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THE ZOOPLANKTON COMMUNITY OF THE MHLATHUZE (RICHARDS BAY) ESTUARY: TWO DECADES AFTER CONSTRUCTION OF THE HARBOUR

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The Mhlathuze (Richards Bay) Estuary on the KwaZulu-Natal coast, South Africa, was substantially altered during the early 1970s, when it was divided into two separate systems. The northern section was developed into a deep-water harbour, whereas the southern part was envisaged to function as the new estuary. This study investigates the composition of the zooplankton community of the new estuary 20 years after its construction and compares it with historical data. Compared with the original estuary, a much-reduced body of water is currently available to estuarine plankton. During the sampling period between February 1996 and February 1997, the surface area of the new estuary was about 75% smaller than that of the original waterbody, originally as a result of a section being lost to harbour development and later to mangrove encroachment. Salinity levels throughout the new estuary were close to that of seawater, except for a few occasions during particularly strong freshwater inflows. Multivariate analyses indicate that patterns of zooplankton distribution of abundance during the present study were mostly determined by a combination of salinity and seasonal temperature variation. Zooplankton density had a seasonal pattern. Overall abundance of the estuarine zooplankton community of the system was low compared with the original system and other South African estuaries. The original estuarine zooplankton community, characterized by the typical estuarine copepods *Pseudodiaptomus stuhlmanni* and *Acartia natalensis,* had been replaced by a predominantly marine community, dominated by small paracalanid copepods.

Keywords: harbour construction, Mhlathuze Estuary, Richards Bay, zooplankton

Before harbour construction, Richards Bay on the KwaZulu-Natal coast (28°47´S, 32°05´E) was a shallow, subtropical estuary of approximately 30 km^2 (3 000 ha) surface area (Begg 1978), consisting of a large basin (lagoon) connected to the Indian Ocean through a narrow mouth north of the basin. The shallow, constricted mouth substantially reduced the tidal range in the estuary (Millard and Harrison 1954), resulting in a relatively stable waterbody in the basin area.

Five rivers flowed into the original system: the Mtantatweni (draining Lake Cubhu), the Mhlathuzi (the major river that drained through a delta area of swamp vegetation into the western part of the basin), the Bhizolo and Manzinyama (currently serving as drainage canals) and the Mzingazi (draining Lake Mzingazi).

Development of the harbour in the Richards Bay Estuary began early in the 1970s and had serious impacts on the system, severely altering the original estuary (Fig. 1). A dike, or berm, wall was constructed across the estuary, dividing the original waterbody into two smaller, distinctly different systems. A floodgate constructed in the dike soon became dysfunctional and has never been used. The northern section became a deep-water harbour, dredged to a depth of 25 m, whereas the southern section was left "unspoiled". It was hoped that conditions similar to those prevailing in the original estuary could be established in the newly constructed estuary, also called "the sanctuary" (Begg 1978). A new mouth was dredged and the major river, the Mhlathuze, was canalized to flow into the new estuary and not the harbour. Construction of the dike and new mouth was completed by the end of 1975.

Grindley and Wooldridge (1974) studied the zooplankton of Richards Bay as part of an overall survey of the biota before construction of the harbour. They conducted quarterly, quantitative, night-time sampling during 1970 and 1971 using a Clark-Bumpus sampler. This initial study was followed by a few *ad hoc* studies by the National Institute of Water Research to monitor the zooplankton of the estuary: during November 1974, before opening of the new mouth (Connell *et al.* 1975) and during December 1981 (Connell *et al.* 1985) and April 1987 (Connell *et al.* 1989). All samples were collected semi-quantitatively during daytime, using a 250-µm mesh net.

Drastic changes to the structure and function of a natural system such as the original Richards Bay estuary are likely to result in substantial changes to its biotic communities. The aim of the present study is to investigate the zooplankton community of the present system, 20 years after construction of the new estuary, and to compare it with historical data.

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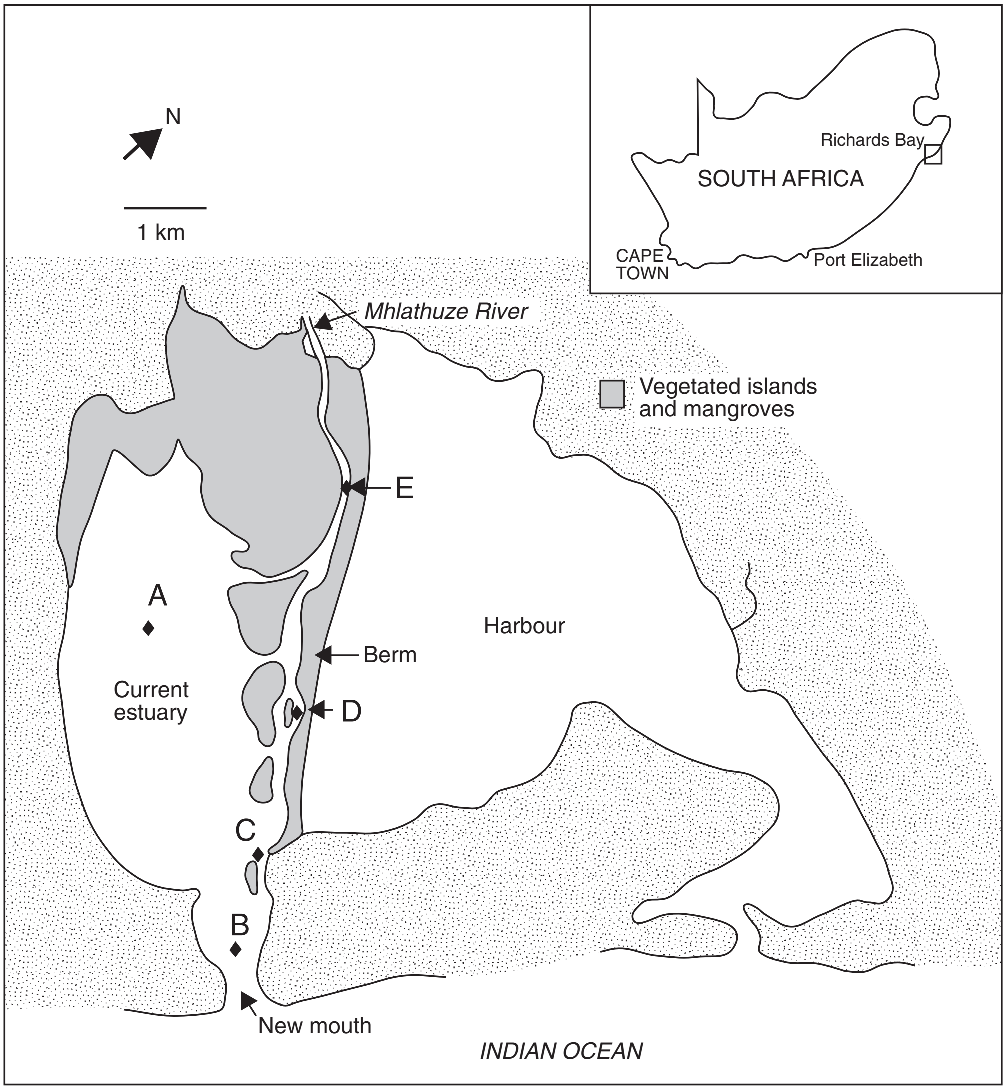

Fig. 1: Map of the original and current Mhlathuze Estuary showing the location of the stations (A–E) where zooplankton were collected during 1996 and 1997

MATERIAL AND METHODS

Sampling

Zooplankton sampling took place monthly between February 1996 and February 1997 at five stations in the Mhlathuze Estuary (Fig. 1). Station A was in the large southern basin, Station B near the new mouth, Station C in the canal leading to the mouth, Station D close to the dysfunctional floodgate between the harbour and the estuary and Station E in the canalized

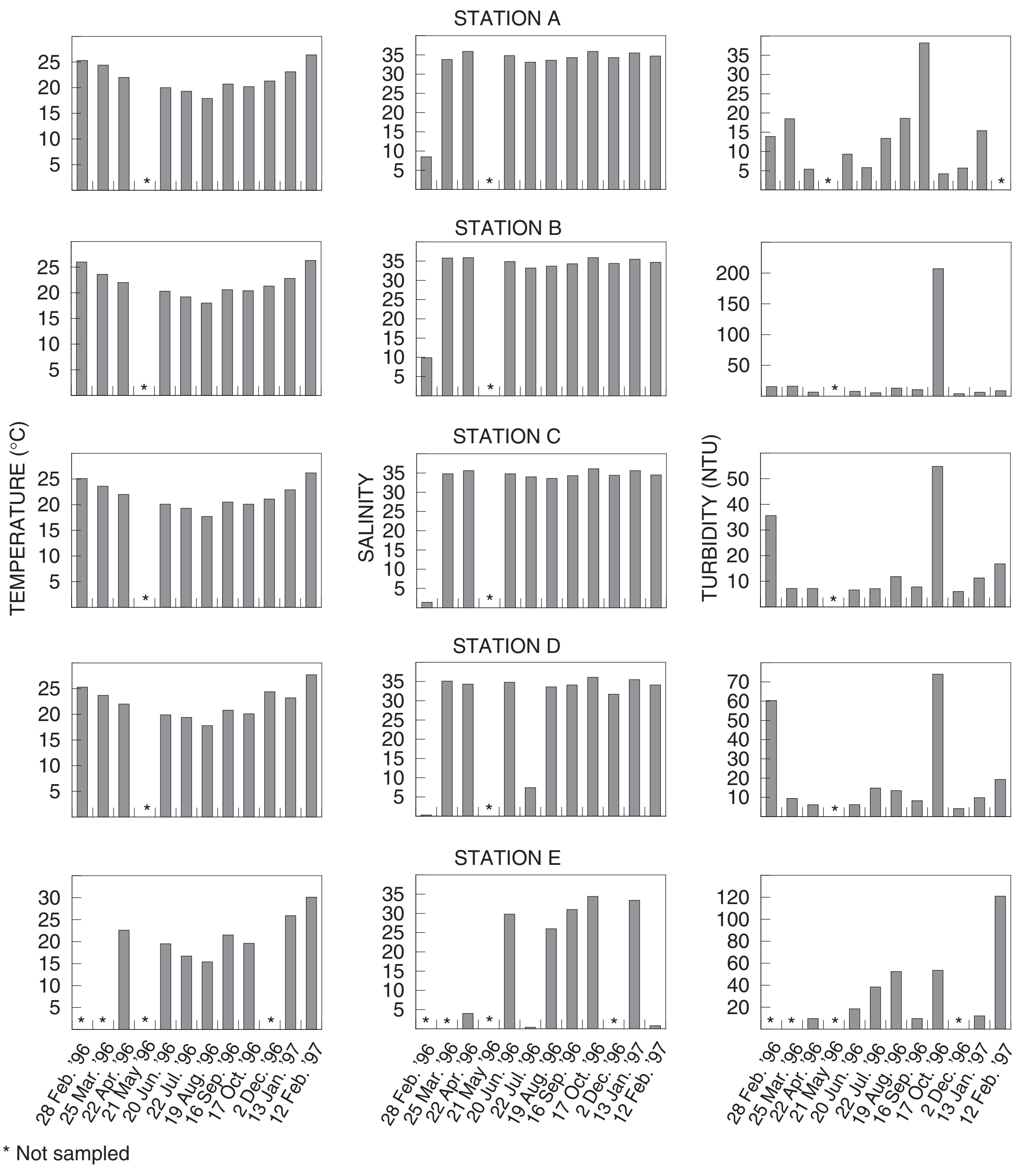

Fig. 2 Trends in temperature, salinity and turbidity at Stations A–E, 1996–1997. Note that no measurements were taken in May 1996 as a result of instrument failure

Mhlathuze River, where it enters the estuary. Sampling commenced after dark, because some estuarine zooplankton are epibenthic during daylight and migrate upwards after sunset, when they are more uniformly distributed through the water column (Grindley 1972, Fulton 1984).

All zooplankton samples were collected using a double plankton net with 63-µm mesh, enabling it to collect duplicate samples simultaneously. Each net was 2 m long, with a mouth diameter of 300 mm and an open area ratio of 4 (Omori and Ikeda 1984). One net was fitted with a flowmeter. The net was towed horizontally using a small, motorized boat at a speed of approximately 1 m s^{-1}. Each net sampled 1–2 m^3 of water. To avoid interference from the boat, the net was mounted onto a boom and towed in front of the bow. The estuary was shallow and was sampled around high spring tide when the average water depth was about 1 m. Owing to the shallow conditions only midwater samples were collected. The zooplankton was preserved in 10% formalin for later analysis. Shallow water and sand banks precluded sampling at Station E during February, March, May and December 1996. No stations were sampled during November 1996.

At each site, temperature, salinity, pH, dissolved oxygen and turbidity were measured near the surface and bottom, prior to zooplankton sampling, using a Hydrolab H20 water quality multiprobe linked to a Surveyor 3 display logger.

In the laboratory, zooplankton was identified to the lowest possible taxon. More abundant taxa were enumerated using the subsampling technique described in Jerling and Wooldridge (1995). Whole samples were also scanned for less abundant taxa. Zooplankton densities were expressed as numbers m^{-3} from knowledge of the volume of water filtered by the net.

Multivariate analysis

The spatial and temporal distribution of the zooplankton community was analysed using the cluster and Multi-Dimensional Scaling (MDS) methods of the PRIMER computer software (Clarke and Warwick 1994). The analyses were done in an attempt to identify and illustrate distribution differences or changes in the zooplankton community structure of the estuary over the study period. Cluster and MDS analyses were based on the Bray-Curtis measure of similarity on fourth root-transformed data. Hierarchical clustering was based on rank orders of similarities. Only samples comprising all five stations were used for the multivariate analyses.

The BIOENV programme of the PRIMER software package was used to select environmental variables that best explained community patterns identified by the MDS analysis. The five environmental variables measured were log-transformed, and the best matches between combinations of environmental and biotic data were determined by weighted Spearman rank correlation (Clarke and Warwick 1994).

RESULTS

Environmental variables

Because of the shallow, well-mixed nature of the estuary, there was little stratification, so only near-surface values are shown in Figure 2. Stratification was evident only at Station E when freshwater from the Mhlathuze River flowed over denser, saline water trapped in bottom depressions. Temperatures at that station fluctuated between 15°C (during August 1996) and 30°C (during February 1997). At the other stations temperatures fluctuated between 18 and 27°C, similar to those reported for the estuary before construction of the harbour (Grindley and Wooldridge 1974).

The entire estuary was characterized by high salinity (34–36), which approximated the values of seawater, because most sampling was carried out around high tide. On a few occasions, salinity was relatively low, coincided with substantial influx of freshwater (Department of Water Affairs and Forestry, unpublished data). During February 1996, the salinity of the entire estuary was low, owing to increased riverine input and as a result of sampling during ebb tide. Salinity was very low at Station E during April and July 1996 and in February 1997, following increased freshwater input.

Levels of pH were close to that of seawater (c. 8.0; data not shown), with slightly lower levels in waters of reduced salinity. Dissolved oxygen concentration was high throughout the study period, ranging between 5.8 and 10.1 mg ℓ^{-1}. Dissolved oxygen increased slightly during winter, when water temperatures were lowest.

Mean turbidity levels for the five sampling stations of each sampling period ranged between 9 and 85 NTU, with an overall mean of 22.4 NTU for the whole sampling period. This value defines the estuary as a semi-turbid system, according to the classification by Cyrus and Blaber (1987). The large turbidity value of 207 NTU recorded in October 1996 at Station B was likely a result of fine silt input from the sea during dredging operations in the harbour (Cyrus and Wepener 1998).

Table I: Zooplankton taxa sampled at Mhlathuze Estuary between February 1996 and February 1997 and used for multivariate analyses

Tintinnids
Cnidaria
Rotifera
Polychaete larvae
Cladocera
Evadne sp.
Moina sp.
Podon sp.
Ostracoda
Calanoida
Acartia natalensis
Acartia sp.
Calanidae
Candacia sp.
Centropages natalensis
Centropages sp.
Eucalanus sp.
Euchaeta sp.
Paracalanidae
Pontellidae
Pseudodiaptomus stuhlmanni
P. nudus
Temora stylifera
T. turbinata
Tropodiaptomus sp.
Undinula sp.
Poecilostomatoida
Copilia sp.
Oncaeidae
Corycaeidae
Cyclopoida
Halicyclops sp.
Oithona spp. (copepodites)
Harpacticoida
Unidentified harpacticoids
Peltidium sp.
Unidentified copepodites
Unidentified nauplii
Cypris larvae
Mysidacea
Gastrosaccus spp.
Mesopodopsis africana
Rhopalophthalmus terranatalis
Tanaidacea
Apseudes digitalis
Isopoda
Cirolana sp.
Leptanthura laevigata
Synidotea sp.
Amphipoda
Decapoda
Lucifer spp.
Prawn larvae
Zoea
Megalopa
Mollusca larvae
Unidentified insect larvae
Cyphonautes larvae
Chaetognatha
Larvacea (Appendicularia)
Fish eggs
Fish larvae

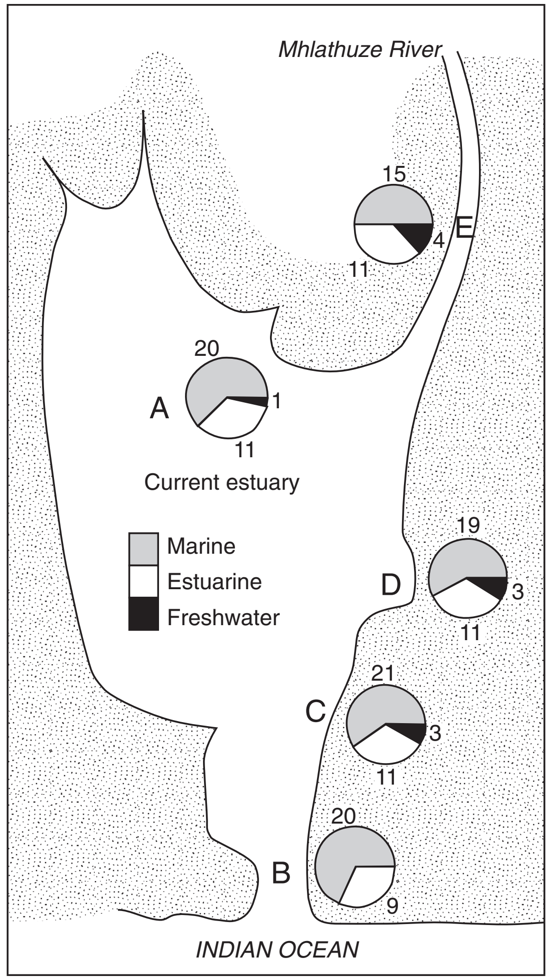

Fig. 3: Total number of marine, estuarine and freshwater taxa sampled at Stations A–E between 1996 and 1997

Zooplankton

Taxa recorded during the study period are listed in Table I. Marine copepods were numerically dominant in terms of number of species at all stations (Fig. 3). These included calanoids, tintinnids, chaetognaths, larvaceans, cladocerans and ostracods. Taxa for which distinction between marine or estuarine was not clear, or taxa that included species from both environments (e.g. nauplii and megalopa), were not included in

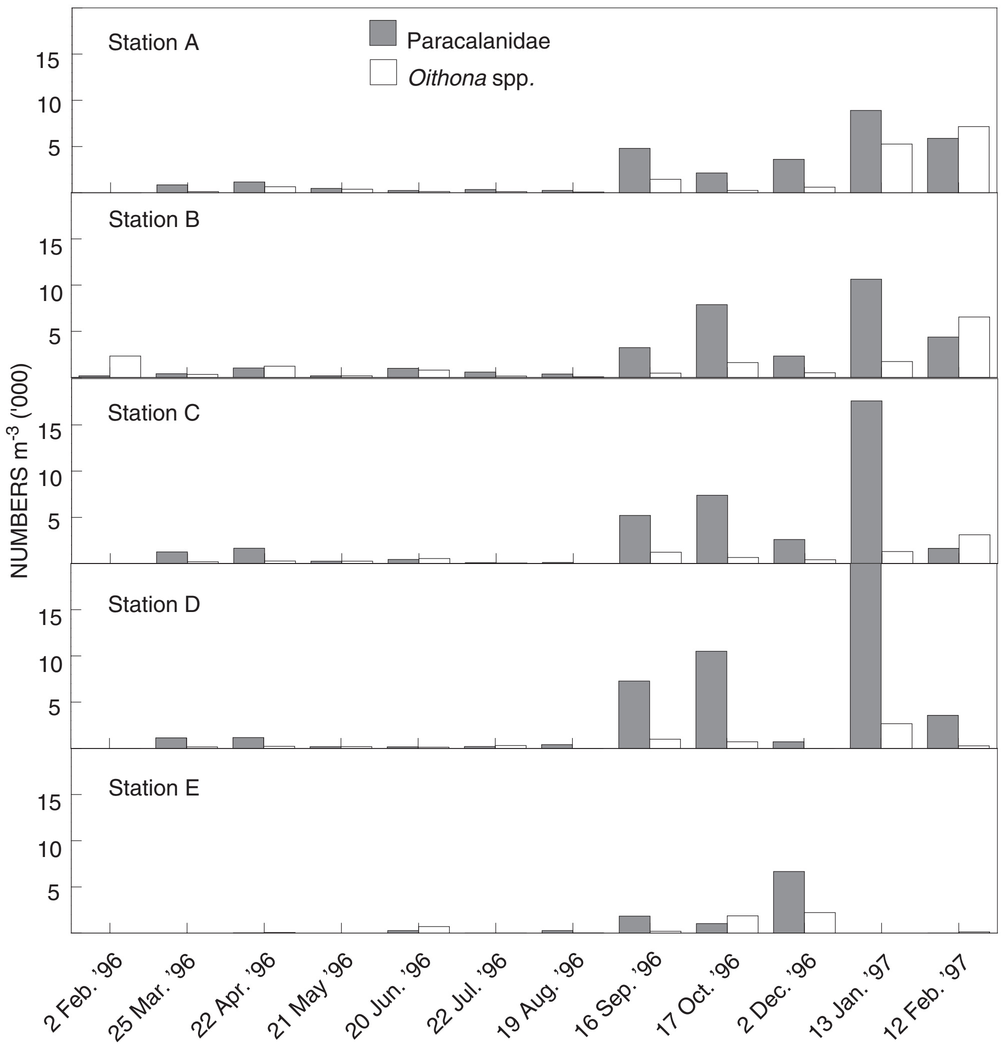

Fig. 4: Monthly abundance of Paracalanidae and *Oithona* spp. sampled at Stations A–E between 1996 and 1997

Figure 3.

The number of taxa ranged between 8 and 36 per sample. There was low species richness (8–15 taxa per sample) at all stations sampled in February 1996, coincident with low salinity. Station E had the lowest species diversity, in terms of number of taxa, of all stations. Zooplankton closely associated with the benthos, such as mysids, tanaids, amphipods and harpacticoids, were present at all stations, most likely because of the shallow, well mixed nature of the estuary and also because many of these species migrate into the water column at night.

Meroplankton consisted of mollusc, polychaete, crab and prawn larvae, and fish eggs and larvae. The small (generally <300 µm long) mollusc and polychaete larvae were found in high densities of up to several thousands of individuals m^{-3}. Most of the crab larvae were zoea stages of *Paratylodiplax blephariskios*,

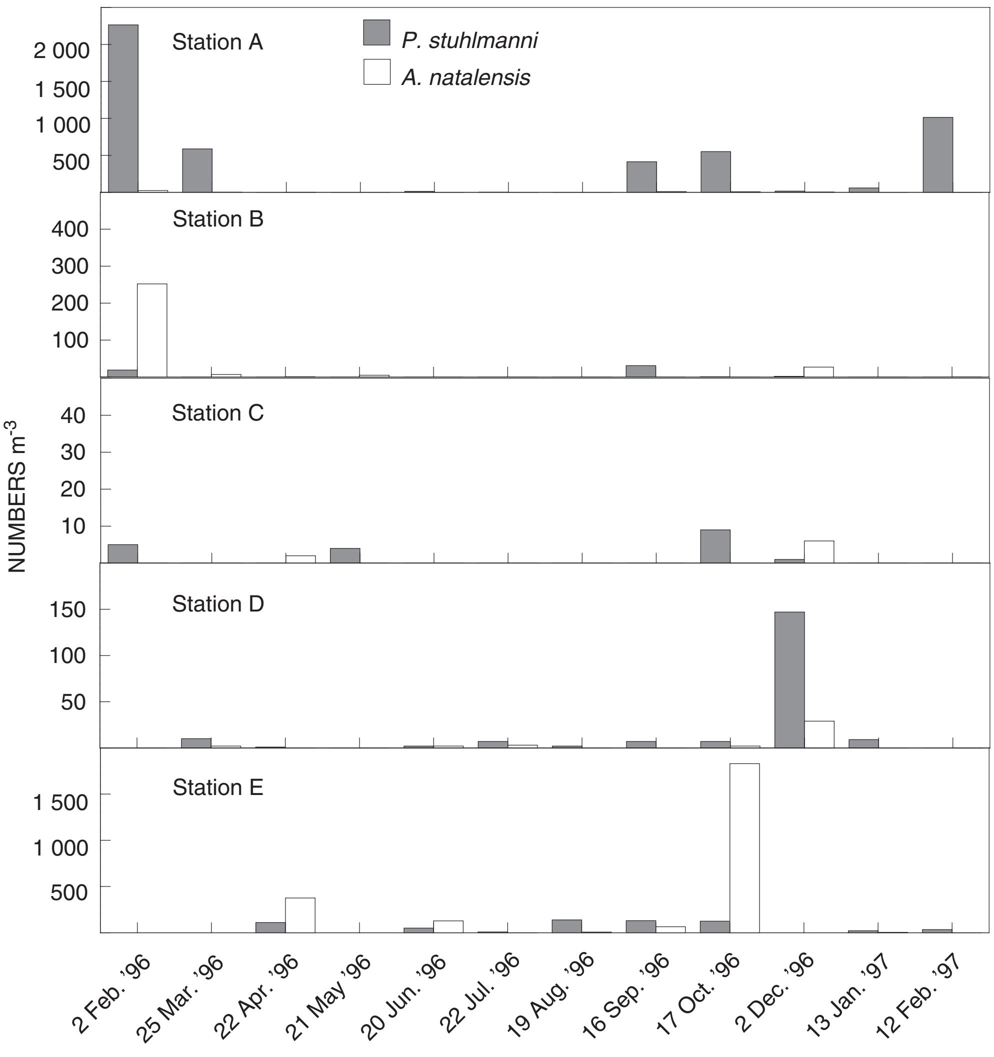

Fig. 5: Monthly abundance of *Pseudodiaptomus stuhlmanni* and *Acartia natalensis* sampled at Stations A–E between 1996 and 1997

the dominant subtidal crab species.

Freshwater zooplankton were recorded on three occasions when pulses of freshwater entered the estuary from the Mhlathuze River: February and July 1996 and in February 1997. These plankters, consisting of a cladoceran, *Moina* sp., insect larvae, calanoid copepods *Tropodiaptomus* sp. and rotifers, were mostly restricted to Stations C, D and E along the main route followed by river water flowing into the system.

Zooplankton density were relatively low during late summer and autumn 1996, following the flushing events of summer 1996 and the onset of winter respectively (Figs 4, 5). Abundances of the majority of zooplankters were also low in winter, increased during spring and peaked during summer 1997. Relatively low densities were recorded on 2 December 1996. Zoo-

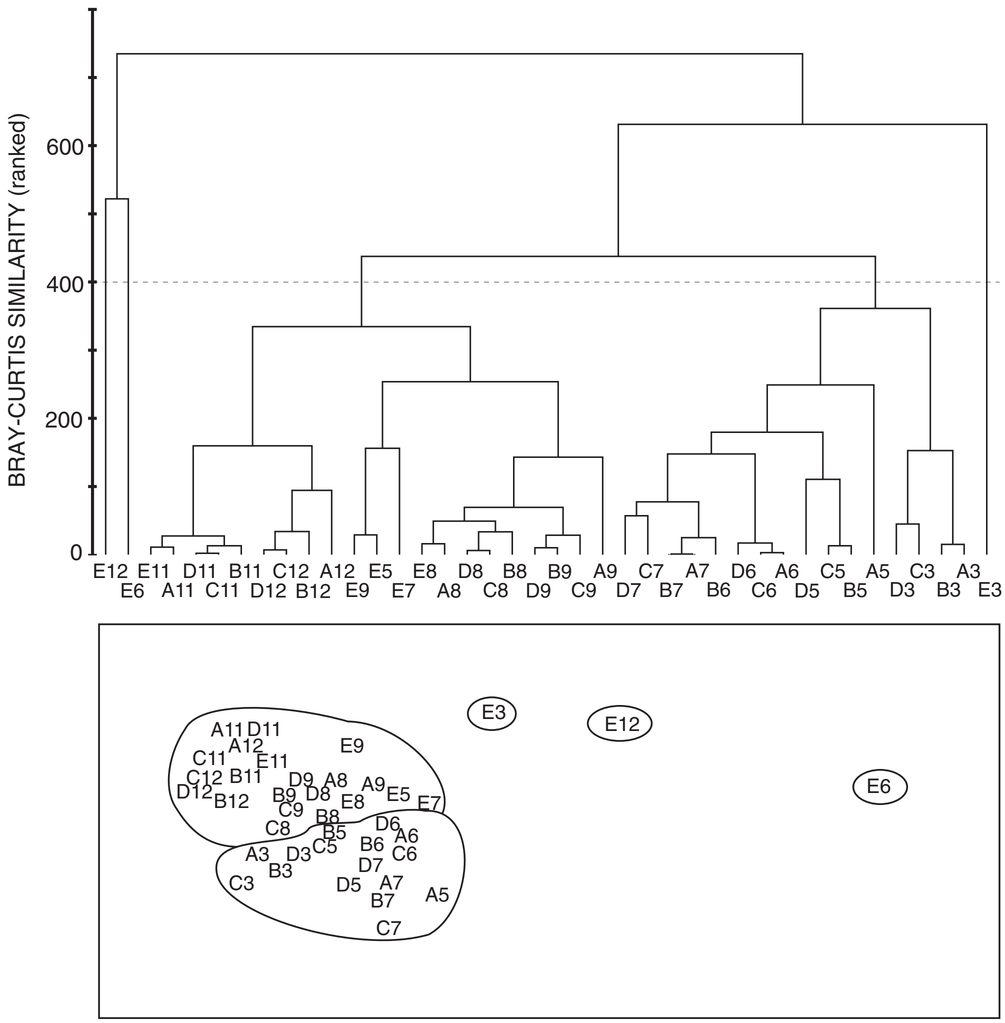

Fig. 6: Cluster analysis and corresponding multi-dimensional scaling (MDS) plot of zooplankton sampled at the five stations (A–E) in the Mhlathuze Estuary in 1996 and 1997. Only sampling periods where all five stations were sampled are included in the analysis. Numerals denote months, i.e. 3 = Apr '96, 5–9 = Jun '96–Oct '96, 11,12 = Jan '97, Feb '97. Codes on the MDS plot that overlap were moved adjacent to each other for clarity, without affecting the groupings

plankton was less abundant following high turbidity in October 1996, when silt washed into the estuary from dredge spoils. Dredging lasted from May 1996 to November 1996, but silt only entered the estuary under certain environmental conditions (CSIR 1993). Zooplankton density recovered to original levels quickly after high turbidity events.

Copepod instars (copepodite and naupliar stages) were numerically dominant at all stations throughout the sampling period, with maximum numbers of 31 000 and 23 000 m^{-3} respectively. Of the copepods, the small (generally <700 µm long) paracalanids (mostly *Parvocalanus* [*Paracalanus*] *crassirostris*) were the dominant adults, at times exceeding 10 000 m^{-3}; a maximum of 20 000 m^{-3} was recorded at station D during January 1997. *Oithona* spp. were the second most dominant copepods (Fig. 4).

The estuarine calanoids *Pseudodiaptomus stuhlmanni* and *Acartia natalensis* were relatively scarce throughout the study (Fig. 5). Maximum densities for the two copepods were at Stations A and E respectively.

Multivariate analysis

A reasonable stress level of 0.13 was obtained for the two-dimensional MDS plot. According to Clarke and Warwick (1994), stress levels of between 0.1 and 0.2 give a potentially useful two-dimensional picture, but a cross-check of any conclusions should be made against those from an alternative technique, e.g. the superposition of cluster groups. Groups from the hierarchical cluster analysis superimposed on the MDS plot showed a good correlation between the two methods (Fig. 6). At a ranked similarity level of 400 for the cluster analysis, the sampling periods were divided into five groups. Samples E3, E12 and E6 separated individually from the bulk of the samples. These were all collected at Station E during strong freshwater inflows. They illustrate the marked change in zooplankton community composition coincident with these events, after which the system quickly reverts back to marine dominance.

The major group of samples on the MDS plot separates into two sub-groups, which represent autumn/winter and spring/summer sampling periods, illustrating the overall increase in zooplankton abundance during spring and summer. As would be expected from seasonal changes, these two groups are not widely separated, but rather reflect a gradual shift. Results from the SIMPER analysis suggest that the MDS groupings are largely a result of abundance differences between the dominant taxa rather than the presence or absence of specific estuarine taxa.

This evidence for seasonal and salinity effects on the sample groupings as shown by the MDS is further supported by a weighted Spearman rank correlation analysis, which indicates that temperature is the single abiotic variable ($\rho_w = 0.467$) that best matches the biotic groups. The best overall match for all possible abiotic combinations is the two-variable temperature and salinity combination ($\rho_w = 0.546$).

DISCUSSION

Salinity is a major factor controlling zooplankton community structure in estuaries; specific zooplankton communities associate with different salinity regimes (e.g. Grindley 1981, Collins and Williams 1982). Although the present study took place during a year of relatively strong freshwater inflow, the Mhlathuze Estuary remained predominantly marine in terms of salinity. Salinity close to seawater value was perennially present throughout the system, with the exception of February 1996, when the estuary was flooded. Studies conducted after construction of the new mouth (Connell *et al.* 1985, 1989) also reported high salinity throughout the lagoon area. This marine dominance is in contrast to conditions in 1970 (Grindley and Wooldridge 1974), when fluctuations ranged from freshwater during flooding events to near-seawater conditions during droughts. Non-drought periods during that study were, however, characterized by a salinity gradient in the estuary, from seawater levels near the mouth to lower salinity close to the farthest parts of the lagoon area. Millard and Harrison (1954) also reported a "normal salinity gradient" from the mouth to the river inlets. It is therefore clear that, since the construction of the new mouth, salinity in the estuary has changed. This may be attributed to the wide, unrestricted new mouth of the current estuary, as well as restricted freshwater input as a result of the construction of the Goedertrouw Dam and Mhlathuze Weir in the Mhlathuze River during the 1980s. The estuary has subsequently changed from what could be called an "estuarine lake" to the present "estuarine bay" (Whitfield 1992).

The composition of the zooplankton community in the Mhlathuze Estuary illustrates its marine dominance. Marine taxa were present throughout the system, notably copepods in the families Calanidae, Pontellidae, Oncaeidae and Corycaeidae, and the genera *Temora*, *Undinula*, *Eucalanus*, *Euchaeta* and *Candacia*. Grindley and Wooldridge (1974) reported that marine zooplankton extended partially into the area close to the mouth of the original estuary during high tide, and that a true estuarine plankton community typified the lagoon area. This latter community was dominated by *P. stuhlmanni*, *A. natalensis* and *Oithona* spp. Although these estuarine species were also recorded during the present study, they were never abundant. Both *P. stuhlmanni* and *A. natalensis* have wide salinity tolerance (1–75; Grindley 1981). They are, however, seldom found near the mouth of estuaries, but rather dominate hyposaline and sometimes hypersaline regions of estuaries. This indicates that factors other than salinity could determine their distribution patterns. Grindley (1981) speculated on the possibility that they compete with marine species. *P. stuhlmanni* and *A. natalensis* occupy regions left vacant by marine species intolerant of hypo- or hypersaline estuarine conditions. They are able to thrive in estuarine areas with higher primary production and detritus levels than marine waters (Grindley 1981).

Zooplankton density in the Mhlathuze Estuary is currently much lower than reported for other non-marine dominated South African estuaries. For example, Wooldridge (1977) found a rich zooplankton component in the Mgazana Estuary, where the calanoid copepod *A. natalensis* reached a density of 100 000 m^{-3}. In the Sundays River Estuary, densities of the dominant calanoid species *Pseudodiaptomus hessei, Acartia longipatella* and *A. natalensis* often exceed 10 000 m^{-3} and can attain abundances up to 100 000 m^{-3} (Jerling and Wooldridge 1995). The only copepod taxon that reached an appreciable density in the Mhlathuze Estuary during the present study was the small paracalanid group, but its density seldom exceeded 10 000 m^{-3}. This result further illustrates the lower zooplankton biomass associated with estuaries of a uniform, euryhaline nature compared with systems with a pronounced axial salinity gradient (Schlacher and Wooldridge 1996).

Of interest is the dominance of the Paracalanidae in the present study, because it was not present in the original estuarine system (Grindley and Wooldridge 1974). Although the mesh size of the sampler used in the 1974 study was larger (124 μm) than the 63 μm used in the present study, paracalanid copepodites would still have been sampled effectively, if they were present. Connell *et al.* (1975) reported high numbers of the paracalanid *Bestiolina (Acrocalanus, Bestiola) similis* in their 1974 collections with a 250-μm meshed net, during harbour construction. In their subsequent *ad hoc* studies, densities of *B. similis* appeared to have declined (Connell 1981, Connell *et al.* 1989). The paracalanids recorded in the present study were not *B. similis*, but mostly *Parvocalanus (Paracalanus) crassirostris*.

Although paracalanids have been found in a number of South African estuaries (Grindley 1981, Wooldridge 1976, 1977, Coetzee 1983, 1985), they were never dominant and were mainly found near the mouths. However, in Saldanha Bay on the West Coast, a natural harbour with marine salinities throughout, paracalanids were the most abundant taxa (Grindley 1977). Along the South African coast, paracalanids such as *P. crassirostris* appear to be mainly associated with sheltered marine inlets. However, *P. crassirostris* is not only restricted to euryhaline waters. It was the most abundant species reported in tidal creeks of the North Inlet, South Carolina (Londsdale and Coull 1977), and relatively high density was found under mesohaline conditions in the lower Neuse River Estuary in North Carolina (Mallin 1991).

Grindley and Wooldridge (1974) regarded tidal exchange as the most important factor controlling the distribution of plankton in the Richards Bay system before construction of the harbour. Since then, construction of the new mouth has substantially changed the flow dynamics in the estuary. Begg (1978) reported a large tidal exchange of 88% after construction of the new estuary mouth, in contrast to the lagoon area construction of the harbour "… where the rate of tidal replacement is limited" (Grindley and Wooldridge 1974). Such a large tidal exchange would inhibit the establishment of a proper estuarine plankton community.

The original Mhlathuze Estuary had an average water depth of about 1 m and a tidal range of between 0.1 and 0.4 m (Huizinga and van Niekerk 2000). After opening the new mouth, the tidal range increased to 1.4 m at spring tides (Huizinga and van Niekerk 2000). Strong tidal flow, related to the size of the estuary and the large vertical tidal variation, keeps the mouth open; it has not closed during the more than two decades since the construction of the harbour. The increase in tidal range has led to the exposure of large areas during low tide. According to Huizinga and van Niekerk (2000), this exposure could be a major cause for the present increase in mangrove-covered areas. Furthermore, because of canalization of the river, floodwater is no longer allowed to disperse over the floodplain before entering the estuary. This extends the soil-carrying capacity of the canalized river water flowing into the estuary. As a result, large amounts of fluvial sediment are deposited in the estuary instead of the original floodplain, especially during flooding (Begg 1978).

Large parts of the estuary created after construction of the harbour are now covered by mangroves, probably as a result of sediment deposition and increased tidal range. Using a map of the estuary surveyed during 1971, before harbour construction, and aerial photographs taken during 1996, it is estimated that, when the system was divided, its estuarine surface area was reduced by some 60% of its original 30 km^2. Also, mangrove encroachment has further reduced the surface area of the newly established estuary. The total reduction in estuarine surface area is estimated to be 75% of its original size. With such a large reduction in habitat and a less stable environment for zooplankton, it is not surprising that current abundance is greatly reduced from that of the original estuary.

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