Vertical gradients in the fauna and oxidation of two exposed sandy beaches

A. McLachlan, A.H. Dye and P. van der Ryst

Vertical profiles of oxygenation and fauna were measured in two exposed sandy beaches. At the less exposed site the whole upper metre of sediment was oxidized although the redox potential discontinuity started at 85 cm. Meiofauna were concentrated in the upper 40 cm and protozoa in the upper 55 cm, but bacteria showed no distinct vertical drop-off in numbers. On a more exposed beach the upper 1,3 m was highly oxidized, with meiofauna concentrated in the upper 80 cm and protozoa in the upper 115 cm. Meiofauna and protozoan numbers correlated with oxygen tensions and redox values and with each other. It is suggested that small protozoans are an important food source for the meiofauna.
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Vertikale profiele van suurstofkonsentrasie en fauna is in twee oop sandstrande bepaal. By die meer beskutte strand was die hele boonste meter sediment geoksideer alhoewel die redokspotensiaal-diskontinuïteit by 85 cm begin het. Meiofauna was in die boonste 40 cm gekonsentreer en protozoa in die boonste 55 cm, maar daar was nie 'n duidelike afname in bakteriegetalle op dieper vlakke nie. In die geval van die meer blootgestelde strand was die boonste 1,3 m hoogs geoksideer. Meiofauna was in die boonste 80 cm en protozoa in die boonste 1,15 m gekonsentreer. Meiofauna- en protozoa-getalle het met suurstofkonsentrasies en redokswaardes sowel as met mekaar gekorreleer. Daar word voorgestel dat klein protozoa 'n belangrike voedselbron vir die meiofauna is.
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Exposed sandy beaches are generally considered to be high oxygen windows in the marine environment (Fenchel & Riedl 1970, Riedl 1975) where aerobic microfauna and meiofauna occur to at least one metre depth (Renaud-Debyser 1963, Riedl 1975). Vertical gradients in poorly oxygenated sediments are more marked, and work on the black or sulphide layers has been summarized by Fenchel & Riedl (1970), while gradients of the Metazoa and chemistry in the partly oxidized redox potential discontinuity (RPD) zone have been studied in detail by McLachlan (1978).

Much of the South African coastline consists of high-energy beaches and work done on such areas in the eastern Cape Province showed that meiofauna was in most cases abundant to the maximum depths sampled, 40–90 cm (McLachlan 1977a,b, in press). The aim of this work was to quantify the deep vertical distribution of the fauna and the degree of oxygenation down to the depths where meiofaunal numbers become insignificant in these beaches.

Study sites

Kings Beach is the least exposed sandy beach in the vicinity of Port Elizabeth and has the finest sand, while Maitland River beach is the most exposed and has the coarsest sand. Both sites may, however, be considered high-energy beaches and they experience continuous moderate to extreme wave action. Mid and lower tide levels on Kings Beach were found to have relatively low interstitial oxygen tensions and very low meiofaunal numbers (McLachlan 1977a,c) while higher tide levels on Maitland River beach have a rich and abundant meiofauna (McLachlan 1977b) and are well oxygenated. These two sites thus represent the least and the best oxygenated sand beach areas near Port Elizabeth.

Methods

The corer

A corer, designed to take cores longer than 50 cm (as a conventional tube corer does not easily penetrate more than 30 cm below the water table) was constructed from 1,5 mm (16G) stainless steel. It consisted essentially of a square

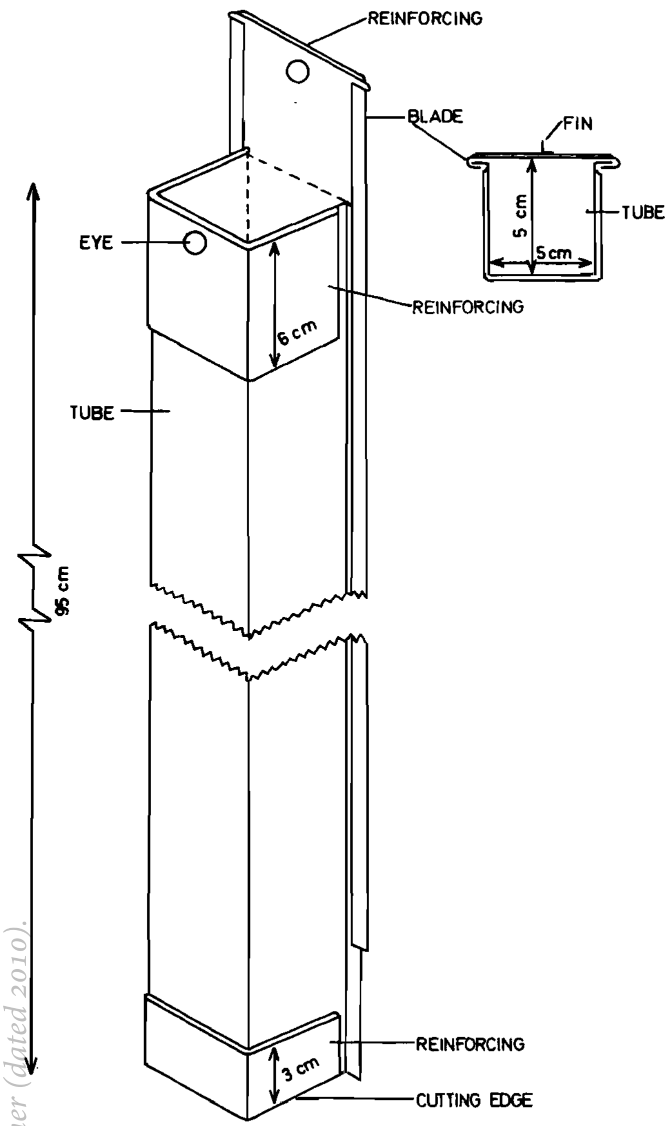

Fig. 1 Diagram of the corer showing the interlocking blade.

tube with one side being an interlocking sliding blade (Fig. 2). The cutting and upper edges of the unit were reinforced with an extra layer of stainless steel and the blade had a 1 cm wide fin along its entire length. Just below the upper edges of both tube (three-sided part) and blade, 1 cm holes were drilled, through which a metal rod could be introduced as a handle to lift the corer. For sampling, tube and blade were interlocked and then driven into the sediment to the required depth using a 2 m log with handles as a ram. A little compression (5-10%) inevitably did occur and this was usually sufficient to ensure that the core did not slide out when the corer was removed from the sediment. After removal from the sediment the corer was laid flat and the blade was slid off the tube, leaving the core exposed and intact.

Sampling

Kings Beach was sampled just above mean tide level (hereafter referred to as MW) on 30.11.1977 and Maitland River Beach was sampled just above the high water neap drift line (HW) on 6.12.1977. Duplicate cores were taken in steps of 40-70 cm to 1 m on Kings Beach and 1,3 m on Maitland River beach. The moment the corer was withdrawn from the sediment and the blade removed the following measurements and samples were taken at 10 cm intervals along the core: temperature was read to 0,1 °C with a mercury thermometer, Eh was measured with calomel and platinum electrodes and interstitial water samples were taken using a modified syringe (McLachlan 1977c). Sand colour was noted and the cores cut into 10 cm lengths and sealed in bottles.

Laboratory analyses

Oxygen content of the interstitial water was read on a Radiometer Acid-base Analyser and salinity on a refractometer. From each core section 20 cm^3 sand was removed for analysis of protozoa and bacteria and the remainder of the core was put through a flotation extractor and the meiofauna trapped on a 45 μm screen. Meiofauna was then stained in rose bengal and counted. Counts were multiplied by 1,25 to correct for 20% loss during extraction (McLachlan 1977a) and divided by 2,3 to give corrected meiofaunal numbers per 100 cm^{-3} sand.

For protozoan analysis, sand samples of 50 cm^3 were shaken in sterile sea water, stained with acridine orange, passed through a 45 μm screen and the protozoa trapped on a 5 μm membrane filter and counted under a fluorescence microscope as described by Dye (in press). For enumeration of bacteria 1 g wet sand was placed in 50 ml filtered sea water and sonicated to dislodge the bacteria. The solution was stained with acridine orange and the bacteria trapped on a 0,45 μm membrane filter and counted under a fluorescence microscope (Dye unpubl. ms).

Substrate samples from all depths were pooled (as there is no distinct layering on these beaches) and analysed by the standard methods of wet sieving (Morgans 1956, Hulings & Gray 1971).

Results and Discussion

At both sites the sands are extremely well sorted with no notable skewness. At Kings Beach the substrate consisted of fine sand with a median particle diameter of 218 μm and a mean of 222 μm, while that at Maitland River beach consisted of medium sand with a median of 264 μm and a mean of 268 μm.

The 1 m depth range sampled at Kings Beach (Table 1) was 40 cm lower than sampled previously (McLachlan 1977a) and appears to have reached the start of the redox potential discontinuity zone (Fenchel & Riedl 1970). Temperature decreased from the surface over the first 30 cm and then stabilized around 20,3 °C. Redox potential decreased slowly over the first 80-90 cm and then more rapidly towards 1 m as grey sand appeared. Oxygen saturation of the interstitial water was only 41% near the surface and remained between 24% and 29% over most of the depth range except for a drop to 16% in the last 10 cm. Even the surface layers at this site are therefore not fully oxygenated; this is because they receive relatively low-oxygen water draining out of the beach from higher tide levels (McLachlan 1977c). Least squares linear regression analysis showed a positive correlation between oxygen and Eh values:

$$\text{Eh (mV)} = 4{,}12\ O_2(\%\ \text{sat.}) + 203\ (r = 0{,}72;\ P < 0{,}05).$$

Table 1 Results from deep cores taken at MW on Kings Beach[a] on 30.12.77

Depth cm	Temp. °C	Eh mV	0_2[b]	Sand colour	Protozoa[c] cells/g	Bacteria[c] cells ×10⁶/g	Meiofauna[d] N	T	P	Total±range	C%[e]
0-10	23,9	350	41	yellow	2966	39	182	11	10	204±16	35,7
10-20	21,8	348	27	yellow	936	107	68	7	3	79±1	49,4
20-30	21,0	335	27	yellow	1170	60	62	5	0	68±2	61,2
30-40	20,5	330	26	yellow	702	35	136	7	30	173±155	91,4
40-50	20,4	330	26	yellow	936	94	14	1	0	15±8	94,0
50-60	20,4	315	26	yellow	624	89	17	1	0	18±7	97,2
60-70	20,3	315	25	yellow	156	82	3	1	0	4±2	98,0
70-80	20,3	300	29	yellow	78	85	3	1	0	4±2	98,7
80-90	20,2	270	24	faintly grey	0	59	4	1	0	5±1	99,6
90-100	20,2	240	16	light grey	0	103	2	0	0	2±0	100,0

[a] Water table depth 27 cm, sea temperature 20,9°C and interstitial water salinity 35°/₀₀ throughout.

[b] Oxygen content of interstitial water as % saturation.

[c] Number of protozoa and bacteria per g wet sand.

[d] Number per 100 cm³ of N, nematodes; T, turbellarians; P. polychaets.

[e] Cumulative percentage of total numbers recorded.

Although oxygen tensions are not high the sediment down to about 85 cm can be considered well oxidized, while the rapid change and lower oxygen tensions around this point herald the start of the redox potential discontinuity zone. This does not mean that fully reduced conditions must occur deeper in the sediment as there may not be sufficient organic input, even under the low oxygen diffusion rates at 1 m depth, and the RPD may just level off. Concentrations of organic matter in this sediment are too low to measure by conventional methods.

The numbers of small protozoans, mostly sarcodinoids, exhibited a clear vertical pattern, decreasing rapidly with depth to be absent at the RPD (Table 1). Linear regression analysis showed that their numbers correlated directly with oxygen tensions:

$$(\text{Nos. g}^{-1}) = 123\ O_2\ (\%\ \text{sat.}) - 2530\ (r=0{,}85;\ P<0{,}01)$$

and logarithmically with Eh values:

$$\text{Log}_{10}\ (\text{nos. g}^{-1}) = 0{,}034\ \text{Eh (mV)} - 8{,}52\ (r=0{,}96;\ P<0{,}001)$$

Bacteria occurred in variable numbers with maxima at 10-20 cm, 40-80 cm and 90-100 cm. As this analysis was purely quantitative, however, it gives no indication of large qualitative bacterial changes that may have occurred in response to Eh and oxygen changes.

Meiofauna, mainly nematodes, decreased rapidly with depth except for one aggregation at 30-40 cm. Dominance by nematodes is typical for areas with relatively low oxygen values and this depth range below 30 cm corresponds to the low-oxygen stratum described by McLachlan (1978b). Turbellarians and polychaetes were fairly common in the top 40 cm although even total numbers were never high. The last column in Table 1 shows that 90% of the meiofauna was in the upper 40 cm while 90% of the protozoans was in the top 55 cm.

By means of linear regression analysis total meiofaunal

Table 2 Results from deep cores taken at HW on Maitland River Beach[a] on 6.12.77

Depth cm	Temp. °C	Eh mV	0_2[b]	Protozoa[c] cells/g	Bacteria[c] cells ×10⁶/g	Meiofauna[d] N	H	T	M	Total±range	C%[e]
0-10	21,1	—	—	1327	28	384	0	46	0	430±56	20,3
10-20	21,5	—	—	546	39	413	15	49	0	488±3	43,4
20-30	22,2	—	—	468	78	267	97	61	24	457±5	65,0
30-40	22,3	—	—	624	45	89	53	31	6	181±4	73,6
40-50	22,3	430	80	390	54	45	34	18	13	116±1	79,1
50-60	22,0	420	73	234	32	46	22	20	5	96±0	83,6
60-70	22,0	400	72	156	54	26	20	18	2	66±6	86,7
70-80	21,7	390	72	0	25	32	25	9	5	71±0	90,1
80-90	21,5	380	54	78	14	33	19	16	4	72±12	93,5
90-100	21,5	380	64	0	68	25	27	13	4	69±12	96,8
100-110	21,6	360	40	0	42	17	12	2	4	35±4	98,5
110-120	21,6	—	39	390	40	1	20	2	3	26±22	99,7
120-130	21,6	—	26	78	19	2	4	0	3	9±4	100,1

[a] Water table depth 55 cm, sea temperature 19,4°C, and interstitial water salinity 35°/₀₀ throughout.

[b] Oxygen content of interstitial water as % saturation.

[c] Number of protozoa and bacteria per g wet sand.

[d] Number per 100 cm³ of N, nematodes; H, harpacticoids; T, turbellarians; and M, mystacocarids.

[e] Cumulative percentage of total numbers recorded.

numbers were correlated directly with oxygen tensions:

(Nos. 100 cm^{-3}) = 7,30 O_2 (% sat.) − 140 (r=0,68; $P<0,05$)

and logarithmically with Eh values:

Log_{10} (nos. 100 cm^{-3}) = 0,017 Eh (mV) − 4,13 (r=0,81; $P<0,01$)

Meiofaunal numbers were also correlated directly with protozoan numbers:

(Nos. 100 cm^{-3}) = 0,067 (protozoan nos. g^{-1}) + 6,7 (r=0,79; $P<0,01$)

The correlation between protozoan and meiofaunal numbers may be largely a result of similar tolerances to gradients of oxygenation or other factors, but it is also possible that these abundant small protozoans may be an important food source for the meiofauna.

The 1,3 m depth range at Maitland River HW was 55 cm deeper than sampled previously (McLachlan 1977b) and was relatively well oxygenated throughout (Table 2). Temperature was stable at all depths and Eh values were high below 40 cm, which was the shallowest depth at which interstitial water could be collected. Unfortunately, owing to malfunctioning of the Eh meter, values could not be obtained below 110 cm. Oxygen saturation of the interstitial water decreased from 80% at 40 cm to 26% at 130 cm and Eh and oxygen saturation values were again significantly correlated:

Eh (mV) = 1,57 O_2(% sat.) + 292 (r=0,88; $P<0,01$)

This whole depth was highly oxidized, suggesting that reduced conditions are unlikely to occur on this beach as organic input 2 m into the sediment must be very slow.

Protozoan numbers again decreased with depth except for an aggregation around 110 cm and did not correlate significantly with Eh or oxygen values. Bacteria occurred in variable numbers with maxima (between 20 cm and 50 cm) lower than maxima in the finer sands of Kings Beach. Meiofaunal numbers showed an initial increase at 10-30 cm and then the usual decrease with depth, with 90% of the recorded numbers occurring in the upper 80 cm. Nematodes, being the least sensitive to desiccation (McLachlan 1978b) dominated the surface layers with harpacticoids more prominent deeper down. Turbellarians, like harpacticoids, are sensitive to low oxygen tensions (Jansson 1968) and to desiccation and were concentrated just below the surface.

Meiofaunal numbers correlated significantly with oxygen tensions:

(Nos. 100 cm^{-3}) ≐ 1,66 O_2 (% sat.) − 33,7 (r=0,93; $P<0,001$)

and Eh values:

(Nos. 100 cm^{-3}) = 0,97 Eh (mV) − 308 (r=0,93; $P<0,001$)

The linear correlations with Eh (as opposed to a logarithmic correlation for Kings Beach) is probably due to a more favourable Eh range resulting in a slower drop in meiofaunal numbers. Whereas densities at 60 cm on Kings Beach were 2% of those at the surface, densities at 1 m on Maitland River Beach were 16% of those at the surface. There was also a significant correlation between protozoan and meiofaunal numbers:

Meiofauna (nos. 100 cm^{-3}) = 0,34 protozoa (nos. g^{-1}) − 50,5 (r=0,72; $P<0,01$)

Conclusions

The aim of this work was to define the thickness or vertical extent of the most densely inhabited part of the interstitial environment on eastern Cape sandy beaches. It has been shown that although oxygenated conditions may penetrate very deep, 90% of the meiofauna and protozoans is concentrated in the upper 50 cm (Kings Beach MW) to 1 m (Maitland River beach HW) of sediment. Within the range of beach types encountered in the eastern Cape maximum biological activity and oxygen demand should thus be confined to the upper metre of sediment, extending well below the permanent water table.

As temperature is very stable below the upper 10-20 cm the fairly rapid decline in animal numbers with depth in Kings Beach appears to be mainly due to relatively low oxygen tensions found there. The RPD zone encountered in the deeper sediment indicates a greater input of organic matter than oxygen and food is thus unlikely to be limiting.

In Maitland River beach interstitial oxygen concentrations are high and unlikely to be directly limiting even though there is a correlation with meiofaunal numbers. More likely a decrease in available food would be a possible cause of the vertical drop-off in numbers. In the upper 10 cm, however, desiccation and temperature stress may well be responsible for the lower numbers than at 10-20 cm depth.

Wieser *et al.* (1974) and Wieser & Schiemer (1977) found on a sheltered subtropical sandy beach that the vertical distribution of most meiofaunal species was closely related to their upper lethal temperatures and pH values, and that there was a relation between respiratory rates of nematodes and their vertical distribution in the sediment. Vertical distribution of individual species, especially in environments with steeper oxygen and chemical gradients than the exposed beaches studied here, is thus intricately regulated by changes in the interstitial environment. On eastern Cape beaches, however, the stable temperatures and relatively high oxygen tensions result in very deep distributions of most species (McLachlan & Furstenberg 1977)

Temperature, oxygen and redox profiles shift with the seasons and the vertical distribution of the interstitial fauna may become deeper in winter (McLachlan 1978). Under the relatively well-oxygenated and temperature-stable conditions in these sediments this effect should be small.

On both beaches the very abundant small protozoans correlated in numbers with the meiofauna. While this similar distribution may be due to similar limiting factors it does indicate that these protozoans may be an important food source for the meiofauna and could even serve as a trophic link between bacteria and meiofauna.

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