ranging from 9 to 36‰. The observed range was 29-35‰. However their sampling campaign covered a bigger part of the creek than the present work hence the large salinity range. Okemwa (1990) also reports a salinity decrease along Tudor creek which he attributes to freshwater influence. Salinity decrease in Ramisi can be linked to dilution effect by fresh water from Ramisi river. The similarity between all stations in Shirazi suggests that there is little or no fresh water influence. No river was observed to drain into Shirazi creek and surface runoff may be minimal. Tidal range may also be high thus influencing most of the creek waters equally leading to similarities in salinity.

Being in the open ocean, the level of SPM is probably low at station ME and resuspension could be minimal due to depth leading to high secchi depth values. The depth of Mtwapa creek at oceanic entrance is 10m (Magori, 1997). Station MK recorded the lowest secchi depth in Mtwapa. This was the extreme uppermost station within the mangrove creeks. Since the tidal range in Mtwapa is large relative to the depth (Mwangi et *al*., 1998), turbulence causes resuspension of sediments and organic detritus within the mangroves leading to increased turbidity hence low secchi depths. Correlations between secchi depth, DW and POC were negative and significant (Spearman R= -0.4 and -0.6, $p< 0.05$). Station R4 in Ramisi was located at the estuary mouth which is highly

influenced by tidal and river currents. Due to interaction between tidal and river currents, the resulting turbulence leads to resuspension of deposited materials which increases turbidity. This effect could explain the low secchi depths recorded in Ramisi. These interactions continue along the estuary though at a lower magnitude and this could explain why secchi depths in Ramisi decreased along the estuary and were the lowest among the three sites. River discharge could be muddy and this coupled with the high levels of organic detritus observed can also probably explain the low secchi depths recorded. However correlations between secchi depth, POC and dertitus were significant ($R= 0.9$, $p< 0.05$) whereas correlation was slightly negative between secchi depth and DW ($R= -0.5$, $p >0.05$). Based on these correlations, it can then be said that the inorganic component of DW could be responsible for the observed low secchi depths.

The observed temperature decrease along Mtwapa reflects the influence of cool ocean waters on the creek waters. Station ME at the mouth of the creek recorded the lowest temperature and station MK at the extreme upper end recorded the highest. During flood tides, cool ocean waters are flushed into the creek. The effect of this cool ocean water on creek water depends on the proximity to the open ocean. Nearby stations are greatly impacted and the effect decreases along the creek. Being near the open ocean, this efffect was probably higher at station ME than at station MK. This could be a probable explanation for the observed temperature decrease towards the seaside stations (Figure 3.12). In Ramisi, the extreme upper station (R1) recorded the lowest temperature than station R4 at the mouth. Ramisi is influenced by both tides and river water flow. The observed pattern suggests that riverine waters could have been cooler than ocean waters leading to the low temperatures recorded at station R1 which experiences minimal interactions with the ocean. Whether this low temperature is also related to the observed shading effect of the river channel by mangrove trees canopy needs to be determined.

All pH values recorded were slightly alkaline (figure 3.12). Shirazi recorded the highest pH and Ramisi the lowest. Dissolved organic substances derived from particulate organic matter brought in by the river could be responsible for the low pH recorded in Ramisi. Humic acid derived from decomposition of mangrove leaves can also be responsible for this low pH.

Ammonia concentrations were highest at stations MB and MP with the peak value at MB. These two stations were located within the vicinity of sewage discharge points. In particular, MB was located near a major point source, a government prison whose sewage discharge pipe was clearly visible during low tide. On several occasions, this sampling station was characterised by foul smell that was evidence of raw sewage discharge. This coupled with surface runoff could explain the observed high ammonia concentrations. A similar finding was reported by Mwangi et *al*., (1998) who attributed their peak value to the sewage discharge and surface runoff. This may explain the significant differences observed between Mtwapa and Shirazi which suffers little or no anthropogenic impacts. The fact that another though lower peak value, occurred at sation MK the extreme upper station, may suggest the contribution from the surrounding mangrove swamps since this station was located far from the sewage discharge points. However the contribution of mangroves to creek nutrients is yet to be known.

The highest nitrate concentrations were also recorded at station MB. The trend was a decrease from this station towards the ocean entrance and the extreme upper stations. This peak value can also be linked to raw sewage discharge.

Phosphates showed a similar pattern in Mtwapa although the highest concentration was recorded in Shirazi station S1.

The fact that Ramisi (estuarine system) experiencing immense riverine discharge recorded lower concentrations of nutrients than Mtwapa may point to the fact that the several sewage discharge points along Mtwapa creek greatly influence the observed peaks in nutrient concentrations especially at station MB.

Although the stations within the vicinity of sewage discharge points recorded high nutrient concentrations, no phytoplankton bloom was observed. This may imply that macro-tidal environment ensures that localised eutrophic conditions are prevented. Mtwapa creek is classified as a weakly choked lagoon based on tidal currents since ebb currents are stronger than flood currents (Magori, 1997). Ebb dominance may lead to high turbidity, a factor which may prevent phytoplankton from taking up the elevated nutrient levels because of poor water clarity hence preventing bloom conditions. The residence time of water within the creek is also another possible explanation. In Mtwapa

this time spans from 3 to 12 days (Magori, 1997). A shorter residence time may mean that nutrients are flushed out before phytoplankton effectively utilise them hence preventing bloom conditions.

Chlorophyll *a* concentrations were significantly higher in Mtwapa than in Shirazi. The peak value in Mtwapa was recorded at station MB which also recorded the peak values for ammonia, nitrate and phosphate concentrations. This suggests that the high nutrient concentrations in this station could be responsible for the high chlorophyll *a* concentration. Spearman correlation showed that chlorophyll *a*, ammonia and phosphates were positively correlated ($R=0.9$, $p< 0.05$) but slightly negatively correlated to nitrates ($R=-0.35$, $p> 0.05$). This station also recorded the peak value for phytoplankton carbon and the highest stocks of dinoflagellates. However chlorophyll *a* and dinoflagellates were negatively correlated meaning that the high abundance of dinoflagellates had little or no influence on the chlorophyll *a* concentration. This could be because dinoflagellates are characterised by red pigments and little of the chlorophyll *a* (Tappan, 1980).

The low values of phytoplankton carbon / chlorophyll *a* ratio in Shirazi is linked to the low concentrations of phytoplankton carbon. This may also suggest that phytoplankton is the main contributor of chlorophyll *a* since true phytoplankton carbon / chlorophyll *a* ratio ranges between 15 to 45. In turbid areas, low phytoplankton carbon / chlorophyll *a* ratio could be an indication that the phytoplankton is adapted to the prevailing low light conditions (Richardson *et al*., 1983). This situation can not however apply to Shirazi since secchi depths were relatively high. But it may be applicable to stations MS and MK in Mtwapa which recorded low values (9 and 10) and had the lowest secchi depth values.

The observed differences between sites in POC concentrations are linked to the levels of detritus and phytoplankton carbon recorded. Ramisi recorded the highest values of these factors hence its high POC concentration. The high levels of detritus in Ramisi relate to riverine input of allochthonous material and the contribution from the mangroves. The observed decrease from R1 to R4 suggests the possible increase in flocculation and sedimentation of organic particles with salinity increase, a phenomenon

which is explained herein. The detritus component in Shirazi was significantly higher than in Mtwapa (97-99% compared to 17-96%) and this explains why Shirazi recorded higher POC concentrations than Mtwapa. The increasing pattern from the creek mouth towards the inner stations in Mtwapa concides with the observed increase in mangrove forest cover along the creek, suggesting contribution of detritus from mangrove leaves.

Phytoplankton carbon distribution followed the pattern of phytoplankton stocks. Ramisi recorded the highest phytoplankton carbon levels whereas Shirazi recorded the lowest.The highest phytoplankton carbon levels were recorded in stations with the highest chlorophyll *a* and inorganic nutrients concentrations.

Cluster analysis produced three main groupings of the stations; one group of purely estuarine stations (R1, R2, R3 and R4), a second group which was a mixture of stations from Mtwapa and Shirazi (MS, MK, MJ, MC, ME, SA, SB, SC and SD, and a third group comprising of only stations MB and MP from Mtwapa. As mentioned earlier, this clustering was based on: phytoplankton carbon, centric diatoms, dry weight and POC for cluster 1, POC / phytoplankton carbon ratio for cluster 2 and dinoflagellates for cluster 3.

The high levels of dry weight and POC in the estuarine stations can be related to riverine supply of allochthonous particulate matter and also the possible resuspension of sediments. Being influenced by both tidal and river currents, turbulence is bound to be high due to the interaction between these two currents. Dry weight and POC however displayed different patterns. Dry weight increased from the extreme upper station (R1) to the mouth (R4) whereas POC showed a decreasing trend. At the estuary mouth, deposition and resuspension may be higher than in the extreme upper stations due to stronger tidal currents. Since DW is a measure of both organic and inorganic particulate matter, the observed pattern may suggest that inorganic particles were important components of SPM towards the estuary mouth. This can be supported by the negative correlations observed between DW and POC and DW and detritus (Spearman $R = -0.6$, $p = 0.05$). Flocculation and subsequent sedimentation of suspended particulate organic matter at the estuary mouth can also explain the observed pattern. In estuarine and nearshore environments physicochemical flocculation takes place. Particles in freshwater posses surface charges which repel neighbouring particles. However in salty and brackish

waters, the repulsion by these surface charges is reduced as the charge approaches zero (Wangersky, 1977) and particles can form large aggregations called 'flocs' which may accelerate the sinking and sedimentation of organic particulate matter. This phenomenon may explain why station R1 with the lowest salinity values recorded the highest POC concentrations whereas station R4 with the highest salinity recorded the lowest (Figure 3.21). Due to consumption of settled organic matter by benthic organisms coupled with bacterial mineralization, resuspension of bottom materials can result in high levels of DW with low organic content (Eima and Kalf, 1987). This also offers a probable explanation of the observed POC decrease towards the estuary mouth.

Mtwapa and Shirazi experience less riverine influence and hence the allochthonous component of their particulate matter is lower. Mtwapa however showed sigficantly higher levels of DW than Shirazi whereas Shirazi recorded higher levels of POC than Mtwapa. This suggests that the inorganic component in Mtwapa could have been significant than in Shirazi. This observation is supported by the lower secchi depths recorded in Mtwapa than in Shirazi (Figure 3.11). As mentioned earlier the tidal range in Mtwapa is high relative to the depth and this may favour resuspension of sediments within the creek and mangroves leading to low secchi depths. Surface runoff could also be significant in Mtwapa owing to poor drainage systems within the neighbouring Mtwapa municipality. This situation leads to storm runoff waters draining into the creek increasing turbidity.

Detritus is the main source of POC in Ramisi as shown by the results. It accounts for between 29-84% of the total POC with a mean of 61±20%. The observed slightly negative correlation between POC and phytoplankton carbon (Spearman $R = -0.4$, $p > 0.05$) may also confirm this conclusion. These high detritus levels are expected because of the allochthonous supply of particulate material by the river and the contribution from mangroves which fringe the banks of the estuary.

Ramisi also recorded the highest abundance of centric diatoms though secchi depth was the lowest. Diatoms contain chlorophyll *c*, a pigment which absorbs blue light better than the other chlorophylls (Tappan, 1980). In turbid environments, light penetration is low due to increased impedance. The high abundance of diatoms in Ramisi is thus an

indication of their adaptability to waters of low transparency for they posess chlorophyll *c* which absorbs blue light which penetrates deeper in the water collumn. This high abudance of diatoms explains the high concentrations of phytoplankton carbon recorded in Ramisi. Stations MS and MK also recorded relatively higher diatom concentrations than the other stations and than Shirazi. This may also be linked to the low secchi depths recorded in these stations. The low phytoplankton carbon to chlorophyll *a* ratio recorded in MS and MK may reflect the adaptation of the diatoms to the low water transparency (Richardson *et al*., 1983).

The two creek systems (Mtwapa and Shirazi) were separated into two distinct clusters. The cluster comprising sations MS, MK, MJ, MC, ME, SA, SB, SC and SD was characterised by high values of POC / phytoplankton carbon ratio and to a lesser extend by pennate diatom stocks. Except station MJ, all stations in this cluster recorded phytoplankton carbon concentrations ranging fom 9 - 27 µgC/l whereas the other clusters recorded concentrations ranging from 89 - 591 µgC/l (Figure 3.22). The high POC / phytoplankton carbon ratio is further confirmed by the extremely weak correlation between POC and phytoplankton carbon observed from these stations (Spearman, $R = 0.1$, $p > 0.05$). Detritus accounted for 97%±0.7 of the total POC in Shirazi and 65%±29 in Mtwapa. This is a clear indication that detritus was the main component of POC in Mtwapa and Shirazi. Phytoplankton carbon and detritus were negatively correlated suggesting that the detritus was mainly of allochthonous origin. The probable origin of this detritus is the mangrove forests which fringe the banks of both creeks. Since the tidal amplitude in Mtwapa creek is relatively high (3m-0.8m) and ebb currents are stronger than flood currents (Magori, 1997), organic detritus from mangrove leaves is exported from the mangrove forests into the creeks. The weak correlation between POC and phytoplankton carbon and the presence of mangrove wetlands characterised by a relatively high tidal range and tidal assymetry helps explain why detritus in these creeks probably originates from the mangroves. Freshwater influence in the creeks is seasonal especially in Mtwapa hence it only influences the detritus component of POC during rainy seasons as reported by Mwangi *et al*, (1998).

Stations MB and MP stand out clearly as a separate cluster characterised by dominance by dinoflagellates. The ranking of these stations can also be explained by their nitrate and ammonia concentrations based on the canonical coefficients in table 3.52. Both stations were located within the vicinity of sewage discharge points and this may explain the high concentrations of inorganic nutrients recorded. Low phosphate concentrations favour dinoflagellate diversity in tropical waters though their numbers may not reach bloom levels (Tappan, 1980). Dinoflagellate blooms usually follow diatom blooms since the period after a diatom bloom is characterised by nutrient poor waters especially lack of silicates. Silicate regeneration takes place deeper in the water column since it involves re-solution of diatom frustules which sink to deep waters after diatoms death. Thus silicate is made available to the surface waters through mixing. (Wangersky, 1977). The time lag between population breakdown of diatoms and re-solution of their frustules may permit the growth of dinoflagellates which are efficient in assimilating nutrients at low concentrations than the diatoms and are also poor competitors for nutrients.

Based on the above facts, it can be postulated that the high numbers of dinoflagellates recorded at stations MB and MP concides with a breakdown of diatom population and as silicate probably becomes limiting, dinoflagellates take over owing to low competition for the available low nutrient concentrations. This is supported by the fact that most dinoflagellates are adapted to low nutrient conditions and their blooms characteristically follow diatom blooms (Tappan, 1980). The abundance of dinoflagellates in these stations thus suggests that the high ammonia, nitrate and phosphate concentrations from sewage discharge could be supporting growth of diatoms which after breakdown of the population, are replaced by dinoflagellates taking advantage of reduced competition, before silicate concentration builds up and diatoms pick up again. This appears to be the probable explanation for the high abundance of dinoflagellates since centric diatoms, mainly *Coscinodiscus*, were found to be the dominant group in Mtwapa creek in a study carried out by Mwangi *et al.*, (1998). This was however during the rainy season in May. Since sampling for the present work was done between August and October (dry season), the results obtained probably suggest that this period could have concided with a decline in diatom population and the

consequent succession by dinoflagellates as ammonia, nitrate and phosphate concentrations probably became too low to support diatoms and silicate concentration could have become too low due to sedimentation of frustules. This conclusion can further be supported by comparing the observed nutrient concentrations in stations MB and MP with those reported by Mwangi *et al*., (1998). They reported ammonia, nitrate and phosphate concentrations of 33.6, 77 and 18.6 µg/l respectively during the rainy season. These values are almost twofold the values recorded in this work.

4.2. Conclusions

From the results obtained, Mtwapa and Shirazi creeks can be differentiated based on their nutrient levels, dominant phytoplankton groups and phytoplankton carbon. These factors are significantly higher in Mtwapa than in Shirazi. These differences can be associated with anthropogenic inpacts (sewage discharge) evident in Mtwapa. This effect is more pronounced in stations MB and MP which were located within the vicinity of major points of sewage discharge and are the stations which are distinctly separated from Shirazi in the cluster analysis (Figure 3.51) or in the PCA sites scatter plot shown in figure 3.53. All stations in Ramisi stand out clearly as a separate cluster. This is expected because of the influence from Ramisi river, a characteristic which is lacking in Mtwapa and Shirazi.

From the results obtained it is evident that detritus is a major component of POC in Mtwapa, Shirazi and Ramisi as evidenced by the high percentage contribution of detritus to the total POC. All mean percentage contributions of detritus were over 60%. Tentatively, mangroves can be said to be the probable sources of detrirus material in these systems though more work needs to be done to determine the relationship between mangrove forests and the detritus in these systems.

To fully understand the effect sewage discharge has on the functioning of Mtwapa creek system, a detailed study of hydrographic factors, physico-chemical factors and SPM components needs to be undertaken. Taxonomic studies on the phytoplankton community structure is also vital to highlight any indicator groups which could be present in the system.

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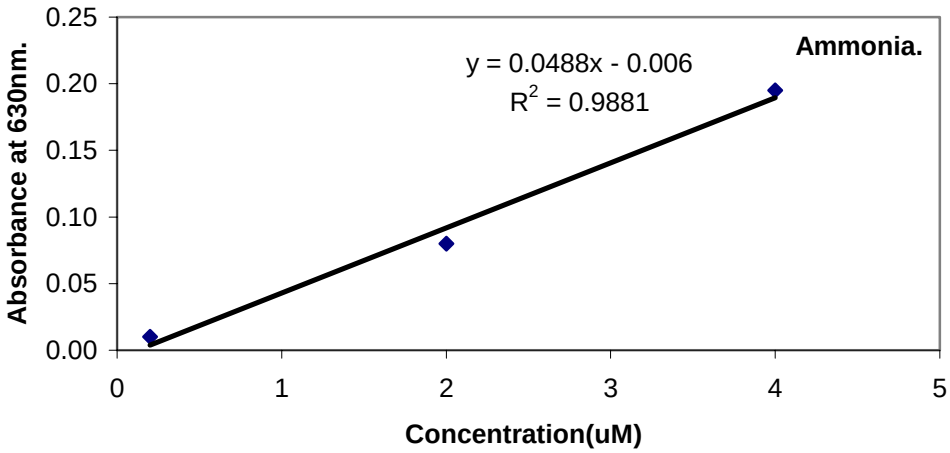
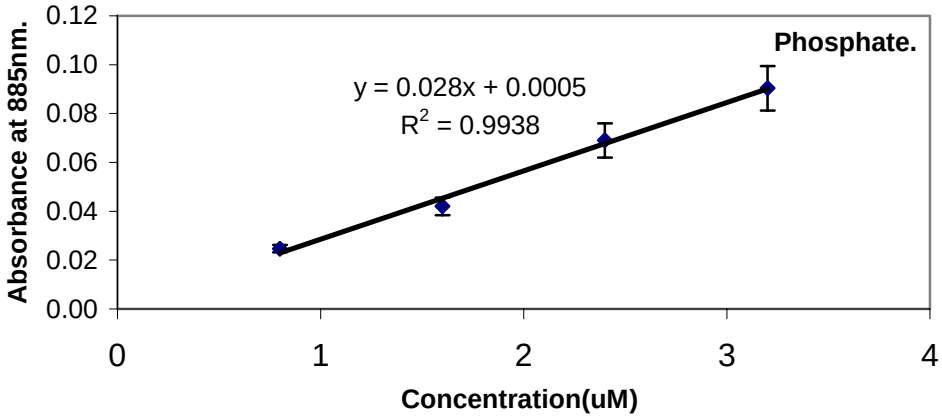
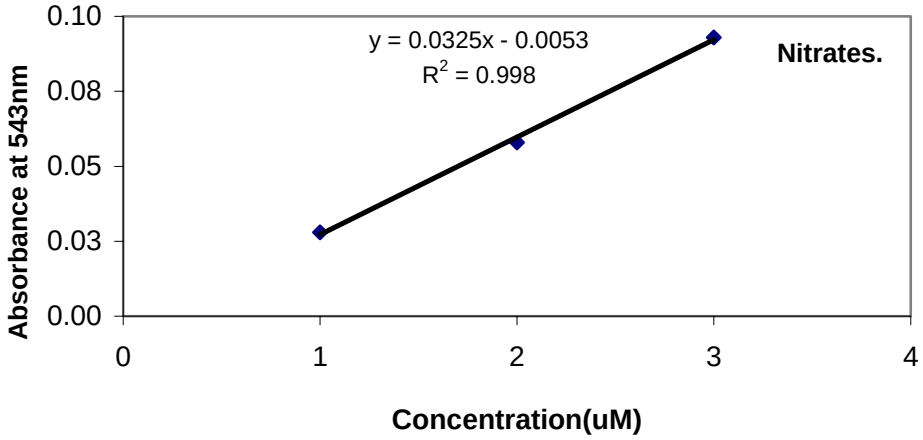
ANNEXE
Nutrients calibration plots







ANOVA TABLES.

Ammonia

MAIN EFFECT: Sites					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	385.3689	2	192.6845	120.2729	0
Error	70.4907	44	1.6021		

Unequal N HSD; variable NH_4			
Probabilities for Post Hoc Tests			
MAIN EFFECT: SITES			
Mean	12.85714	7.133333	8.283334
Stations	{1}	{2}	{3}
		p- level	
{1}		0.00013	0.00013
{2}	0.00013		0.078031
{3}	0.00013	0.078031	

MAIN EFFECT: Stations.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	546.1873	14	39.01338	24.352	0
Error	70.4907	44	1.60206		

Nitrates.

MAIN EFFECT: SITES.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	172.5898	2	86.29488	161.3715	0
Error	23.5294	44	0.53476		

Unequal N HSD; variable NO_3			
Probabilities for Post Hoc Tests			
MAIN EFFECT: SITES			
Mean	10.04	5.8	10.075
Stations	{1}	{2}	{3}
		p- level	
{1}		0.00013	0.992533
{2}	0.00013		0.00013
{3}	0.992533	0.00013	

MAIN EFFECT: Stations.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	1075.728	14	76.83773	143.6866	0
Error	23.529	44	0.53476		

Phosphates

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	39.94349	2	19.97175	36.55192	0
Error	24.04133	44	0.54639		

Unequal N HSD; variable PO_4			
Probabilities for Post Hoc Tests			
MAIN EFFECT: SITES			
Mean	7.982857	9.8	9.491667
Stations	{1}	{2}	{3}
		p - level	
{1}		0.000131	0.000153
{2}	0.000131		0.567345
{3}	0.000153	0.567345	

MAIN EFFECT: Stations.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	782.4011	14	55.88579	102.2811	0
Error	24.0413	44	0.54639		

Salinity.

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	338.508	2	169.254	576.4067	0
Error	12.92	44	0.2936		

Unequal N HSD; variable Salinity.			
Probabilities for Post Hoc Tests			
MAIN EFFECT: SITES			
Mean	33.04286	34.5	27.63333
Stations	{1}	{2}	{3}
		p-level	
{1}		0.00013	0.00013
{2}	0.00013		0.00013
{3}	0.00013	0.00013	

MAIN EFFECT: Station.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	860.4404	14	61.46003	209.3066	0
Error	12.92	44	0.29364		

pH

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	2.839274	2	1.419637	308.2107	0
Error	0.202667	44	0.004606		

Unequal N HSD; variable pH Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	8.162857	8.341666	7.691667
Stations	{1}	{2}	{3}
		p-level	
{1}		0.00013	0.00013
{2}	0.00013		0.00013
{3}	0.00013	0.00013	

MAIN EFFECT: Stations.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	5.216655	14	0.372618	80.89738	0
Error	0.202667	44	0.004606		

Temperature.

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	1.974871	2	0.987435	6.880357	0.002512
Error	6.314667	44	0.143515		

Unequal N HSD; variable Temperature. Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	26.57143	26.99167	26.475
Stations	{1}	{2}	{3}
		p-level	
{1}		0.02505	0.808151
{2}	0.02505		0.004886
{3}	0.808151	0.004886	

MAIN EFFECT: Stations.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	7.923299	14	0.56595	3.943486	0.000238
Error	6.314667	44	0.143515		

Secchi depth.

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	11.94057	2	5.970286	125.9715	0
Error	2.08533	44	0.047394		

Unequal N HSD; variable Secchi depth. Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	1.74571	2.558333	1.158333
Stations	{1}	{2}	{3}
		p-level	
{1}		0.00013	0.00013
{2}	0.00013		0.00013
{3}	0.00013	0.00013	

MAIN EFFECT: Stations.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	27.32043	14	1.951459	41.17529	0
Error	2.08533	44	0.047394		

Chl *a*

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	64.25718	2	32.12859	459.5886	0
Error	3.07592	44	0.06991		

Unequal N HSD; variable Chlorophyll *a* Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	1.955143	1.641667	4.45
Stations	{1}	{2}	{3}
		p-level	
{1}		0.01563	0.00013
{2}	0.01563		0.00013
{3}	0.00013	0.00013	

MAIN EFFECT: Stations.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	119.5113	14	8.536521	122.1121	0
Error	3.0759	44	0.069907		

DW

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	34153.51	2	17076.75	2005.241	0
Error	374.71	44	8.52		

Unequal N HSD; variable Dry weights. Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	27.88571	18.30833	84.49167
Stations	{1}	{2}	{3}
		p-level	
{1}		0.00013	0.00013
{2}	0.00013		0.00013
{3}	0.00013	0.00013	

MAIN EFFECT: Stations.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	35458.86	14	2532.776	297.4117	0
Error	374.71	44	8.516		

POC

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	9213542	2	4606771	17075.67	0
Error	11871	44	270		

Unequal N HSD; variable Particulate organic carbon. Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	408.5829	643.5417	1423.675
Stations	{1}	{2}	{3}
		p-level	
{1}		0.00013	0.00013
{2}	0.00013		0.00013
{3}	0.00013	0.00013	

MAIN EFFECT: Stations.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	12545217	14	896086.9	3321.477	0
Error	11871	44	269.8		

Phyto Carbon.

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	1476153	2	738076.4	15089.76	0
Error	2152	44	48.9		

Unequal N HSD; variable Phytoplankton Carbon. Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	134.2857	13.025	478.3917
Stations	{1}	{2}	{3}
		p-level	
{1}		0.00013	0.00013
{2}	0.00013		0.00013
{3}	0.00013	0.00013	

MAIN EFFECT: Stations.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	2164090	14	154577.8	3160.3	0
Error	2152	44	48.9		

Detritus.

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	4350093	2	2175046	6626.947	0
Error	14441	44	328		

Unequal N HSD; variable Detritus. Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	274.2971	630.5167	945.2833
Stations	{1}	{2}	{3}
		p-level	
{1}		0.00013	0.00013
{2}	0.00013		0.00013
{3}	0.00013	0.00013	

MAIN EFFECT: Stations.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	8446463	14	603318.8	1838.196	0
Error	14441	44	328.2		

Pennate diatoms.

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	74480208	2	37240104	119.9776	0
Error	13657251	44	310392		

Unequal N HSD; variable Pennate diatoms. Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	8295.172	5561.25	6700.333
Stations	{1}	{2}	{3}
		p-level	
{1}		0.00013	0.00013
{2}	0.00013		0.000153
{3}	0.00013	0.000153	

MAIN EFFECT: Stations.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	654745664	14	46767548	150.6725	0
Error	13657251	44	310392		

Centric diatoms.

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	1.63E+10	2	8151449600	13429.64	0
Error	26706880	44	606975		

Unequal N HSD; variable CENTRIC Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	6434.971	5205.25	47400.92
Stations	{1}	{2}	{3}
		p-level	
{1}		0.001142	0.00013
{2}	0.001142		0.00013
{3}	0.00013	0.00013	

MAIN EFFECT: Stations.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	1.71E+10	14	1224309120	2017.068	0
Error	26706880	44	606975		

Dinoflagellates.

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	4729954816	2	2364977408	17436.01	0
Error	5968052	44	135638		

Unequal N HSD; variable DINOFLAG Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	20449.57	1293.417	3239.417
Stations	{1}	{2}	{3}
		p-level	
{1}		0.00013	0.00013
{2}	0.00013		0.00013
{3}	0.00013	0.00013	

MAIN EFFECT: Stations.					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	2.70E+10	14	1928792320	14220.2	0
Error	5968052	44	135638		

Cyanophyta.

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	7749758	2	3874879	645.2702	0
Error	264222	44	6005		

Unequal N HSD; variable Cyanobacteria. Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	921.8	264.8333	115.9167
Stations	{1}	{2}	{3}
		p-level	
{1}		0.00013	0.00013
{2}	0.00013		0.000195
{3}	0.00013	0.000195	

MAIN EFFECT: STATIONS					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	10830298	14	773592.7	128.8237	0
Error	264222	44	6005		

Tintinnids.

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	245581856	2	122790928	2609.755	0
Error	2070233	44	47051		

Unequal N HSD; variable Tintinnids. Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	1375.971	518.0833	6157.167
Stations	{1}	{2}	{3}
		p-level	
{1}		0.00013	0.00013
{2}	0.00013		0.00013
{3}	0.00013	0.00013	

MAIN EFFECT: STATIONS					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	559599424	14	39971388	849.5378	0
Error	2070233	44	47051		

POC/Chl *a*

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	285712.2	2	142856.1	139.8658	0
Error	44940.7	44	1021.4		

Unequal N HSD; variable POC:Chl *a* Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	260.3802	397.255	406.5695
Stations	{1}	{2}	{3}
		p-level	
{1}		0.00013	0.00013
{2}	0.00013		0.756694
{3}	0.00013	0.756694	

MAIN EFFECT: STATIONS					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	1783696	14	127406.9	124.7399	0
Error	44941	44	1021.4		

Phyto. Carbon:Chl *a*

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	69222.73	2	34611.36	315.8301	0
Error	4821.9	44	109.59		

Unequal N HSD; variable Phyto.Carbon:Chl *a* Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	73.23794	8.159827	113.9137
Stations	{1}	{2}	{3}
		p-level	
{1}		0.00013	0.00013
{2}	0.00013		0.00013
{3}	0.00013	0.00013	

MAIN EFFECT: STATIONS					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	172453	14	12318.08	112.4029	0
Error	4821.9	44	109.59		

POC:Phyto. Carbon.

MAIN EFFECT: SITES					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	22462.31	2	11231.15	1528.728	0
Error	323.26	44	7.35		

Unequal N HSD; variable POC:Phyto. Carbon. Probabilities for Post Hoc Tests MAIN EFFECT: SITES			
Mean	9.98825	56.31906	3.292669
Stations	{1}	{2}	{3}
		p-level	
{1}		0.00013	0.00013
{2}	0.00013		0.00013
{3}	0.00013	0.00013	

MAIN EFFECT: STATIONS					
Anova	Sum of Squares	df	Mean Square	F	p-level
Effect	30380.35	14	2170.025	295.3729	0
Error	323.26	44	7.347		

Spearman correlations

Mtwapa.

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
Secchi & DW	-0.483173	0.00328

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
SECCHI & POC	-0.608363	0.000106

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
POC & Detritus.	0.65518	0.000019

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
DW & POC	0.831045	0

Station MB and MP

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
Chl-*a* & Ammonia	0.9	0.037

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
Chl-*a* & Phosphates	1	0

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
Chl-*a* & Nitrates	-0.35	0.55

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
DINOFLAG & NH4	0.139818	0.700057
DINOFLAG & NO3	0.680854	0.030211
DINOFLAG & PO4	0.632222	0.049846

Ramisi.

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
Secchi & DW	-0.573051	0.051454

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
DW & POC	-0.58042	0.04786

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
SECCHI & POC	0.916127	0.000028

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
DW & Detritus	-0.5594441	0.05859

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
SECCHI & Detritus	0.904817	0.000052

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
POC & Detritus	0.979021	0

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
POC & Phyto.C	-0.447552	0.144586

Shirazi

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
POC & Detritus	0.99125	0

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
POC & Phyto. C	0.11053	0.73238

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
DW & POC	0.0668	0.83662

ME, MJ, MC, MS and MK

Spearman		
	MD pairwise deleted	
Pair of Variables	Spearman R	p-level
POC & Phyto. C	0.12	0.56776