The Chemistry and Meiofauna of Some Unpolluted Sandy Beaches in South Africa

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Abstract

Chemical and meiofaunal studies have been carried out on ten sandy beaches along the south and west coasts of South Africa with the aim of establishing base line levels of some parameters, including trace metals, nutrients, dissolved oxygen, oxygen absorbed from alkaline permanganate (OA), temperature and salinity and the diversity and size of meiofaunal populations. Guidelines for the normal levels of the various parameters have been set out and some reasons for their variability have been suggested. The various sites share similarities with regard to exposure, granulometry and hydrology.

Introduction

The South African National Programme for Marine Pollution Surveys began formally in 1974. An objective of the programme was to identify areas where pollution had made an impact on the environment and, if possible, to quantify the extent of this impact. In order to do this a number of 'clean' beaches were surveyed to obtain some criterion for measuring pollution impact and to determine the extent of natural variation of some parameters between different areas and during different seasons. Environmental analyses depend on the availability of good base-line data that must be gathered in contemporary environments. Only on this basis is it possible to measure the impact of change or the effect of a pollutant on the quality of the environment.

This paper deals with the chemical and meiofaunal results obtained from reference surveys along South Africa's south and west coasts. The concentrations measured can be taken as normal background levels for these areas, since the beaches sampled were all apparently unpolluted and were some distance from any known pollution source or other discharge. Some of the beaches were sampled both during summer and winter to give an indication of seasonal variations. Beaches selected were Jeffreys Bay, Keurboomstrand, Witsand, Arniston and Betty's Bay (south coast), Swartklip (False Bay), and Sandy Bay, Camps Bay and Silwerstroomstrand (west coast) (Fig. 1).

It has since become apparent that Witsand and Swartklip may not be suitable as reference areas for reasons which will be discussed later. The results of the Camps Bay survey have been published elsewhere (Eagle *et al.*, 1977) but some are included here for the purposes of comparison. Similar surveys by another group have been carried out along the South African east coast (Oliff *et al.*, 1967a, 1967b, 1970).

The surveys were multi-disciplinary, including both chemical and biological investigations. From the biological point of view, initial attempts were aimed at the assessment of the macrofaunal populations (animals larger than 1mm) of the beaches studied. However, most of the beaches along this stretch of South Africa's coast are characterised by a paucity of macrofauna such as bivalves, polychaete worms and crustaceans. High wave energy, which varies seasonally, causes constant rebuilding of the beaches and this prevents significant colonization by macrofauna. Attempts to collect quantitative samples from just outside the surf zone by means of a diver-operated air lift suction apparatus (Christie and Allen, 1972) also proved unsuccessful, and attention was therefore turned towards the study of the psammolittoral meiofauna (animals passing through a 1mm, but retained by a 45 μm, sieve). The numbers of these interstitial animals are much larger, although they vary greatly, not only from beach to beach but also between different stations along the same beach. There are a number of reasons for these variations, including sediment particle size, the patchiness of food sources, dissolved oxygen content, organic content, wave energy and others. In an effort to reduce the effect of this patchiness, core samples, spaced 2 m from each other, were taken in quintuplicate at each station. Nevertheless this variability emphasizes the fact that comparisons between beaches which are remote from each other should be treated with caution. Other studies of psammolittoral meiofauna have been undertaken in Algoa Bay (McLachlan, 1977a, 1977b, McLachlan and Furstenberg, 1977, McLachlan *et al.*, 1977a 1977b, 1978).

Another problem encountered in the meiofaunal study has been that of taxonomy. One of the most important criteria for judging the health of a beach is the diversity of its fauna. The lack of taxonomic expertise, coupled with the fact that the majority of the meiofaunal animals are new and have not been described, has thus proved a serious obstacle.

The aim of this study therefore was to provide base line data on the natural levels of the various physical and chemical parameters as well as meiofauna on unpolluted beaches on South Africa's south and west coasts. It is against these that pollution effects may be measured in future.

Sample Collection and Methods

The sample collection and analytical procedures were similar to those of Oliff *et al.* (1967a, 1967b, 1970), working along the east coast. Samples were collected from all beaches during the low water of spring tides, from five or six evenly spaced stations (usually 100 m apart). Surface water samples were taken from the surf zone, while sediments and interstitial water were obtained from approximately the half-tide mark. Interstitial water

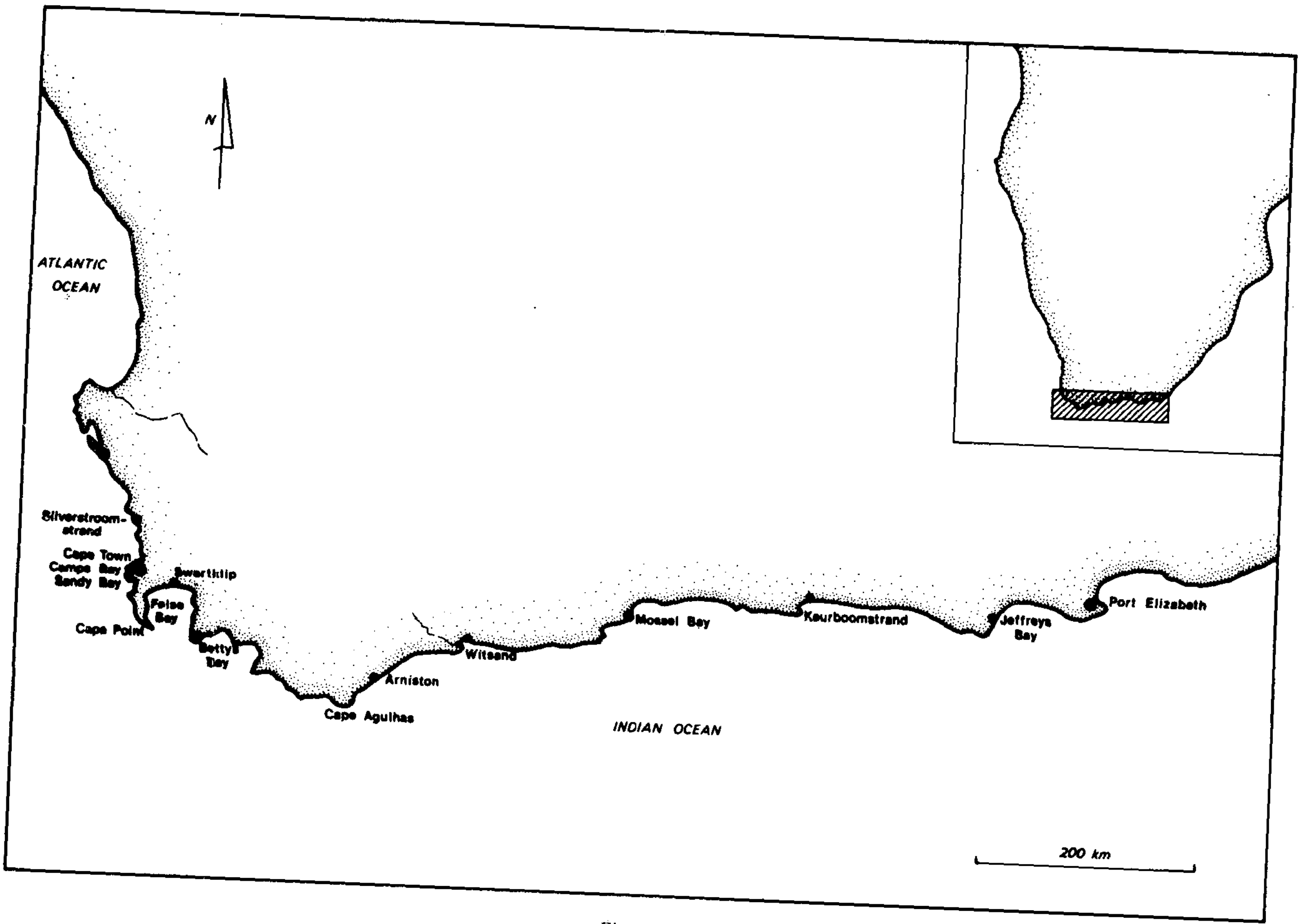

Figure 1
Reference beach sites

and sub-surface sediments were collected from a depth of approximately 1 m, the water being obtained through a stainless steel probe connected to a hand-operated vacuum pump.

Water samples were analysed for salinity, temperature, dissolved oxygen, oxygen absorbed from alkaline permanganate (OA), pH and nutrients (total phosphorus, silicate, nitrate and nitrite). Some water samples were analysed for trace metals (Cd, Cu, Pb, Ni and Zn) using atomic absorption spectroscopy. Sediment samples were analysed for meiofauna, particle size, OA and trace metals (Cd, Co, Ni, Pb, Zn, Cu, Fe and Mn). The temperature and pH measurements were made in situ but all other samples were preserved and analysed later in the laboratory. Standard methods of analysis were used for salinity, dissolved oxygen, OA and nutrients (Standard methods of water analysis, 1946; Strickland and Parsons, 1960, 1968; Murphy and Riley, 1962). Trace metals in water and sediments were determined according to the methods of Watling and Watling (1976, 1977), while sediment particle size was determined in a settling tube (Flemming and Thum, 1978). Cores for meiofauna (5,2 x 30 cm) were taken in quintuplicate at each station, divided into three equal 10 cm sections (a = 0 – 10 cm, b = 10 – 20 cm, c = 20 – 30 cm) and the corresponding sections of all five cores were mixed. A subsample of 100 cm^3 was assumed to be representative of the whole sample. Animals were separated from the sediment by the modified flotation technique of Oostenbrink (Fricke, 1979), classified as far as possible and counted. Populations in this paper are expressed as the number of animals per 100 cm^3 of sediment.

Results and Discussion

Apart from a few exceptions to be discussed, the concentrations of most of the chemical parameters measured showed only slight variations between stations. Mean values thus give a fair indication of the concentrations of the various parameters in the water around the coast, see Tables 1 – 4. Standard deviations are given in the tables and are generally low.

It was originally hoped that some relationship would be found between the chemical and biological measurements, and samples were collected simultaneously from all stations. However, apart from correlations of silicate and nitrate concentrations with animal numbers, no other relationships between populations and the measured chemical parameters could be found (Fricke *et al.*, submitted for publication). This may be due to the fact that the response of a biological community to a chemical change is relatively slow. For example, at the time of sampling, Witsand had a low mean salinity due to the contribution of freshwater from the Breede River, yet the concentration and composition of the meiofauna showed no difference from

TABLE 1:
SURFACE WATER SAMPLES — MEAN CONCENTRATIONS (STANDARD DEVIATIONS GIVEN IN BRACKETS)

Station	Season	Salinity (°/oo)	Total phosphorus (μmol/l)	Silicate (μmol/l)	Nitrite (μmol/l)	Nitrate (μmol/l)	OA (mg/g)	Dissolved oxygen (mg/l)	Temp. (°C)	pH
Jeffreys Bay	winter	35.01 (0.19)	0.78 (0.14)	6.49 (1.59)	0.35 (0.03)	8.91 (9.08)	.003 (.001)	6.97 (1.12)	15.6 (.7)	8.10 (0.20)
	summer	35.13 (0.08)	1.07 (0.31)	1.94 (0.25)	0.17 (0.16)	3.23 (0.97)	.005 (.001)	7.00 (0.13)	21.3 (.8)	8.15 (0.04)
Keurboom-strand	winter	35.27 (0.01)	0.70 (0.08)	5.49 (0.46)	0.46 (0.04)	4.42 (0.98)	.005 (.006)	7.45 (0.70)	17.1 (1.5)	8.24 (0.04)
	summer	35.22 (0.06)	2.43 (2.85)	3.37 (1.84)	0.07 (0.03)	5.14 (3.69)	.004 (.001)	7.06 (0.07)	20.4 (.1)	8.27 (0.04)
Arniston	summer	35.43 (0.03)	1.20 (0.59)	4.88 (0.91)	0.08 (0.05)	2.97 (2.29)	.004 (.002)	6.97 (0.29)	19.5 (.3)	8.23 (0.07)
Betty's Bay	winter	34.74 (0.07)	1.13 (0.17)	8.98 (0.87)	0.32 (0.04)	10.06 (0.75)	.003 (.001)	4.80 (1.59)	13.5 (.4)	
Swartklip	summer	34.99 (0.04)	2.22 (0.53)	3.96 (0.51)	0.32 (0.05)	4.38 (0.25)	.003 (.002)	7.00 (0.61)	20.8 (.2)	8.14 (0.08)
Sandy Bay	summer	34.59 (0.13)	1.79 (0.16)	13.39 (1.30)	0.21 (0.05)	16.72 (0.76)	.008 (.008)	6.27 (3.05)		7.64 (0.09)
Camps Bay	winter	35.04 (0.02)	1.28 (0.16)	7.79 (0.63)	0.56 (0.90)	7.82 (1.39)	.003 (.001)	7.79 (0.56)	15.7 (.2)	7.99 (0.16)
	summer	34.76 (0.06)	1.60 (0.12)	11.25 (0.87)	0.22 (0.01)	14.17 (1.29)	.004 (.002)	8.97 (0.30)	10.6 (.7)	7.84 (0.09)
Silwerstroomstrand	winter	34.47 (0.96)	2.24 (0.21)	21.91 (6.13)	0.33 (0.06)	8.26 (1.10)	.009 (.001)			8.02 (0.08)

TABLE 2
INTERSTITIAL WATER SAMPLES — MEAN CONCENTRATIONS (STANDARD DEVIATIONS GIVEN IN BRACKETS)

Station	Season	Total phosphorus (μmol/l)	Silicate (μmol/l)	Nitrite (μmol/l)	Nitrate (μmol/l)	OA (mg/g)	Dissolved oxygen (mg/l)	pH
Jeffreys Bay	winter	3,14 (0,35)	25,42(13,98)	0,15 (0,11)	42,81(39,07)	0,003(0,002)	3,13 (1,54)	7,90 (0,04)
	summer	4,97 (0,65)	32,23(14,00)	3,54 (3,84)	59,85(33,91)	0,003(0,001)	1,50 (1,38)	7,97 (0,10)
Keurboomstrand	winter	1,57 (0,66)	10,15 (2,63)	0,08 (0,05)	22,92 (5,13)	0,002(0,001)	6,07 (1,03)	8,15 (0,13)
	summer	3,42 (1,80)	14,99 (3,63)	0,55 (0,54)	14,53 (5,74)	0,004(0,003)	4,36 (1,40)	8,12 (0,05)
Arniston	summer	1,47 (0,33)	3,77 (0,48)	0,18 (0,07)	6,91 (4,27)	0,009(0,004)	7,12 (0,20)	8,13 (0,20)
Betty's Bay	winter	4,73 (2,11)	23,10(21,17)	—	19,39(12,89)	0,003(0,002)	1,41 (0,50)	—
Swartklip	summer	3,17 (0,76)	8,34 (3,74)	0,03 (0,01)	28,79 (8,59)	0,003(0,001)	4,26 (0,88)	7,97 (0,16)
Sandy Bay	summer	9,28 (5,07)	13,40 (6,37)	—	—	0,006(0,004)	1,64 (1,44)	7,52 (0,09)
Camps Bay	winter	3,25 (1,69)	17,55(15,77)	0,18 (0,07)	10,17 (3,29)	0,007(0,004)	5,66 (2,03)	7,95 (0,20)
	summer	3,01 (1,44)	13,21 (6,41)	0,12 (0,15)	19,24(12,11)	0,003(0,001)	5,41 (2,76)	7,83 (0,15)
Silwerstroomstrand	winter	14,95 (8,53)	48,85 (9,11)	0,23 (0,11)	1,86 (1,57)	0,008(0,004)	—	7,91 (0,24)

TABLE 3
MEAN CONCENTRATIONS AND RANGES OF METALS IN SURFACE WATER (μg/l)

Site		Cd	Cu	Pb	Ni	Zn
Jeffreys Bay	mean	0,15	0,9	0,7	1,3	5,5
	range	1,10 – 0,28	0,6 – 1,4	0,5 – 0,9	0,6 – 3,1	2,9 – 8,5
Keurboomstrand	mean	0,41	0,7	0,6	0,8	3,8
	range	0,19 – 0,86	0,3 – 1,2	0,4 – 1,0	0,4 – 1,5	2,1 – 7,0
Arniston	mean	0,28	1,0	0,7	3,2	5,9
	range	0,13 – 0,62	0,6 – 1,5	0,5 – 1,0	0,5 – 4,5	3,3 – 7,6

TABLE 4
MEAN CONCENTRATIONS AND RANGES OF METALS IN THE NITRIC/PERCHLORIC ACID LEACH OF SEDIMENTS (μg/g DRY MASS)

Site		Cd	Co	Cu	Fe	Pb	Mn	Ni	Zn
SURFACE SEDIMENTS									
Jeffreys Bay	mean	0,05	< 0,5	< 0,5	2810	2,0	17,9	< 1,0	3,1
	range	0,01 – 0,15	< 0,5	< 0,5	2540 – 3000	1,3 – 2,7	16,8 – 18,5	< 1,0	1,8 – 7,7
Keurboomstrand	mean	0,02	< 0,5	< 0,5	3590	2,0	19,9	< 1,0	2,8
	range	0,01 – 0,03	< 0,5	< 0,5	3410 – 4110	1,4 – 2,4	18,3 – 21,8	< 1,0	2,6 – 3,1
Arniston	mean	0,07	< 0,5	< 0,5	960	2,1	11,3	< 1,0	1,5
	range	0,01 – 0,11	< 0,5	< 0,5	620 – 1150	1,6 – 3,0	10,2 – 12,7	< 1,0	0.9 – 2,0
Swartklip	mean	0,05	< 0,5	< 0,5	1210	2,5	7,7	< 1,0	1,9
	range	0,01 – 0,13	< 0,5	< 0,5	980 – 1320	1,6 – 3,7	6,2 – 8,9	< 1,0	1,3 – 2,8
SUBSURFACE SEDIMENTS									
Jeffreys Bay	mean	0,04	< 0,5	< 0,5	2880	1,7	16,8	< 1,0	2,1
	range	0,01 – 0,08	< 0,5	< 0,5	2580 – 3050	1,0 – 2,2	14,9 – 17,7	< 1,0	2,0 – 2,2
Keurboomstrand	mean	0,01	< 0,5	< 0,5	4020	2,3	22,7	< 1,0	2,9
	range	0,01 – 0,03	< 0,5	< 0,5	3730 – 4220	2,1 – 2,8	21,3 – 24,6	< 1,0	2,7 – 3,1
Arniston	mean	0,05	< 0,5	< 0,5	1340	3,9	17,0	< 1,0	2,9
	range	0,01 – 0,10	< 0,5	< 0,5	560 – 2070	2,7 – 6,4	12,9 – 23,0	< 1,0	2,4 – 4,3
Swartklip	mean	0,02	< 0,5	< 0,5	1310	2,4	8,2	< 1,0	1,9
	range	0,01 – 0,06	< 0,5	< 0,5	1240 – 1430	1,7 – 3,1	7,2 – 8,9	< 1,0	1,5 – 2,6

those at other reference beaches. Similar results have been obtained by Reid (1939), Smith (1955), Brown (1971), Wieser (1975) and McLachlan and Furstenburg (1977).

Salinity

The mean salinity of 32,9‰ of the water at Witsand indicated significant influence of the Breede River, in spite of the fact that samples were taken 5 – 6 km east of the river mouth. The percentage of fresh water is given by the formula

$$\frac{S_o - S}{S_o} \times 100$$

where S_o is the salinity of undiluted seawater and S is the salinity of the diluted seawater (Oliff *et al.*, 1970). Taking S_o as the mean salinity of the water at the south coast stations (35,13‰), calculation shows that the contribution from the Breede River was over 6%.

Two sites on the south coast, Jeffreys Bay and Keurboomstrand, were sampled in both summer and winter. Statistical tests showed that there was no significant difference in the salinity with season. This is in contrast to the west coast where the only beach sampled twice, Camps Bay, had a significantly lower salinity in summer. This was because this part of the coast lies in one of the world's most intensive upwelling areas, caused mainly by the south-easterly winds which prevail during the summer. Salinity measurements of samples taken by this group up to 100 km offshore (unpublished results) indicate that there is a decrease in salinity with depth; thus upwelled water would be expected to have a lower salinity. In general, the salinity along the south cosat was slightly higher than 35‰, while that of the west coast was less than 35‰. The mean salinity at Swartklip, the only beach in False Bay which was sampled, was almost exactly 35‰.

Temperature

Temperatures along the south coast were lower, by approximately 5°, in winter than in summer. Along the west coast, the effect of upwelling is clearly seen, as the temperature at Camps Bay during summer was 5° lower than in winter. Thus winter temperatures around the coast are fairly constant (approximately 15°C) whereas during summer there is a difference of up to 10°C between the water temperatures on the west and south coasts.

Dissolved oxygen

The mean concentration of dissolved oxygen in the surface water was slightly low at Betty's Bay (4,8 mg/ℓ), but varied between 6,3 and 9,0 mg/ℓ at other localities. This indicates a high degree of oxygenation at all beaches. The dissolved oxygen concentration in the interstitial water varied between 1,4 and 7,1 mg/ℓ. At each site there was a tendency for those samples with the coarser sediment particles to have higher dissolved oxygen concentrations although this could not be correlated from site to site. Better irrigation would be expected through coarser sediments, and this should lead to higher dissolved oxygen concentrations (McLachlan, 1977a).

OA

This somewhat crude technique measures the 'easily oxidisable organic content' of the sample, although it is not known with certainty what this constitutes. However, it is a far easier and more rapid method of analysis than other similar measurements such as BOD and COD, and although OA results are not directly comparable with these other measurements, rigid standardisation of the procedure should allow OA values to be compared with themselves. Results indicate the relative amounts of easily oxidisable organic material which will absorb oxygen from the surroundings and which is thus important in a pollution context.

The amount of oxygen absorbed from alkaline permanganate by the surface water varied randomly between 0,003 and 0,009 mg/g (highest at Silwerstroomstrand), while interstitial water had results between 0,002 and 0,009 mg/g (highest at Arniston). These values are between 2 and 10 times higher than those obtained at Brighton Beach in Natal by Oliff *et al.*, (1970), indicating a much higher organic content in the water around the Cape coast although it must also be stated that the Natal beaches were coarser and thus expected to have a larger organic content. OA values of sediment samples ranged between 0,04 and 0,18 mg/g (surface) and 0,04 and 0,14 mg/g (subsurface). Again, variations were random with no particular trends apparent.

Nutrients

Concentrations of nutrients in the surface waters were generally lower than those in the interstitial waters. Levels in the interstitial waters at Jeffreys Bay (during both summer and winter) were much higher than those in other south coast beaches, and the same was true for Silwerstroomstrand on the west coast. The reason for these anomalous results is not known, although the number of holiday houses at Jeffreys Bay with soakpit sewage systems could account for the high nutrient concentrations obtained there. These high values are apparently coupled with low levels of dissolved oxygen. In general, the nutrient concentrations in the surface water along the west coast were approximately twice those on the south coast. Camps Bay had higher nutrient concentrations in summer as a result of upwelling. Nitrate and nitrite values obtained in Natal (Oliff *et al.*, 1970) were similar to those obtained at the south coast locations, whereas total phosphorus levels in the Natal water were closer to those of the Cape west coast.

The nutrient concentrations at most stations seemed to follow a definite trend, particularly in the surface water samples, where there was a strong correlation between total phosphorus, silicate and nitrate and an inverse correlation of all three with nitrite. These correlations were less evident among the interstitial samples, which is to be expected because of the more limited mixing within the sediment. At some sites, particularly Sandy Bay, there was a curious range of concentrations for certain nutrients which cannot be explained. For example, two interstitial samples contained very high levels of nitrite and nitrate (greater than 6 and 10 μmol/l respectively), while the other three were much lower (less than 0,08 and 0,7 μmol/l respectively). It is thought that the high concentrations were not due to contamination but rather to some natural variation. Because of this, the calculation of mean values for this beach was not possible. This illustrates the large variations which can occur with environmental samples.

Trace metals

The ranges of concentrations of the various metals are given in Table 3. The concentrations obtained here fit into ranges similar to those given by Phillips (1977) in a summary of results obtained by other workers, mostly in Britain and the United States. Results obtained by Chester and Stoner (1974) for samples collected off the South African coast were also of the same magnitude. The results obtained for lead and cadmium were higher than those obtained in oceanic water (Brewer 1975), but it is felt that this was not due to contamination or experimental procedure, since samples collected up to 100 km offshore and analysed by the same procedure, had very low lead and cadmium concentrations (unpublished results). It appears therefore that trace metals concentrations in inshore waters are higher than those further offshore.

In the analysis of sediments, an acid leach technique was used rather than complete dissolution of the sediments. This method measures the available trace metals and hence is more important from the pollution viewpoint. The mean concentrations and ranges of metals are given in Table 4, but the levels measured are, in general extremely low when compared with those obtained by other workers using the same technique (e.g. Watling and Watling, 1977; Helz, 1976). The reason for these low values is not known but may be partly due to the low organic content of the sediments, indicated by low OA values, since it is known that trace metals are associated with organic material in sediments (Phillips, 1977; Orren *et al.*, 1979). However, as with most environmental parameters, the relative concentrations are more important because of the large variations which occur with different locations. Levels measured here cannot be regarded as universally applicable, but rather as guidelines for possible concentrations in sandy beaches.

Sizes of sediment particles

The median sizes of the sediment particles varied between 196 and 383 μm, the one exception being the sediment from Arniston, with a mean particle size of 661 μm, (Table 5). This sediment was also only moderately well sorted. There were some dif-

TABLE 5
PHYSICAL CHARACTERISTICS OF THE SEDIMENTS

Beach	Median particle diameter (μm)	Sorting (ϕ)	Skewness
Jeffreys Bay	334	0,289	0,183
Keurboomstrand	334	0,283	0,403
Witsand	262	0,314	0,041
Arniston	661	0,653	0,121
Betty's Bay	243	0,304	0,032
Swartklip	250	0,567	−0,192
Sandy Bay	291	0,303	0,285
Camps Bay	383	0,312	0,249
Silwerstroomstrand	196	0,203	0,150

ferences between sediment sizes at stations along individual beaches, depending on aspect, and pronounced stratification was observed. The sediments were, on the whole, much finer than those along the Natal coast where the mean values ranged between 600 and 900 μm (Oliff *et al.*, 1970) but were similar to those found in Algoa Bay (200 — 266 μm) (McLachlan, 1977). Natal sediments varied over a smaller range and could be classified as granular coarse sand (Folk, 1968).

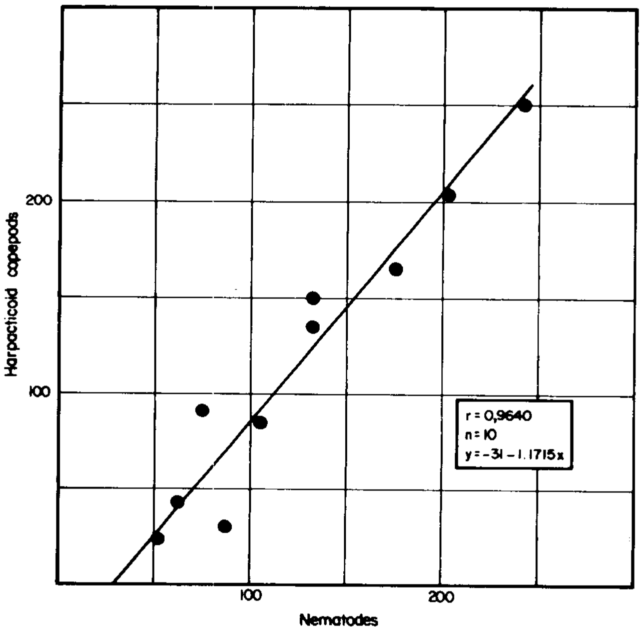

Figure 2
Relationship between nematode and harpacticoid copepod populations. (number of animals per 100 cm³ sediment)

Meiofauna

One of the characteristics of meiofaunal communities is the recurrence of certain species assemblages with particular substrates. The communities generally consisted of a number of groups, of which nematodes and harpacticoid copepods were by far the most dominant, and there was a strong correlation between the abundance of these two groups (Fig. 2). Correlations were also found between animal numbers and the concentrations of silicates and nitrates. These relationships are summarised in Table 6. The actual numbers of animals obtained varied considerably from place to place, illustrating the patchiness with which they occur. Mean values have been calculated for comparison purposes, although their use may be limited by the large standard deviations which occur (Table 7). Harpacticoids apparently have an even more patchy distribution than nematodes. Unusually high nematode densities were found at Swartklip in False Bay, where samples of the top 10 cm of sediment contained 690—3770 animals per 100 cm^3 of sediment. Numbers decreased with depth but were high throughout. This was most probably due to the high organic content of the beach, either from the natural abrasion of macrophytes by sediments which are transported longshore (J.G.K. Glass, personal communication) or from the Cape Flats sewage outfall to the west (Eagle, 1980), or from a combination of these two. In any case, the fine sediment (mean diameter 167 μm) found along this beach acts as a detritus trap and this forms the first step in a food chain which supports the high concentration of nematodes. For this reason the beach at Swartklip should not be regarded as a reference beach.

Regression analysis showed that in general the harpacticoids were slightly less numerous than the nematodes. No real difference between the populations on the south and west coast beaches could be observed.

The better correlation of harpacticoid numbers to silicate and nitrate concentrations may indicate that they are more sensitive to chemical changes. Other work by this laboratory (Fricke *et al.*, 1979; Orren *et al.*, 1979) has shown that the absence of harpacticoid copepods is a good indicator of low oxygen stress. The present work also indicates that there is a fairly good correlation between the dissolved oxygen content of the interstitial water and the number of animals in the 'c' samples. Although

TABLE 6
SIGNIFICANT REGRESSIONS BETWEEN PARAMETERS MEASURED ON SANDY REFERENCE BEACHES

x	y	Regression equation	r	
Grain size	No. nematodes	y = 195 — 1,9074x	−0,7241	**
Grain size	No. harpacticoids	y = 194 — 2,1578x	−0,6757	**
No. nematodes	No. harpactocoids	y = −31 + 1,1715x	0,9640	***
Silicate	No. nematodes	y = 241 — 5,2852x	−0,6428	*
Silicate	No. harpacticoids	y = 282 — 7,5648x	−0,7460	**
log (nitrate + 1)	log (nematodes + 1)	y = 2,59 — 0,4052x	−0,6242	*
log (nitrate + 1)	log (harpactocoids + 1)	y = 3,14 — 0,8813	−0,8151	**

Significance at 99% = ***; 95% = **; 90% = *

TABLE 7
MEAN MEIOFAUNAL NUMBERS

(Figures represent the numbers of animals per 100 cm³ sediment)

	WEST COAST				SOUTH COAST			
	Nematodes		Harpacticoid Copepods		Nematodes		Harpacticoid Copepods	
Depth (cm)	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.
0–10	205	238	410	796	160	152	238	682
10–20	85	91	475	1042	93	76	199	489
20–30	60	56	205	395	103	177	103	148

these two parameters are not strictly comparable since the interstitial water was collected from a depth of 1 m while the biological samples were collected between 20 and 30 cm, it nevertheless seems to confirm previous results.

Smaller numbers of other taxa, e.g. flatworms, acarines, juvenile crustacea, polychaetes, oligochaetes, mystacocarids and archiannellids, were found on most beaches but a more detailed analysis of faunal relationships will have to await solution of the taxonomic problems.

Conclusions

It is apparent from the limited number of measurements made that the extensive upwelling which occurs along the west coast in summer gives rise to greater seasonal differences, higher nutrient concentrations and lower salinities on the west coast than along the south coast. Within the observed sediment particle size range of 196–337 μm. standards for the population densities of meiofauna can be set according to grain size, since this appears to be the main cause for variation in the unpolluted beaches studied. (Fricke *et al.*, submitted for publication). The ratio of nematodes to harpacticoids should remain constant.

However, the variability of the biological results demon-

TABLE 8
MEAN VALUES OF MEASURED CHEMICAL PARAMETERS

	SOUTH COAST		WEST COAST	
Surface water	$\bar{x}$	s.d.	$\bar{x}$	s.d.
salinity (‰)	35,1	0,2	34,7	0,2
total phosphorus (μmol/ℓ)	1,2	0,6	1,7	0,4
silicate (μmol/ℓ)	5,2	2,5	13,6	6,0
nitrite (μmol/ℓ)	0,2	0,2	0,3	0,2
nitrate (μmol/ℓ)	5,8	3,0	11,7	4,4
dissolved oxygen (mg/ℓ)	6,7	1,0	7,7	1,4
OA (mg/g)	0,004	0,001	0,006	0,003
pH	8,2	0,1	7,9	0,2
trace metals (μg/ℓ)				
Cd	0,28	0,21		
Cu	0,86	0,34		
Pb	0,69	0,19		
Ni	1,7	1,5		
Zn	5,1	1,9		
Interstitial water				
total phosphorus (μmol/ℓ)	3,2	1,5	7,6	5,7
silicate (μmol/ℓ)	18,3	10,5	23,3	17,2
nitrite (μmol/ℓ)	0,2	0,2	0,2	0,1
nitrate (μmol/ℓ)	27,7	19,8	10,4	8,7
dissolved oxygen (mg/ℓ)	3,9	2,4	4,2	2,3
OA (mg/g)	0,004	0,003	0,006	0,002
pH	8,1	0,1	7,8	0,2
Sediments				
surface OA (mg/g)	0,11	0,05	0,08	0,03
subsurface OA (mg/g)	0,09	0,04	0,08	0,02
trace metals (μg/g)				
Cd	0,04	0,04		
Cu	< 0,5			
Co	< 0,5			
Fe	2260	1170		
Pb	2,4	1,0		
Mn	15,2	5,5		
Ni	< 1,0			
Zn	2,4	1,1		

strates that considerable differences exist between unpolluted beaches, both temporally and with location. Thus it is the relative differences in measurements which are important and which can be used to point out impact sites, (Eagle *et al.*, 1979). No fixed values can be put forward as being universally applicable, although many measurements fall between certain limits. The main values of all chemical measurements made in this study are given in Table 8 and can be used as guidelines for conditions applicable to unpolluted sandy beaches along the south and west coasts of South Africa.

The overall objective of setting standards should be to protect human health or a natural resource. The problem is to determine the capacity of the environment to receive pollutants, or combinations of pollutants, and then to set controls in such a way that this capacity is not exceeded. These controls will vary from one situation to another and will depend on the environmental conditions existing at each place (Preston, 1979). Since a zero effect of any discharge into the sea is normally not practicable, the standards set will depend on the level of effect which is acceptable in any situation and it should be the practice of any regulatory authority to set standards well below those associated with the capacity of the environment to deal with a particular discharge.

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