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Seasonal cycle of planktonic communities at Inhaca Island, southern Mozambique

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Abstract. Monthly plankton sampling was carried out at three stations on the west coast of Inhaca Island, southern Mozambique, from August 1994 to August 1995. Sampling included water mass physical parameters, nutrients, chlorophyll and zooplankton with nets of 125 and 330 µm pore aperture. Nutrient concentration has shown maxima during the summer months, where rain provides the maximum outflow of rivers discharging into Maputo Bay. Following the nutrient peak, chlorophyll *a* has shown maxima around the month of April, with another minor peak in September, when temperature begins to increase. Zooplankton densities followed closely the phytoplankton peaks, especially small herbivorous taxa and larval stages, such as gastropod and bivalve larvae.

Introduction

Plankton studies over the long coast of Mozambique are very scarce, and mainly restricted to specific aspects of a few taxonomic groups, such as phytoplankton (Silva, 1956, 1960) and foraminiferans (Braga, 1960). Gove and Cuamba (1989) made preliminary observations on the seasonality of plankton at Inhaca Island. The whole coast of eastern Africa is poorly studied, and the main available references may be quoted as 'gray literature', such as reports from research projects and unpublished conference papers.

Inhaca is a small sandy island at the entrance of Maputo Bay, southern Mozambique. The waters of Maputo Bay are a complex system, receiving the inputs of three rivers and the tide from the Indian Ocean. Inhaca Island has been the object of numerous studies of various aspects of coastal research (see Kalk, 1995). The island is of great scientific interest, as it is located in the transition between the tropical and temperate western Indian Ocean, presenting numerous examples of both types of biological communities. The rainfall cycle falls within the tropical humid climate, due to the warm current of the Mozambique channel (De Freitas, 1984), but also exhibits a marked thermic seasonality which is characteristic of warm temperate areas. The island presents the main types of tropical coastal habitats, such as mangroves, extensive seagrass meadows, coral reefs and sandy and muddy flats, which support a variety of biological assemblages. The waters around Inhaca Island receive a strong influence from the flooding tide entering Maputo Bay from the Indian Ocean (Kalk, 1995), and the influence of brackish water at low tide is dependent on regime of estuaries discharging into the bay.

Maputo Bay is a major fishery area (Silva and Macia, 1997), being the second major zone for the shrimp fishery off Mozambique. The west banks off Inhaca Island support a variety of activities, such as fish and invertebrate collecting, and constitute the main artisanal fisheries center of Maputo Bay (De Boer and Longamane, 1996). The local fisheries include a number of species directly dependent on plankton abundance, such as bivalve mollusks (e.g. *Pinctada capensis* and *Modiolus phillipinarum*). The main objective of this work was to describe the seasonal cycle of planktonic communities on the east coast of Inhaca Island, namely phytoplankton abundance and distribution, and its relationship to nutrients and physical parameters, and zooplankton abundance, distribution and seasonal fluctuations. Particular attention was given to the larval stages of bottom invertebrates, especially bivalve mollusks and decapod crustaceans, due to the importance of a great number of these organisms for local consumption.

Method

Research area

The study area was the west coast of Inhaca Island. Three collecting stations along the coast were defined (Figure 1): Portinho (#1), Estação de Biologia Marítima (#2) and Saco (#3). All stations are located within the complex system of channels and seagrass banks which border the west coast of the island. Station 1, located near Portinho on the northwest coast, is close to the northern mangrove area, bordered by seagrass associations dominated by *Thalassodendron cilliatum*. Station 2, on the channel facing the Marine Biology Station, is adjacent to the main oyster banks growing on *T.cilliatum*. Station 3 is close to the entrance of Saco mangrove, and it is located between seagrass banks, to the south mainly *Zostera capensis* and to the west mainly *T.cilliatum*.

Sampling strategy

Regular sampling was made monthly, during 13 months. The timing for sampling was during the neap water period, in order to minimize the dislocation of the water mass and maintain similar physical conditions throughout the collecting stations. The high-tide period was chosen as during low tide the low depth of the water column does not permit effective zooplankton trawls to be performed. Sampling was from north to south, following the tidal front (tidal height ranges from 2.5 to 3.5 m).

Nutrients and phytoplankton

In view of the low depth at the collecting stations, stratification of the water column is not significant. Sampling was made subsuperficially, at ~1 m depth. The following parameters were sampled: temperature, salinity, light penetration, nutrients (phosphorus, total nitrogen, nitrite, nitrate, silicate) and chlorophyll *a*.

Water for nutrient and phytoplankton pigment analysis was collected with 6 and 12 l Van Dorn bottles. Nutrient samples were immediately frozen, and water for phytopigments was filtered in 1.2 μm filters, with a vacuum pump. After filtration, filters were immediately frozen until analysis.

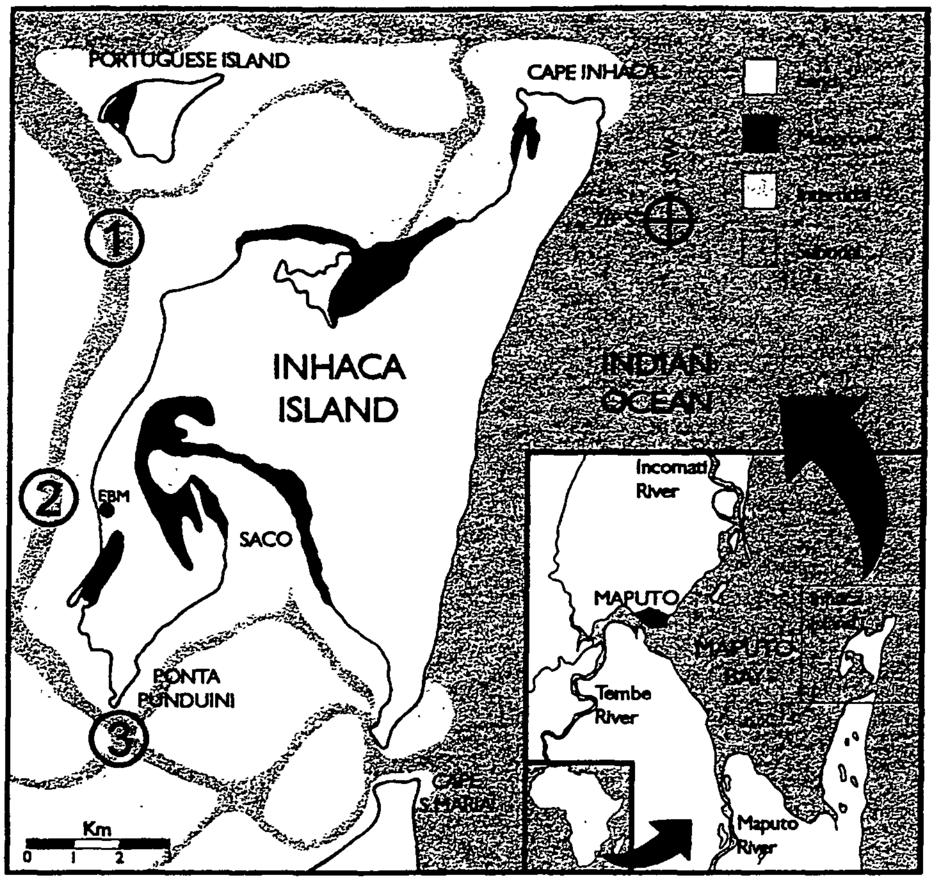

Fig. 1. Map of Inhaca Island, showing the position of plankton collecting stations.

Nutrient analysis followed general procedures by Strickland and Parsons (1972). Pigments were extracted with methanol and quantified by spectrophotometry.

Zooplankton

For zooplankton, two tows were made: one horizontal subsuperficial tow with a net of 125 µm pore aperture for 3 min, and a similar tow with a net of 330 µm pore aperture for 5 min. The nets were equipped with Hydrobios flowmeters, and samples were fixed and preserved in buffered 4% formaldehyde.

Sedimentation volume was determined with a conical jar. Sample fractionation used a Folsom plankton splitter. Identification of the most abundant organisms and counting of major zooplanktonic groups was carried out using an Olympus stereomicroscope. Identifications were made only to major taxonomic groups, except for larval stages of mollusks and crustaceans where they were made as far as available information permits. In the case of mollusks, a number of species were identified with reasonable confidence, due to the fact that some families are represented by a few or single species, and the abundance of larvae may reflect the abundance of adults. For crustaceans, the assignment of larvae to adult species is also difficult, as most local species have still undescribed larvae. A program for larval description of intertidal and shallow water crustaceans was implemented, and a reasonable number of species was obtained ovigerous, producing hatching in captivity (J.Paula and T.Dray, in preparation). This permitted species to be ascribed to a number of decapod crustacean larvae present in the zooplankton samples.

Results

Physical conditions

The maximum range of temperature was observed at station 1, between 18.6°C in July and 37.0°C in January (Figure 2). The maximum value clearly reflects local conditions at a particular sampling moment, due to the low depth of the water column and strong insolation. The annual cycle of temperature at collecting sites followed a clear maximum during summer and a minimum in winter, reflecting the subtropical conditions of Maputo Bay. Salinity showed an irregular pattern (Figure 2), fluctuating between 30 and 42‰. Salinity fluctuations reflect a complex set of factors, namely the circulation in the bay, in which three rivers discharge, and evaporation due to insolation and dilution due to rainy periods, over a short water column (at sampling sites between 0.75 and 5 m deep). The maximum temperature occurred simultaneously with the maximum salinity.

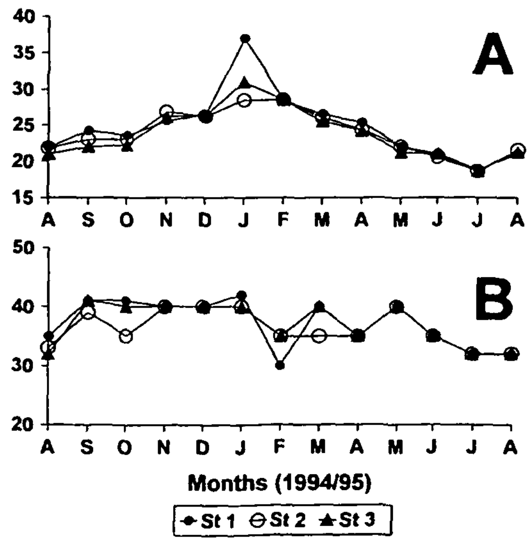

Fig. 2. Seasonal fluctuation of physical parameters. (A) Temperature; (B) salinity.

Nutrients and phytoplankton

Figures 3 and 4 show the concentration of nutrients in the sampled layer of the water column. The nutrients that show a net trend are the nitrates, silicates and, to some extent, total phosphorus, all showing an increase during the warmest months, probably coupled with the maximum values of precipitation in the hydrographic basins of the rivers which discharge to Maputo Bay. Nitrates were negligible from May to December, but between January and April concentration increased at all stations, reaching >2 μmol l^{-1}. Silicates were more stable throughout the year, at around 2 μmol l^{-1}, reaching >7 μmol l^{-1} during the rainy season.

Owing to the accumulation of nutrients during the summer/rain period, maximum values of chlorophyll *a* were reached in March (Figure 5), with a decrease towards the cooler months, and with a minor peak in September, when temperature begins to rise. During the chlorophyll peak, the highest value was observed at collecting station 3 (1.23 mg m^{-3}), with a decrease towards the entrance of the bay. The lowest values were observed during January and February with a minimum of 0.04 mg m^{-3} at station 2. The average monthly values ranged between 0.08 and 0.87 mg m^{-3}, respectively, in February and March.

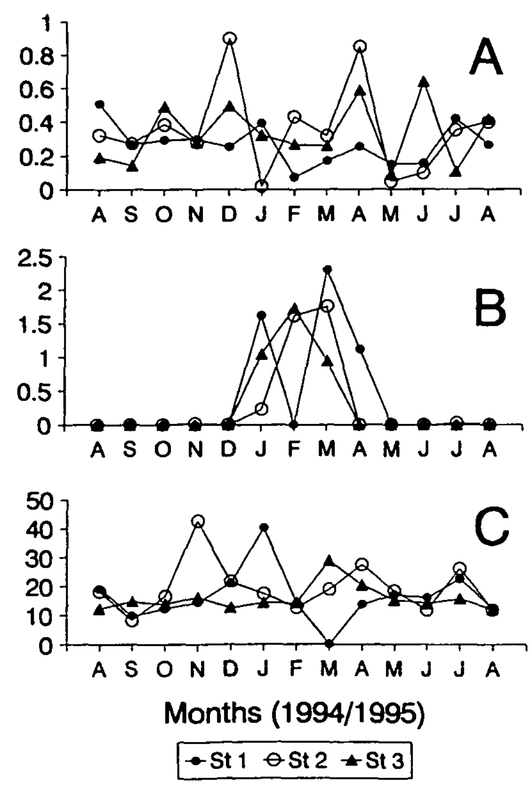

Fig. 3. Seasonal fluctuation of nutrients in the water column. (**A**) Nitrites; (**B**) nitrates; (**C**) total nitrogen. All in μmol l^{-1}.

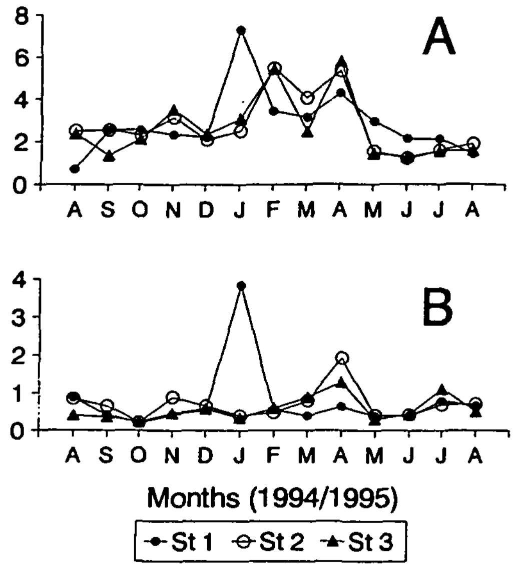

Fig. 4. Seasonal fluctuation of nutrients in the water column. (**A**) Silicates; (**B**) total phosphorus. All in µmol l^{-1}.

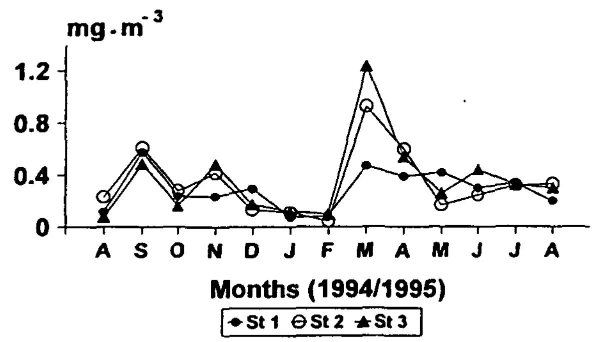

Fig. 5. Seasonal fluctuation of chlorophyll *a*.

Zooplankton

Sedimentation biovolumes followed the global trends of the total organism density, in each zooplankton net (Figures 6 and 7). Biovolumes present a more biased estimation of zooplankton abundance, as reflecting non-living matter and especially the presence of large jelly organisms, such as medusae and ctenophores. In the 125 µm net, highest abundance and biovolumes were reached during September, where biovolume had a maximum of nearly 20 ml m^{-3} and abundance reached 400 000 organisms m^{-3}. On the other hand, in the samples

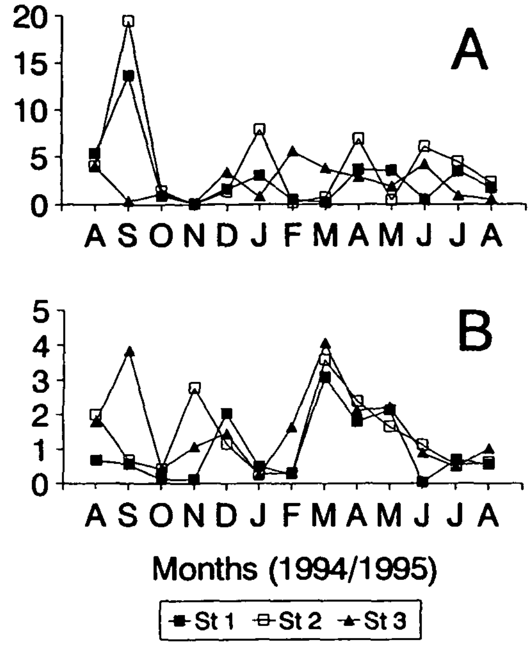

Fig. 6. Seasonal fluctuation of zooplankton biovolume (ml m^{-3}). (**A**) 125 μm net; (**B**) 330 μm net.

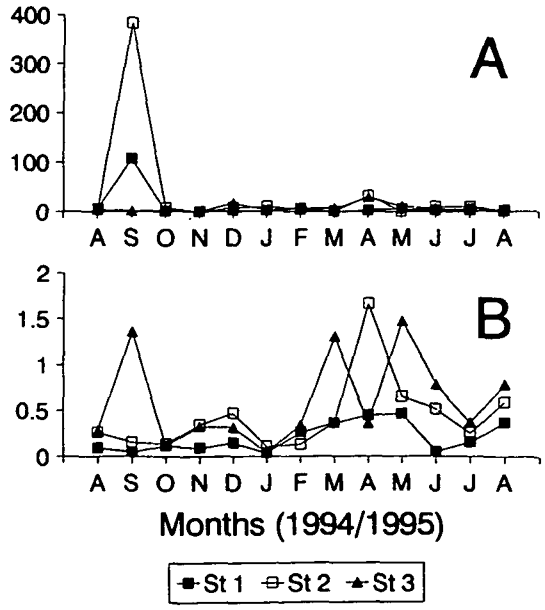

Fig. 7. Seasonal fluctuation of zooplankton density (ind. m^{-3}). (**A**) 125 μm net; (**B**) 330 μm net.

from the 330 µm net, the peak was reached just in November, where biovolume showed a maximum of ~17 ml m^{-3} and abundance around 5000 organisms m^{-3}. This last peak was reached at collecting station 3, at the entrance of Saco mangrove, and reflects a high abundance of brachyuran larval stages in the water mass. On the other hand, the peak of the 125 µm net reflects abundance of larval stages of mollusks. Gastropod larvae, the most abundant organisms of the zooplankton, reached highest densities in September with nearly 350 000 individuals m^{-3}. It is practically impossible to identify these forms, due to the state of current knowledge and given their diversity in the area.

Mollusk larvae

Although it was not possible to ascribe a high percentage of bivalve mollusk larvae to species (46.3%), >50% were determined at species or familial level (Figure 8). The most abundant determined species was the seagrass (*Z.capensis*) mussel *M.phillipinarum*, which accounted for 23% of total catches. This species is very abundant in the banks off the south and north coasts of the island where it is exploited for local consumption. The west banks are formed by assemblages based on the seagrass *T.cilliatum*, where the pearl oyster *P.capensis* is very abundant, and subjected to intensive fishery during spring tides. However, the larvae of this species were not very abundant, only accounting for 1.9% of catches. The other larvae ascribed to species were the rock mussel *Choromytilus meridionalis* (3.9%), the oyster *Saccostrea cucculata* (3.1%) and *Loripes clausus* (3.5%).

Some common seasonal trends can be observed among some of these species, and seem to indicate a spawning related to the annual peak of chlorophyll concentration in the water mass (Figures 9 and 10). This is the case for *P.capensis* and *Saccostrea cucculata*, both of which present maximum densities around the month of April. *Modiolus phillipinarum* showed a somewhat longer period

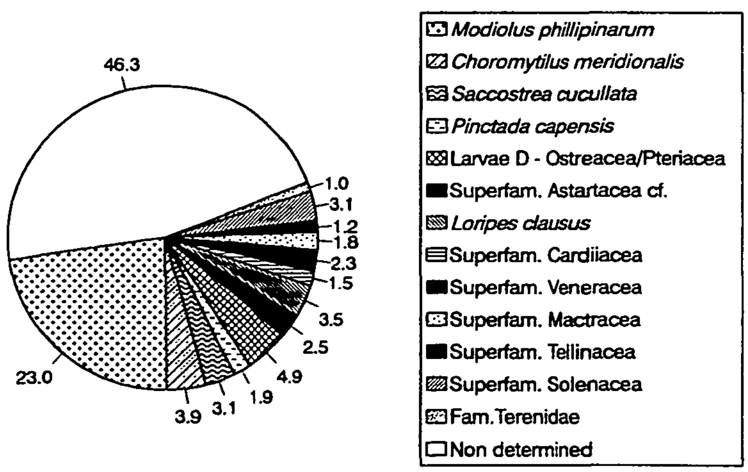

Fig. 8. Major collected taxa among bivalve mollusks (percentage).

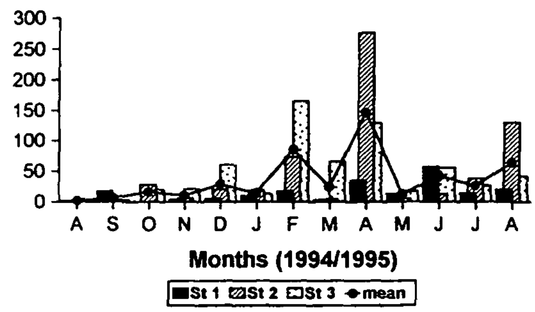

Fig. 9. Seasonal fluctuation of bivalve larvae (ind. m^{-3}).

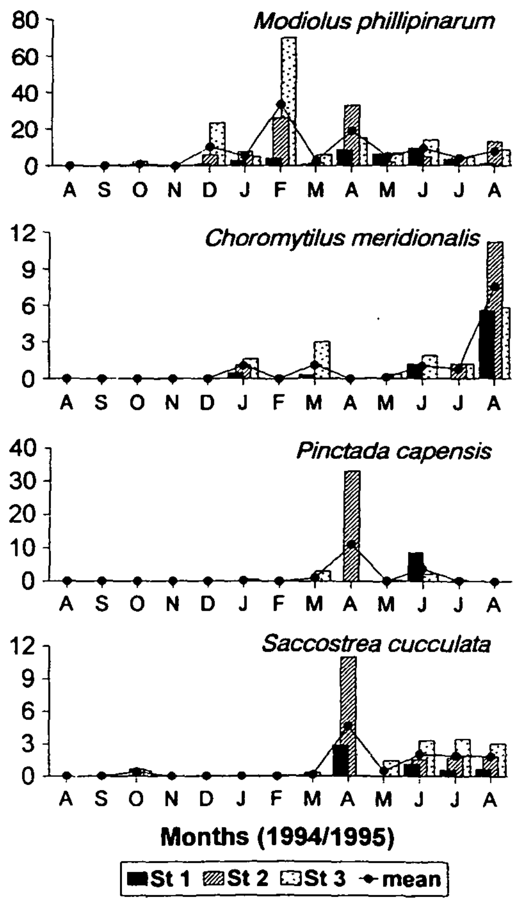

Fig. 10. Seasonal fluctuation of *Modiolus phillipinarum*, *Choromytilus meridionalis*, *Pinctada capensis* and *Saccostrea cucculata* larvae (ind. m^{-3}).

of reproduction, with a maximum in February at station 3 (>70 ind. m^{-3}), *P.capensis* and *S.cucculata* with a net peak in April at station 2 (nearly 30 and 10 ind. m^{-3}, respectively). *Choromytilus meridionalis* presented a peak in August at station 2 (nearly 12 ind. m^{-3}).

Decapod crustacean larvae

A few decapod larvae were ascribed to species, but as stated in Method, strong limitations of reference information preclude most identifications. Natant larvae were a significant fraction of collected decapod crustacean larvae. Penaeid shrimp protozoeal and mysid stages accounted for 39.2%, the remainder belonged to caridean families, namely Alpheidae (17.0%) and Processidae (0.4%). Alpheids are very abundant on the island, namely as commensals of a diversity of other burrowing animals in the intertidal and shallow water zones. These forms were more abundant during September at station 3, reaching a density of 70 ind. m^{-3}.

Penaeid larval stages were abundant during the month of May (Figure 11), and almost restricted to station 3 near Saco mangrove bay. Protozoeal stages reached a density of >200 ind. m^{-3}, whereas mysid stages reached >100 ind. m^{-3}. The most abundant species in the area are *Penaeus semisulcatus* and *P.indicus*, and most likely the collected larvae belong to these two species.

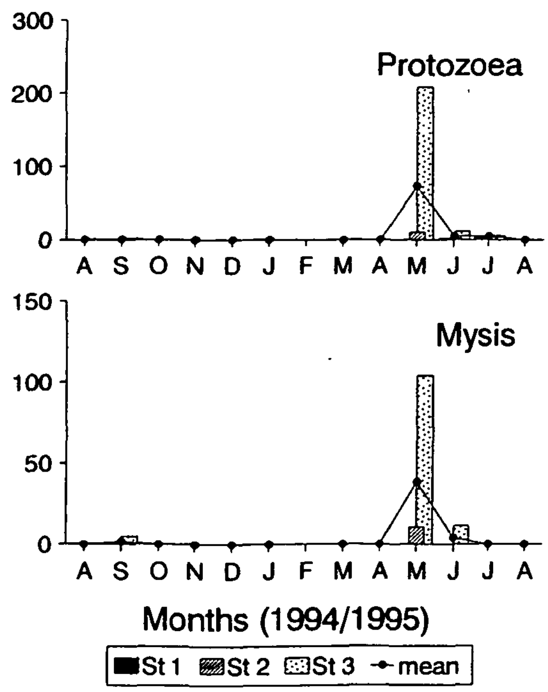

Fig. 11. Seasonal fluctuation of larval stages of penaeid shrimps (ind. m^{-3}).

Other decapod larvae were mainly represented by larval stages of brachyuran crabs, which together accounted for 93.5% of total reptant catches (Figure 12). The genus *Macrophthalmus* was by far the most abundant taxon with 52.7%, followed by undetermined brachyurans (20.7%, mainly composed by portunids, xanthids, atelecyclids and calapids), Pinnotherids (9.7%, probably *Arcotheres palaensis* commensal of the mussel *Modiolus phillipinarum*), leusosiids (6.4%), diogenids (3.7%), majids (2.7%), thallassinids (2.7%) and others (1.3%). Within this last group, a number of generic or specific taxa were identified, such as *Dotilla fenestrata* and *Uca* spp.; however, the observed abundances were very low.

The seasonal fluctuations of the larval stages of the Brachyura presented higher densities from August to December, reaching a peak in September with nearly 300 ind. m^{-3} (Figure 13). This pattern followed closely the abundance fluctuations of *Macrophthalmus* spp., with a maximum of nearly 150 ind. m^{-3} at station 3. Most brachyuran larvae were collected at station 3, showing the importance of Saco Bay habitats for crustacean populations.

Discussion

Globally, results suggest that a favorable period occurs from September to November, where temperature rises and phytoplankton grow, and a second and major period of planktonic abundance occurs by March, where phytoplankton grow due to nutrient accumulation in Maputo Bay along the rainy season. The availability of nutrients is related to rain and connected river discharge into the coastal zone, as shown by Kitheka *et al.* (1995) for Gazi Bay, Kenya. The rain cycle thus seem to be the main factor controlling the global seasonality of plankton assemblages at Inhaca Island coastal waters.

Values of chlorophyll concentration were relatively low when compared with data from Brown (1992) for the southwest coast of South Africa, which are due to the upwelling conditions in that area. However, in the inshore shelf of the southern coast, this author found an average of 1.46 mg m^{-3} throughout the year,

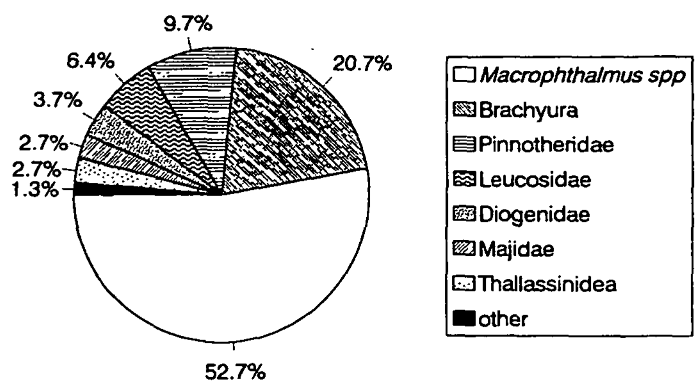

Fig. 12. Major collected taxa among decapod crustaceans (percentage).

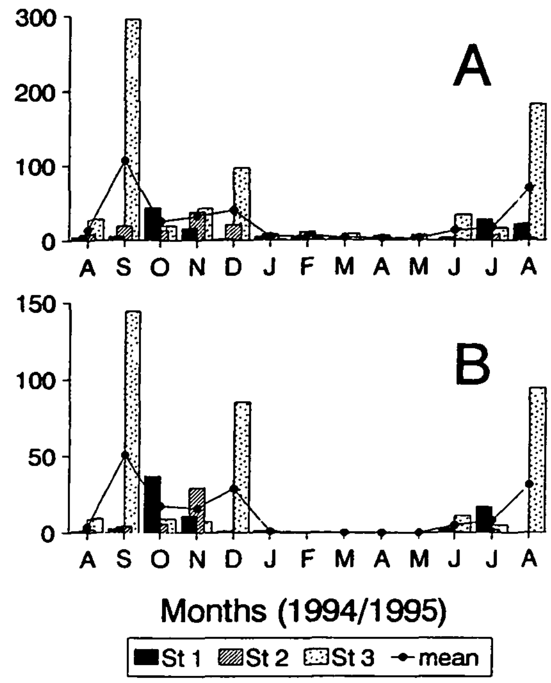

Fig. 13. Seasonal fluctuation of larval stages of (A) total brachyuran crabs and (B) the genus *Macrophthalmus* (ind. m^{-3}).

with a seasonal maximum average of 1.7 mg m^{-3} during autumn. Lugomela (1995) observed a range of 0.12–0.37 mg m^{-3} of chlorophyll concentration at Chwaka Bay, Zanzibar, and Bryceson (1977) observed a higher maximum of 1.4 mg m^{-3} and a minimum of 0.2 mg m^{-3} near Dar-es-Salaam. Kitheka *et al.* (1995) found mean values of chlorophyll between a minimum of 0.24 mg m^{-3} over coral reefs, and a maximum of 1.74 mg m^{-3} in mangrove channels, for Gazi Bay. Maximum values were found by these authors to be related to rainy seasons in the area, May and November, respectively. The mean values of phytoplankton biomass seem to be somewhat similar along the east African coastal waters. It is, however, difficult to compare these results in detail, as the patchy distribution of chlorophyll concentration in the mosaic of coastal habitats produces a strong spatial variability at various scales. The dynamic characteristics of plankton distributions in coastal habitats are also strongly influenced by tidal currents and salinity gradients, and thus timing of sampling together with spatial location in relation to salinity and coastal environment mosaics will determine plankton type and concentration.

The organisms collected by the 125 μm net are mainly herbivorous species, which could be expected to match the peaks of phytoplankton. It seems that the chlorophyll peak of the early warm season, from September to November, has a better response in the trophic chains than the highest values during March, where the abundance of zooplankton was not very high. However, for the 330 μm net, the high density values of November were observed only at one collecting station. These were mainly formed by larval brachyurans, not necessarily due to planktonic stimuli, but to cues for larval releasing activity by respective adult populations. Also, the abundance of benthic invertebrate larvae is conditioned by rhythmic processes in the larval release activity (see, for instance, Paula, 1989), and subsequent dispersal which is mainly related to particular hydrographic conditions.

Analyzing the abundance fluctuations of the larval stages of mollusks, it is interesting to observe that most bivalve larvae have their maximum in April following the chlorophyll peak. These organisms were more abundant at stations 2 and 3, which are placed close to the major bivalve banks around Inhaca Island. Penaeid shrimp larval stages were also more abundant during April, when settlement to coastal nursery areas occurs (De Freitas, 1986).

Acknowledgements

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