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Spatial Distribution of Suspended Particulate Matter in Mtwapa Creek and Funzi Bay, Kenya

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Abstract—Surface water concentrations of inorganic nutrients and suspended particulate matter (SPM) components from Mtwapa and Shirazi creeks in Kenya were measured and compared. This was aimed at assessing the contribution of phytoplankton carbon, particulate organic carbon (POC) and detritus on the total SPM pool, and the influence of sewage discharge on these components of SPM. The results obtained were compared with those from Ramisi, an estuarine system. Using PCA and cluster analysis, three clear clusters of stations were obtained. The two creek systems (Mtwapa and Shirazi) were separated into two distinct clusters. The cluster comprising five stations in Mtwapa and four in Shirazi was characterised by high levels of POC: phytoplankton carbon ratio and to a lesser extent by pennate diatom stocks. All stations from Ramisi estuary were clustered together and were characterised by high concentrations of phytoplankton carbon, centric diatoms, dry weight, POC and detritus. A third cluster, comprised of two stations in Mtwapa, was characterised by high numbers of dinoflagellates. From the results obtained, detritus forms the main source of POC in the three sites; it accounts for a mean of 61% ± 20 in Ramisi, 97% ± 0.7 in Shirazi and 65% ± 29 in Mtwapa. These high detritus levels are expected because of the allochthonous supply of particulate material by the river in Ramisi and the contribution from mangroves, which fringe the banks of the estuary and the creeks.

INTRODUCTION

Suspended particulate matter includes all particles suspended in water, whether organic or inorganic. They may either originate autochthonously or allochthonously. Autochthonous particles are derived *in situ* and include planktonic organisms together with their remains and faeces, whereas allochthonous particles are derived from the land, air or from rivers draining into the system (Lenz, 1977).

Apart from its role in the trophic relations of aquatic ecosystems, suspended particulate matter (SPM) plays other important roles. It affects both biological and physico-chemical processes and may serve as a source or sink of carbon and other nutrients. Labile fractions of SPM from terrestrial sources and from dead planktonic organisms are easily degraded by microorganisms and provide sources of dissolved organic carbon. A correlation exists between productivity and concentration of SPM in the open ocean waters. Except in cases of upwelling and the spring blooms in temperate and boreal waters, the productivity of open oceans is largely governed by the rate of nutrient regeneration in surface waters. This regeneration is a function of the number of actively metabolising bacteria, which in turn is a function of the particle content (Wangersky, 1977). Small, autotrophic and heterotrophic organisms are prevalent in any water sample filtered from the sea and dominate the sestonic particulate organic

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carbon. Consequently, aquatic ecologists have used the measure of this sestonic organic carbon as a measure of the corresponding food that can be ingested by mesozooplankton.

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

Anthropogenic activities can influence the levels of suspended particulate matter through waste dumping and sewage discharge. These activities lead to elevated levels of particulate matter and nutrient levels, which promote phytoplankton growth. Increased phytoplankton growth increases the phytoplankton carbon and hence the total particulate organic carbon (POC) and SPM of the affected system.

The Kenyan coastal zone has experienced much physical development as a result of tourism and industrialisation, resulting in increased production of solid and liquid waste. Unfortunately, there has been no improvement in sewage treatment and disposal, and most establishments rely on septic tanks/soakage pits. Consequently, sewage from hotels and residential facilities finds its way into the marine environment directly through discharge or indirectly through seepage, especially where disposal systems are close to the shore (Mwangi et al., 1998). Increased nutrient concentration due to sewage discharge leads to increased phytoplankton growth, phytoplankton carbon and consequently the POC load of the system.

The overall aim of this study was to assess the concentrations and composition of suspended particulate matter of two localities at the Kenyan coast. The specific objective was to determine the influence of sewage discharge on the levels of particulate organic carbon (POC). This was achieved by measuring and comparing the following factors:

- Concentration of suspended particulate matter (SPM) as dry weights.
- Concentrations of particulate organic carbon (POC),
- The most abundant phytoplankton genera and their contribution to POC,
- Concentrations of inorganic nutrients (ammonia, nitrates and phosphates), and
- Chlorophyll *a* levels.

MATERIALS AND METHODS

Study sites

Two sites, Funzi bay located about 90 km south of Mombasa town (4^{o} 25’ S and 39^{o} 40’ E) and Mtwapa creek located 25 km north of Mombasa town (3^{o} 55’ S and 39^{o} 45’ E) were studied (Fig. 1). Funzi bay connects to Shirazi creek and Ramisi estuary. Four sites (S1–S4) were sampled at Shirazi creek, four (R1–R4) at Ramisi estuary and seven at Mtwapa creek.

Funzi bay is relatively unpolluted. The tourism industry and urbanisation have developed slowly in this area and there is little economic activity to attract human migration. Thus population density is low in the neighbouring area and there are no serious anthropogenic activities that might threaten the coastal ecosystems. Mtwapa creek system, on the other hand, receives raw sewage from nearby beach hotels, residential quarters and a government prison, which discharge waste directly into the creek, and from underground seepage from septic tanks. Poor drainage systems within the neighbouring Mtwapa municipality lead to storm run-off waters flowing into the creek. Mtwapa creek is also strongly influenced by seasonal river discharge (Mwangi et al., 1998).

The three systems are, however, bordered by mangrove forests, which may export organic matter into the estuary and creek systems with the tides.

Sampling

Sampling was done during slack waters in August, September and October 1999. Duplicate samples were taken for the measurement of each parameter and a mean and S.D. calculated. For the whole sampling period, a mean and S.E. was calculated

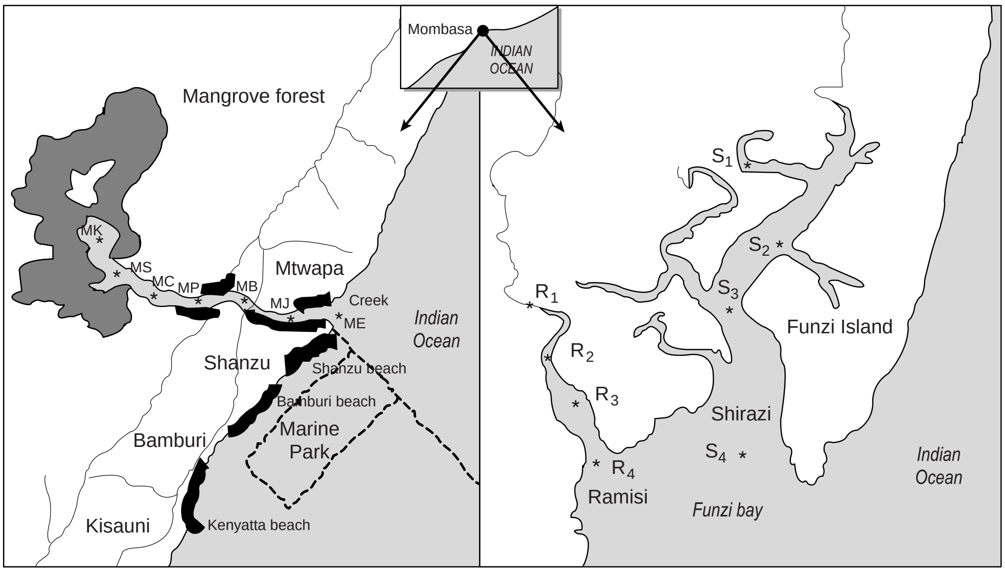

Fig. 1. Maps of Mtwapa creek 'M' and Funzi bay (Ramisi estuary 'R' and Shirazi creek 'S' showing the sampling stations.

for each parameter and for each station. Ammonia (NH_4^+), nitrate (NO_3^-) and phosphate (PO_4^{3-}) and chlorophyll-a levels in the water samples were analysed (Grasshoff 1976).

For POC, known volumes of seawater samples were filtered using a suction pump through pre-combusted (450 ºC for 3 hours) 0.45 μm pore Whatman® GF/F filters. The filters were then dried at 60 ºC overnight and stored in a dessicator for later analysis. Particulate total carbon (PTC) and particulate inorganic carbon (PIC) were measured using automatic coulometric titration with a Strohlein Coulomat 702.

Dry weights were determined by filtration, using a suction pump, of known volumes of seawater samples through pre-weighed 0.45 μm GF/F filters. Filters were then dried at 60 ºC 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.

Phytoplankton samples were prepared using the serial decantation method. Five-litre water samples preserved with Lugol's 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 then analysed using an inverted microscope. Abundance (cells/ml) of each taxonomic group and of the total phytoplankton was calculated using the appropriate conversions. Tintinnids were also counted and since it was difficult to determine whether the lorica contained individuals, they were counted to represent tintinnids. Size measurements were taken for the most abundant group (> 60%) in each station. Phytoplankton cell volume was calculated assuming the cells to be spherical or ellipsoidal (Mullin et al., 1966; Smayda, 1978). Phytoplankton cell carbon content, C (μg/l), for diatoms and non-diatoms was calculated using the Eppley formula (Smayda, 1978) given as

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

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

where V = cell volume (μm^3)

The detritus component of POC was estimated as the difference between particulate organic carbon and phytoplankton carbon (POC - Phyto. C). The Statistics software package Statistica® was used to perform cluster analysis and ANOVA whereas Canoco software was used for principal component analysis (PCA).

RESULTS AND DISCUSSION

PCA species-sites biplot (Fig. 2) revealed three clear clusters. One cluster was composed purely of the estuarine stations R1, R2, R3, and R4; the second cluster comprised a combination of stations from both Mtwapa and Shirazi creeks (MS, MK, S1, MJ, S3, S2, S4, MC and ME) and the third cluster was comprised of stations MB and MP all from Mtwapa creek. Sites close together have similar characteristics whereas positively correlated species have small angles between their arrows. The relative importance of a species to a site is obtained by plotting the site point perpendicular on to the species arrow. The shorter the distance, the more important the species is to that site. Based on this description, it is clear that stations R1, R2, R3 and R4 are characterised by high concentrations of phytoplankton carbon, centric diatoms, dry weight, POC, tintinnids and detritus. Stations ME, S4, S2, S3, MJ, S1, MK, MC and MS are characterised by high POC/phytoplankton carbon ratio. Stations MB and MP are characterised by high numbers of dinoflagellates.

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 current systems. Dry weight increased from the extreme upper station (R1) to the mouth (R4) (Fig. 3e) whereas POC showed a decreasing trend (Fig. 3f). 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 shows that inorganic particles are important components of SPM towards the

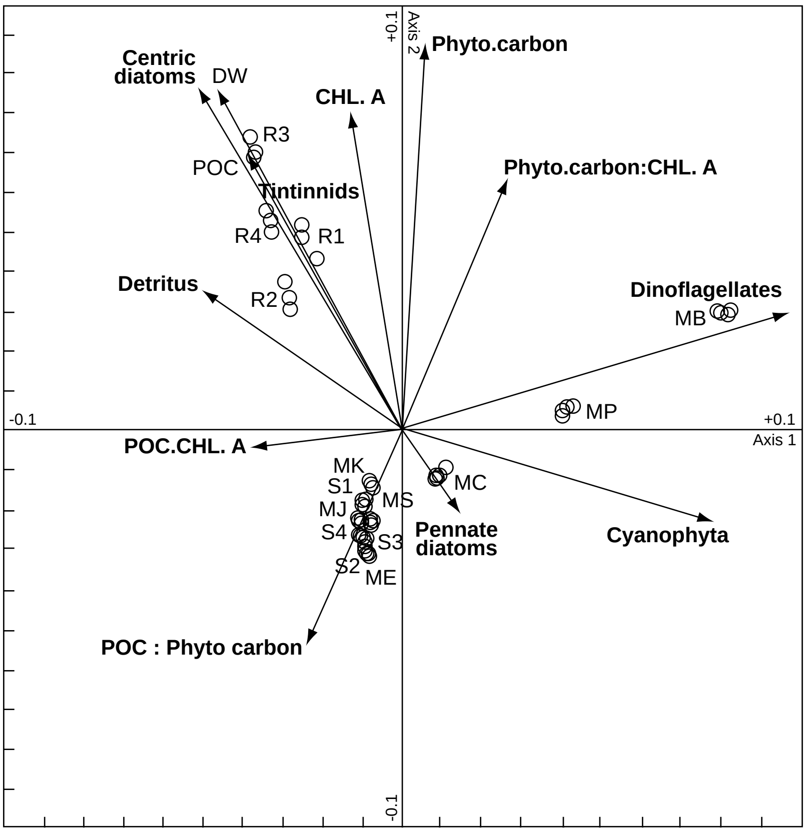

Fig. 2. Principal component analysis (PCA) biplot of 'species' (SPM) components and sites. Arrows represent SPM components and points represent the stations.

estuary mouth. This is supported by the negative correlation 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. This is because in salty and brackish waters, the surface charge of particles approaches zero hence repulsion significantly decreases (Wangersky, 1977), and particles can form large aggregations—known as flocs—which may accelerate the sinking and sedimentation of organic particulate matter. Also, due to consumption of settled organic matter by benthic organisms coupled with bacterial mineralisation, resuspension of bottom materials can result in high levels of DW with low organic content (Eisma & Kalf, 1987).

Mtwapa and Shirazi creeks experience less riverine influence and hence the allochthonous component of their particulate matter is lower. Mtwapa, however, had significantly higher levels

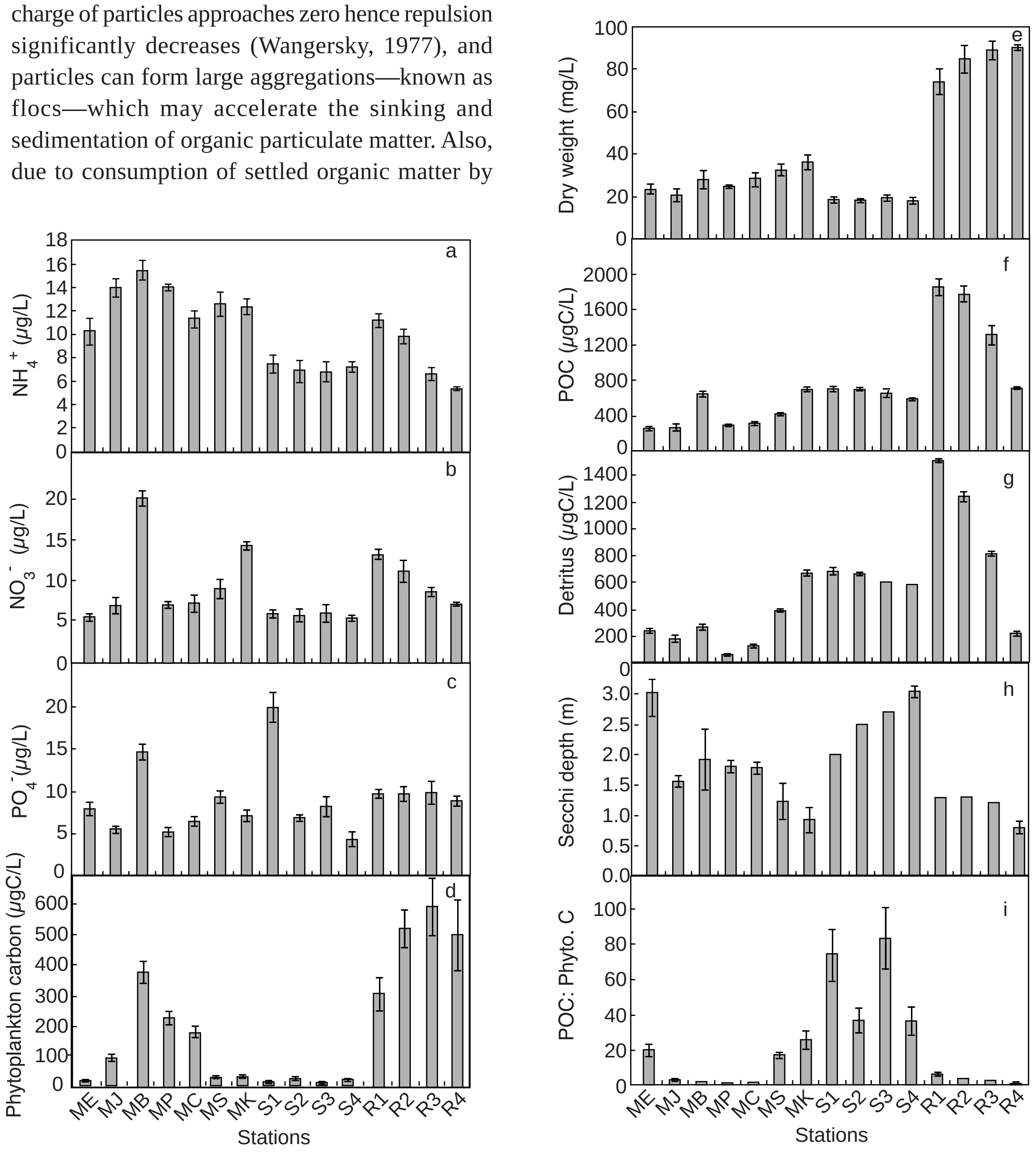

Fig. 3. Spatial variations in (a) ammonia; (b) nitrates, (c) phosphates, (d) pytoplankton carbon, (e) dry weights, (f) particulate organic carbon = POC, (g) detritus, (h) Secchi depth and (i) ratio of POC to phytoplankton carbon in samples from sites at sampling stations at Mtwapa (M), and Shirazi (S) and Ramisi (R) along the Kenyan coast

of DW and lower levels of POC than Shirazi (Fig. 3e, f). This suggests that the inorganic component of SPM in Mtwapa is more significant than in Shirazi. 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 high DW.

Ramisi also recorded the highest abundance of centric diatoms (Fig. 4c) though its Secchi depth was the lowest (Fig. 3h). Diatoms contain chlorophyll *c*, a pigment that 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 turbid waters, because they contain chlorophyll *c*, which absorbs blue light, which has higher penetration ability. This high abundance of diatoms explains the high concentrations of phytoplankton carbon (Fig. 3d) recorded in Ramisi. Stations MS and MK also recorded relatively higher diatom concentrations than the other stations in Mtwapa creek and Shirazi (Fig. 4a and 4b). This may also be linked to the low Secchi depths (Fig. 3h) recorded in these stations, thus reflecting the adaptation of diatoms to the low water transparency (Richardson et al., 1983).

The two creek systems (Mtwapa and Shirazi) were separated into two distinct clusters (Fig. 2). The cluster comprising stations MS, MK, MJ, MC, ME, S1, S2, S3 and S4 was characterised by high values of POC / phytoplankton carbon ratio and to a lesser extent by pennate diatom stocks (Fig. 2). Except station MJ, all the stations in this cluster recorded phytoplankton carbon concentrations ranging from 9–27 µgC/l whereas the other clusters recorded 89–591 µgC/l (Fig. 3d). The low phytoplankton carbon level in stations of this cluster explains the observed high POC/ phytoplankton carbon ratio (Fig. 3i). This 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 is the main source of POC in Ramisi; it accounts for between 29–84% of the total POC with a mean of 61 ± 20%. 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. Detritus also accounted for 97% ± 0.7 of the total POC in Shirazi and 65% ± 29 in Mtwapa (Fig. 3g). This is a clear indication that detritus is the main component of POC in Mtwapa, Shirazi and Ramisi. This detritus likely originates from the mangrove forests that fringe the banks of both creeks and the estuary. Since the tidal amplitude in Mtwapa creek is relatively high and ebb currents are stronger than flood currents (Magori, 1997), organic detritus from mangroves 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 asymmetry, helps explain why detritus in these creeks probably originates from the mangroves. Freshwater influence in the creeks is seasonal 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 of dinoflagellates (Fig. 4a) and high concentrations of ammonia, nitrates and relatively low phosphates (Figs. 3a, b and c). Both stations are located within the vicinity of observed sewage discharge points and this may explain their high concentration of nitrates and ammonia. 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 waters poor in nutrients, especially silicates. Silicate regeneration takes place deeper in the water column since it involves re-solution of diatom frustules, which sink to deep waters after diatom 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 more efficient in assimilating nutrients at low concentrations than diatoms, and are also poor competitors for nutrients. The abundance of dinoflagellates in these stations thus suggests that the ammonia, nitrates and phosphates from sewage discharge could be supporting the growth of diatoms. The breakdown of the diatom population is replaced by dinoflagellates taking advantage of reduced competition and low nutrient levels, before silicate concentration builds up and diatoms pick up again. This offers a 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).

It is evident that detritus is the major component of POC in the three sites, as evidenced its high percentage contribution to the total POC (Ramisi 61 ± 20 %, Shirazi 97 ± 0.7 % and Mtwapa 65 ± 29 %). Tentatively, mangroves can be said to be the probable sources of detritus in these systems,

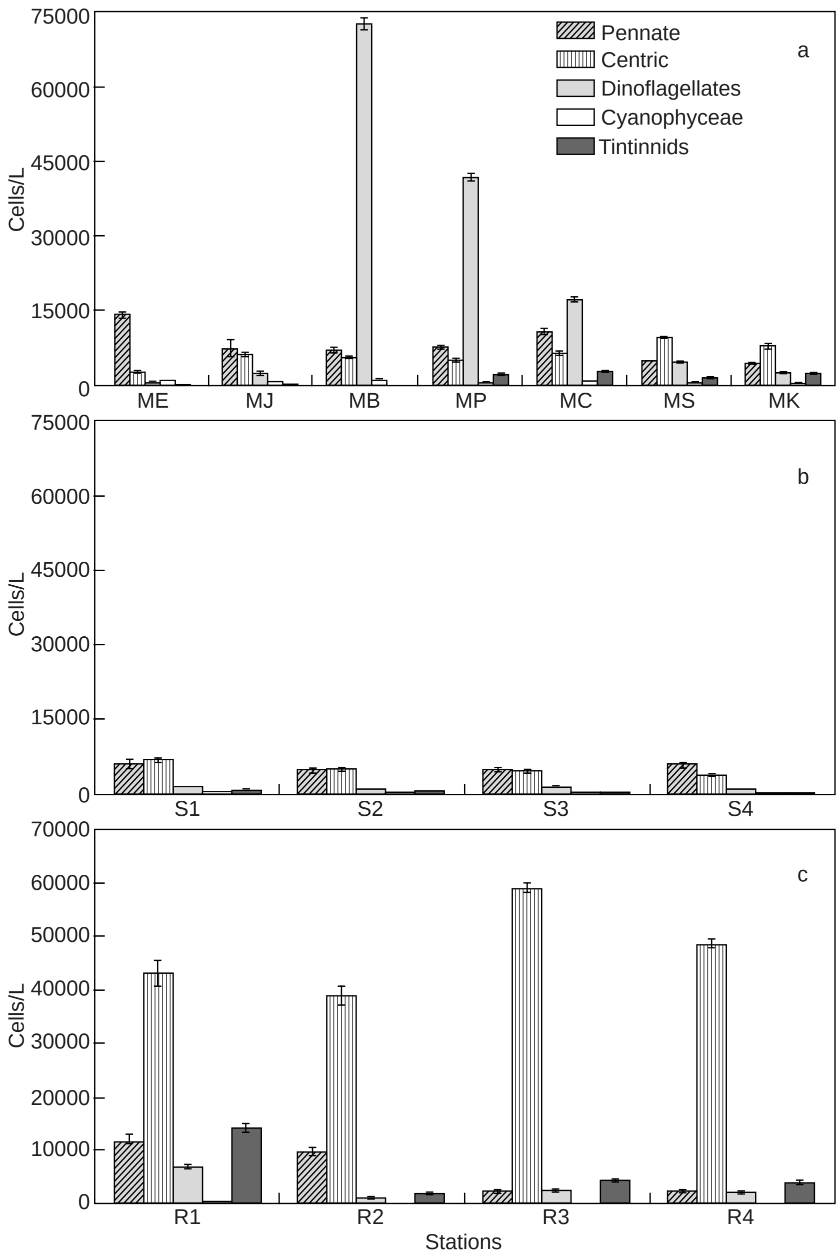

Fig. 4. Relative abundance of dominant phytoplankton groups in (a) Mtwapa creek, (b) Shirazi creek and (c) Ramisi estuary

though more work needs to be done to determine the relationship between mangrove forests and the detritus in these systems.

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