AN ECOPHYSIOLOGICAL STUDY OF THE MEIOFAUNA OF THE SWARTKOPS ESTUARY.

1. THE SAMPLING SITES: PHYSICAL AND CHEMICAL FEATURES.

A H DYE

Zoology Department, University of Port Elizabeth.

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ABSTRACT

As part of a larger project, a number of physical and chemical features of two beaches in the Swartkops Estuary near Port Elizabeth were monitored over a period of fourteen months. These features included temperature, nitrogen, chlorophyll *a*, oxygen and salinity. In addition measurements were made of particle size, porosity, permeability and desiccation. It was found that environmental conditions were most severe at the higher tidal levels as well as in the upper reaches of the estuary. Nitrogen and chlorophyll *a* varied greatly from month to month and the usefulness of such determinations as indicators of available food is questioned. The interstitial environment was found to be greatly influenced by the presence of sand prawns (*Callianassa kraussi*). It is suggested that burrowing macrofauna, particularly those forms with burrows extending from the surface, have profound effects on the physical and chemical conditions in beaches and mud flats.

INTRODUCTION

Since the comprehensive study of Day (1951) on South African estuaries, a number of papers have been published on aspects of estuarine ecology in South Africa but these have dealt exclusively with macrofauna. The ecology of the meiofauna has been ignored. This ubiquitous group of organisms has been defined on the basis of size, as being between 1 and 0,045 mm in length. The present study, which covered a 14-month period from May 1975 to June 1976, sheds some light on the subject of estuarine meiofauna ecology in this country. Since so little was known about the meiofauna a "black box" approach was adopted whereby the group was regarded as a unit and its relationships with the environment studied on that basis.

Diverse factors are at work determining the distribution and abundance of the meiofauna and some of these are peculiar to the interstitial environment. One of the most important factors is the substrate itself. General physical factors have been covered by Bruce (1928), water tables by Emery & Forster (1948), temperature by Johnson (1965) and the direct effect of grain size by Wieser (1959) and Jansson (1967). The oxygen content of interstitial water has been found to influence the distribution of meiofauna (Braefield 1964). Attempts have also been made to correlate available food, using chlorophyll *a* and nitrogen as indicators, with the distribution of meiofauna (Tietjen 1966, 1968; McLachlan 1975). The present paper presents the results of studies on such physical and chemical features in two beaches in the Swartkops estuary.

METHODS

Sampling sites

The Swartkops estuary near Port Elizabeth is 16 km in length from the mouth to the limit of tidal influence which is marked by a concrete causeway (Figure 1). The estuary is characterized by sandy beaches on the south bank near the mouth, but the sand on the north bank rapidly gives way to rocky conditions at the residential area of Amsterdamhoek. The salt marshes characteristic of the lower and middle reaches, become less extensive towards the upper reaches where the substrate consists of rounded boulders, and the banks are steep and covered by dense vegetation. The reader is referred to the comprehensive description of the fauna and flora given in Macnae (1957).

Two sampling sites, Stations A and B, were chosen to enable the effects of environmental factors on spatial as well as temporal distribution and abundance of the meiofauna to be assessed. Station A was 500 m upstream from the mouth on the south bank (Figure 1) and Station B was 11 km upstream on the north bank. The mouth station was characterized by a large, flat expanse of sand 200 m wide from HWMST to LWMST. The only vegetation was a few clumps of *Arthrocnemum* spp. near the high tide level. The beach also supported a small population of the sand prawn *Callianassa kraussi* at midwater. Station B was characterized by a relatively narrow beach extending 36 m from HWMST to LWMST. The

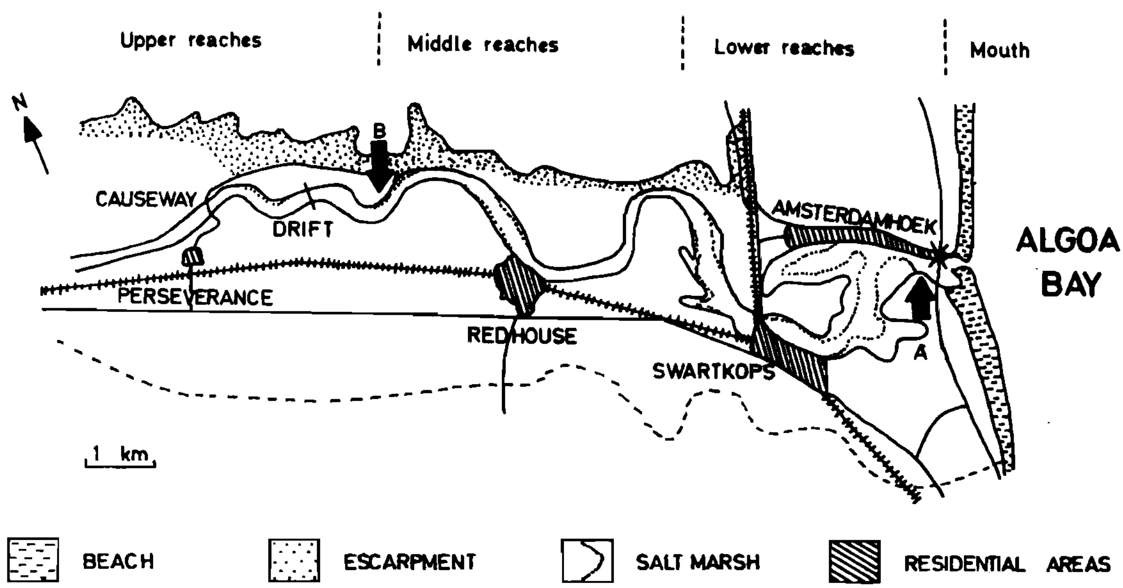

FIGURE 1
Map of the Swartkops Estuary showing sampling sites and main residential areas.

vegetation consisted of a dense bed of *Arthrocnemum* spp. between HWMST and HWMNT, a distance of 11 m. A large population of *C. kraussi* occurred at this station, particularly from midwater downwards.

Physical features

Beach surveys. The beaches were surveyed on two occasions according to the method of Day (1969). Four sampling levels were chosen along each transect, i.e. high water (HW), as close as possible to HWMST; midwater (MW), corresponding to half of the tidal range; low water (LW), again as close as possible to LWMST; and under water (UW), permanently covered by at least 0,30 m of water. At Station B the dense bed of *Arthrocnemum* spp. made it necessary to put the HW level some 11 m downbeach from true HWMST. It was felt that samples from the vegetated area would not be comparable to the rest of the samples.

Sampling. Samples were taken monthly during spring low tide. A hand-held copper corer, 30 cm in length and 3,6 cm in diameter, was used to take ten vertical cores, 30 cm apart, along a line parallel to the water at each sampling level. The top 20 cm was retained and divided into three approximately equal lengths of 6,5 cm. Ten subsections were thus obtained from the 0 - 6,5; 6,5 - 13,0 and 13,0 - 20,0 cm zones. The subsections from each zone were pooled and two subsamples of 200 cm^3 were taken from each for faunal analysis. The remainder was remixed into one sample, representing 0 - 20,0 cm and two subsamples of 50 cm^3 were taken for physical and chemical analysis.

Substrate analyses. Particle size was determined on 30 g of oven-dried sand by wet sieving through sieves conforming to the Wentworth scale (Morgans 1956).

Porosity was determined by measuring the amount of water needed to saturate 100 g of oven-dried sand. This was done in a glass measuring cylinder which was tapped gently to dislodge air bubbles. Porosity was determined as the loss in weight upon drying expressed as a percentage of the dry weight (Hulings & Gray 1971).

Permeability was determined by measuring the time taken for a 50 cm column of water to pass through a 10 cm column of sand in a glass tube of 1,5 cm internal diameter. The manner in which the sand was packed into the tube affected the permeability, so that maximum permeability was measured by packing the sand from below and minimum by allowing the sand to percolate through the water (Hulings & Gray 1971; McLachlan 1975).

Desiccation was measured once during the study, on a sunny day in May 1976. A light breeze blew and the air temperature was 17,8°C. Samples of 30 g of sand were collected from the three depth zones as described and sealed in pre-weighed glass containers. The loss in mass, when expressed as a percentage of the porosity gave the degree of desiccation.

Mid-morning temperatures were measured at depths of 1, 10 and 20 cm at each tidal level, using a "Zeatron" thermistor. At the UW level only the sand surface temperature was measured.

Chemical features

Nitrogen concentration in the substrate was determined on 0,08 g of oven-dried sand by microkjeldahl distillation. Since the mass of meiofauna in this amount of sand was found to be negligible, the determinations represent "available" nitrogen.

Chlorophyll a was extracted from 5 g of oven-dried sand by grinding it for three minutes with 10 ml 95% acetone and 1 ml of a 1 per cent magnesium carbonate suspension. The samples were filtered and the filtrate centrifuged. The extinctions at 6450 Å and 6630 Å were read on a Bausch and Lomb "Spectronic 20" spectrophotometer and the values substituted into the following formula given by Harborne (1973):

$$\text{Chl } a \text{ (mg/g)} = \frac{^{12,3}\text{E6630} \;-\; ^{0,86}\text{E6450}}{\text{X} \quad \times \quad \text{W}} \times \text{V}$$

where X is the light-path length (1 cm).
W is the mass of the sample (5 g).
V is the volume of the filtrate (25 ml).

Oxygen. Interstitial water was obtained from the 1; 10 and 20 cm depths, with the exception of UW, by means of a 30 cm stainless steel syringe needle. The end of this had been blocked and perforated instead with eight 200 μm holes. Water was drawn into a glass syringe which had been flushed with concentrated formalin to prevent respiration by micro-organisms (Pamatmat 1968). The syringes were sealed with standard needles fitted with plastic caps. Although oxygen was measured within two hours of sampling, tests had shown that delays of up to six hours had no significant effect on oxygen concentrations.

At Station B, which had a fine substrate, the needle tended to clog if inserted directly into the sand. This problem was overcome by a coring device based on those used by Braefield (1964) and Pamatmat (1968). A stainless steel tube, 20 cm in length and 2,5 cm in diameter, was provided with a pointed bung of the same material and two rings of 1 mm holes, covered by 1 mm wire mesh, near the bottom (Figure 2). The whole assembly was provided with a movable PVC sleeve to prevent clogging during insertion into the substrate. When at the required depth the sleeve was slid up to expose the mesh and holes through which water could percolate. Water was then drawn into the syringe as described. Exposure to air usually did not exceed 30 seconds and Braefield (1964) showed that under these conditions the amount of oxygen dissolving in the water is negligible. The oxygen content was determined polarographically by a Clark oxygen electrode (E5042) connected to a Radiometer - Copenhagen Acid-base analyser PHM 71. The results were expressed as percentage saturation of sea water after correction for salinity and atmospheric pressure.

Salinity. Interstitial water was obtained as for oxygen and the salinity was read in the field by means of a hand-held refractometer accurate to 0,5 parts per thousand.

RESULTS

Physical features

Beach surveys (Figure 3). The mean slope of Station A was 1:180, but the beach flattened out above midwater to a slope of 1:1400. The greatest slope of 1:40 occurred between LW and UW. The beach at Station B had a mean slope of 1:12. Between HW and MW the beach formed a berm with a 9 cm hollow behind it. The maximum slope of 1:7,5 also occurred between LW and UW. Both beaches were stable and, apart from some scouring at UW of Station A during the floods of September 1975, no significant changes took place during the study.

Substrate analyses (Table 1). The substrate at A was coarser than at B, 175 as opposed to 130 μm, and there was a tendency for the substrate to become finer towards HW. The phi-

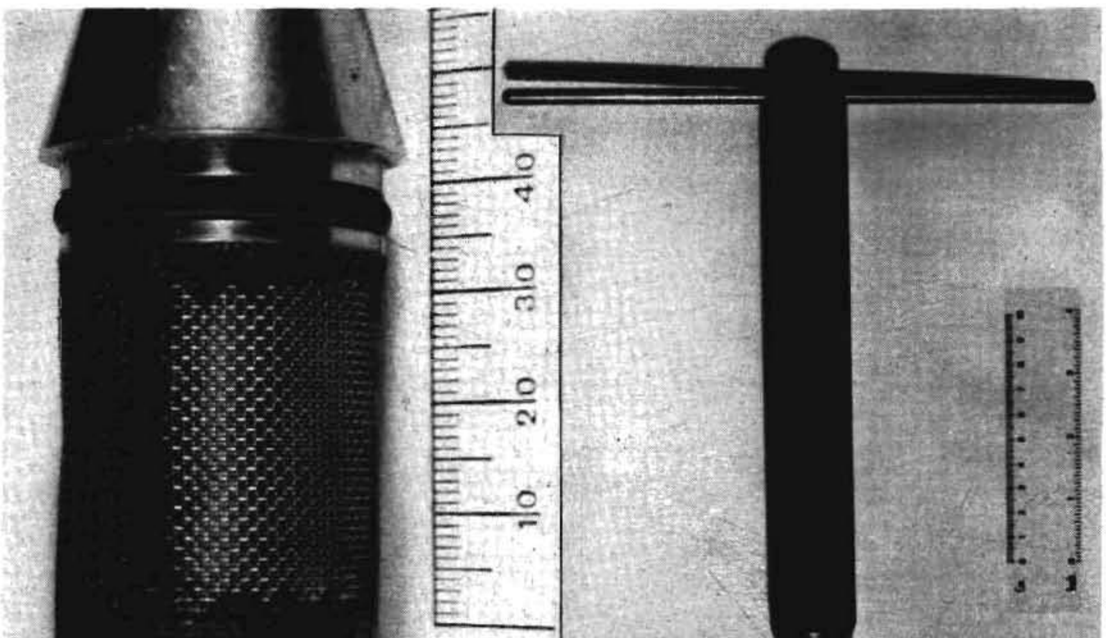

FIGURE 2
Coring device for obtaining interstitial water in fine substrates.

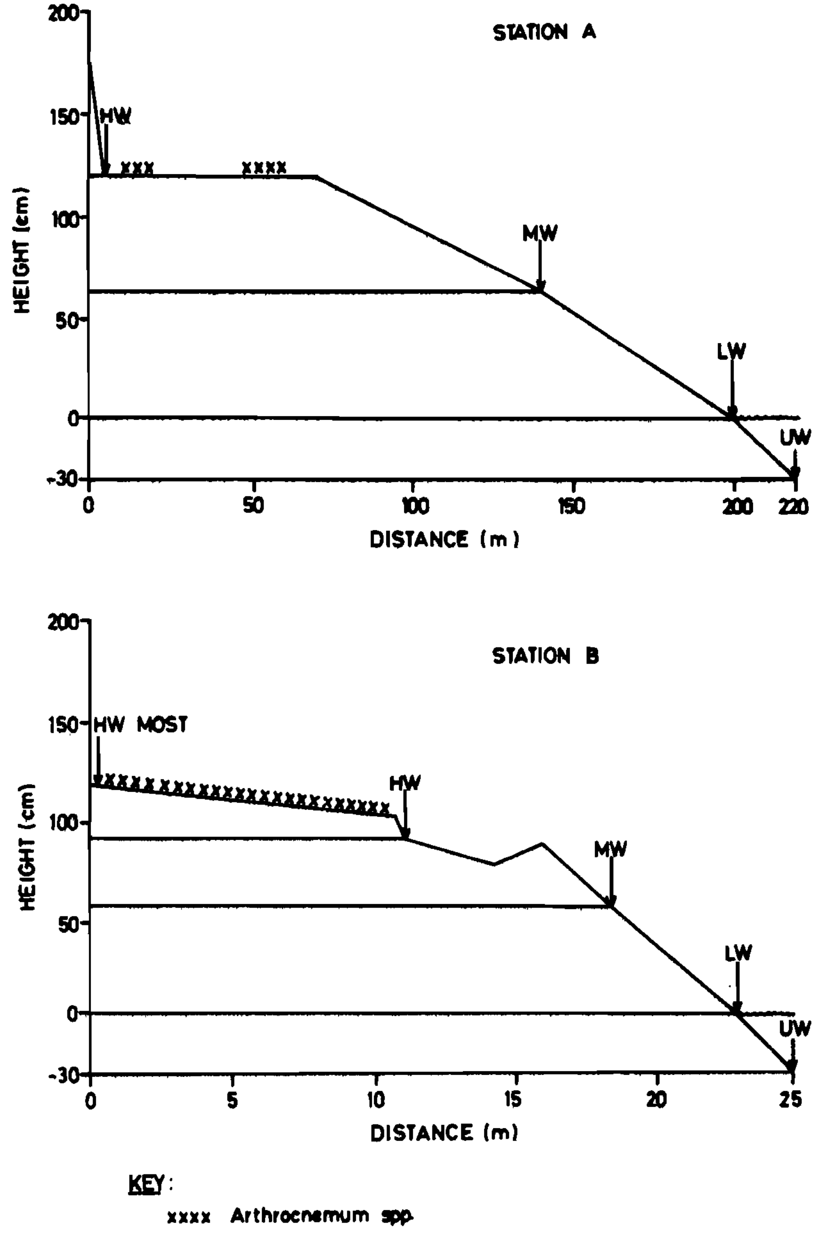

Figure 3
Results of beach surveys showing slopes and sampling levels.

quartile deviation values were relatively low indicating good sorting. The degree of sorting tended to increase from HW to LW at both stations, but UW was slightly less well sorted than LW. Low skewness values indicated equal sorting of particles above and below the median. Due to the trapping of silt by finer substrates the percentage of particles smaller than 63 μm (mud fraction) was not only higher at Station B but increased from LW to HW at both beaches.

The difference in particle size between the two stations resulted in a mean difference of 3,5% porosity, the coarser substrate having the lower porosity (Table 1). The substrate at Station A was considerably more permeable than that at B. This explains why the degree of desiccation was greater at A than at B.

Figures 4 and 5 show the seasonal temperature fluctuations at three depths in the substrate of Stations A and B respectively. The highest temperatures occurred in January and February and the lowest in May, June and July. Temperature fluctuations were most severe near the surface of the higher tidal levels. Temperature decreased with depth but the difference between surface and deep temperatures was greater at the higher tidal levels.

Chemical features

Nitrogen (Table 2). Large fluctuations in nitrogen occurred from month to month and no pattern was evident. Station A had a mean nitrogen content of 4,48 mg/g and Station B 5,30 mg/g.

TABLE 1.

Results of substrate analysis, porosity, permeability and desiccation determinations at Stations A and B. Permeability times are given in minutes (P max and P min).
a: 0 - 6,5 cm; b: 6,5 - 13,0 cm; c: 13,0 - 20,0 cm.

Parameter	Station and sampling level.							
	A				B			
	HW	MW	LW	UW	HW	MW	LW	UW
Md_ϕ	2,62	2,58	2,53	2,48	3,00	2,95	2,98	2,82
Qd_ϕ	0,40	0,38	0,37	0,38	0,55	0,52	0,47	0,49
Sk_ϕ	-0,09	-0,07	+0,02	-0,01	+0,07	+0,09	-0,03	-0,03
Mud %	2,25	0,25	0,20	0,56	4,35	4,07	2,51	2,80
Porosity %	28,73	28,52	28,45	28,66	32,96	31,61	31,30	32,45
P max	135	120	70	90		greater than 720 mins.		
P min	24	16	13	34	720	450	225	441
H_2O%								
a	79,46	86,63	100,00	100,00	100,00	96,84	100,00	100,00
b	85,10	93,41	100,00	100,00	100,00	98,41	100,00	100,00
c	92,10	96,67	100,00	100,00	100,00	99,58	100,00	100,00

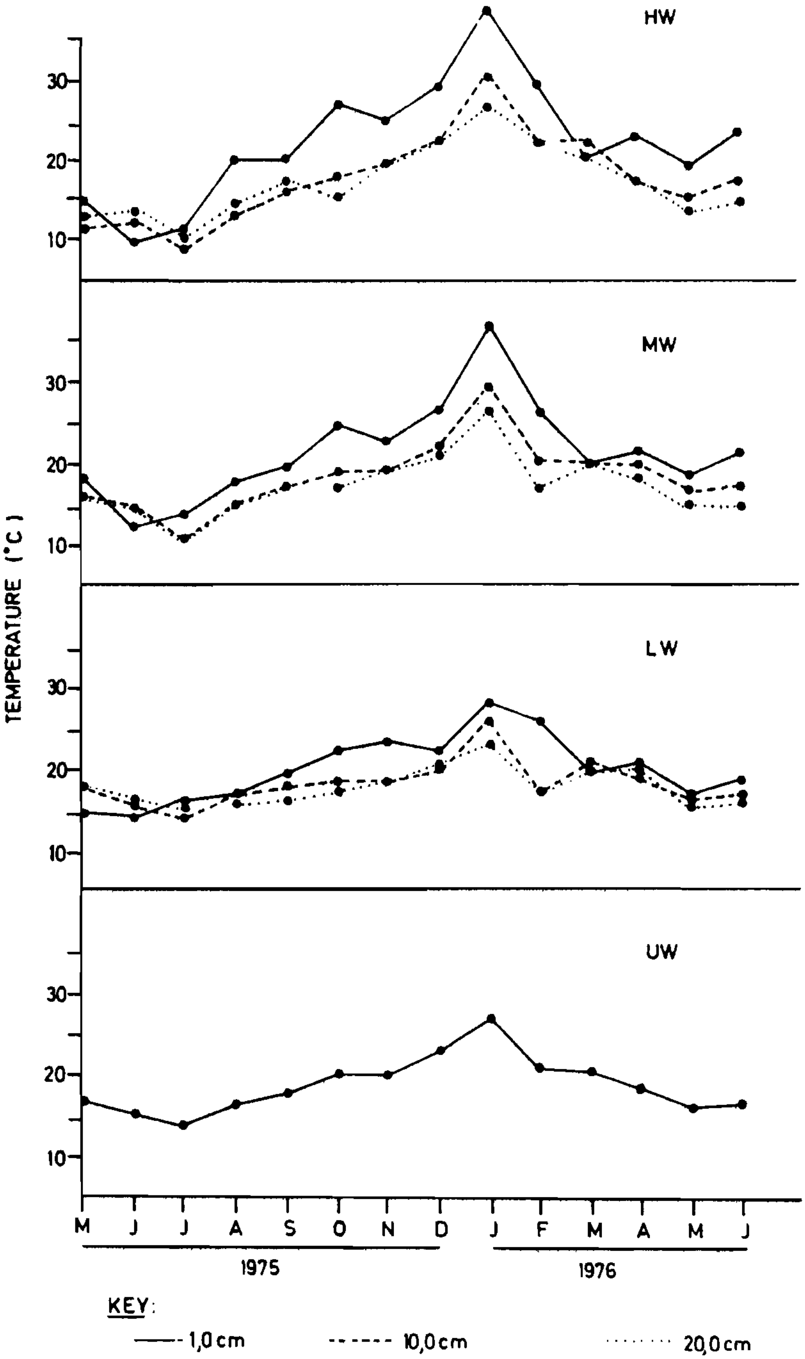

FIGURE 4
Seasonal fluctuations in temperature in the substrate of Station A.

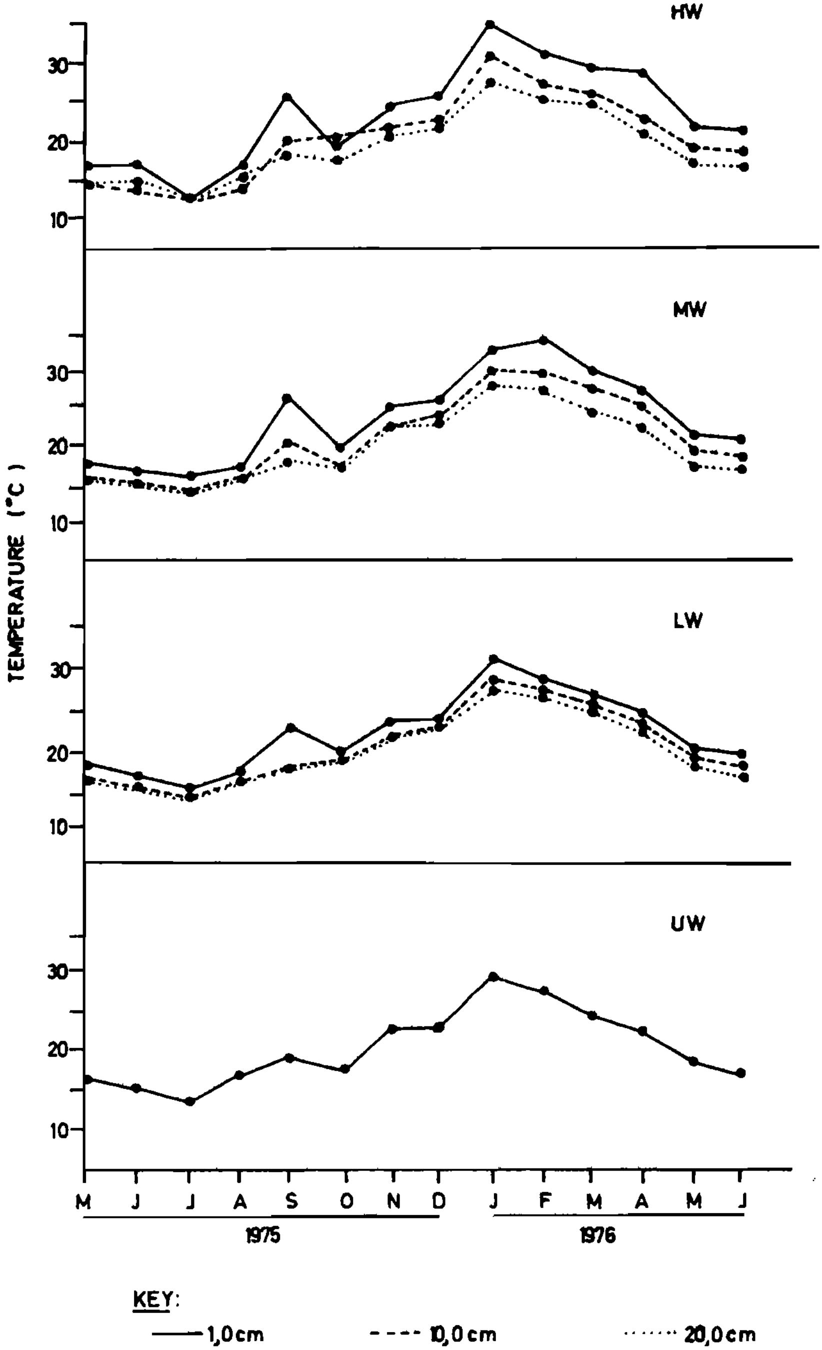

FIGURE 5
Seasonal fluctuations in temperature in the substrate of Station B.

Chlorophyll a (Table 3). As with nitrogen, a large variation occurred and no pattern could be discerned. At both beaches the chlorophyll *a* content decreased from HW to LW and then increased slightly to UW. Station A had a mean chlorophyll *a* content of 0,0105 mg/g and Station B 0,0315 mg/g.

Oxygen (Figures 6, 7). During some of the summer months the surface sand at MW and HW of Station A became too dry to obtain interstitial water. It is clear that oxygen tensions were highest in winter (May to July) and lowest in summer (November to March), except where desiccation occurred and air replaced water in the substrate. The mean overall

TABLE 2

Results of substrate nitrogen determinations at Stations A and B. All figures expressed as mg/g dry sand.

Date.	Station and sampling level.							
	A				B			
	HW	MW	LW	UW	HW	MW	LW	UW
1975								
May	15,54	13,48	7,41	7,43	7,57	7,3	7,93	7,53
June	0,70	1,70	0,23	1,45	1,98	1,46	0,48	1,94
July	14,70	12,45	10,41	12,09	16,46	12,58	10,44	9,22
Aug	3,17	6,15	1,88	2,10	3,44	4,40	4,37	3,76
Sept	5,34	4,95	4,58	4,54	5,50	6,60	6,18	7,58
Oct	3,37	6,12	8,73	4,81	4,57	6,91	8,00	11,89
Nov	6,45	5,58	6,43	4,81	7,81	5,13	5,76	6,00
Dec	5,48	4,15	9,90	5,32	5,95	8,52	8,59	7,30
1976								
Jan	5,88	5,53	6,22	3,09	6,40	4,71	13,29	8,09
Feb	3,59	3,84	3,56	3,26	7,90	7,87	8,50	9,15
Mar	0,56	0,50	0,67	0,75	1,04	1,10	1,35	1,67
Apr	1,46	1,23	0,74	1,16	1,30	1,89	1,24	1,13
May	0,36	0,36	0,70	0,75	0,96	0,87	0,85	0,95
June	0,78	0,65	0,58	0,96	1,05	0,88	0,66	1,20
Mean	4,81	4,76	4,43	3,92	5,14	5,02	5,55	5,53

oxygen tension at Station B was 34,3% while that of Station A was 50,1%. The deeper layers of Station B contained zero oxygen on a number of occasions during the summer. Although oxygen almost invariably decreased with depth at Station A, a peak concentration was frequently found at a depth of 10 cm at Station B.

Salinity (Figures 8, 9). As with temperature, salinity tended to be highest in summer and lowest in winter or during floods. There was usually little difference between the depth zones, particularly between 10 and 20 cm. The mean salinity at Station A was 36‰ and the mean salinity at B was 28‰.

TABLE 3

Results of chlorophyll *a* determinations at Stations A and B. All figures expressed as mg/g dry sand ($\times 10^2$).

Date	Station and tidal level							
	A				B			
	HW	MW	LW	UW	HW	MW	LW	UW
1975								
May	1,7	1,4	2,4	2,5	4,7	3,3	2,8	3,5
June	1,5	0,8	0,6	0,6	3,0	1,7	1,6	1,6
July	0,6	0,9	0,0	2,8	9,3	7,6	4,0	4,6
Aug	4,9	4,8	1,7	2,6	5,9	6,8	1,0	0,9
Sept	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Oct	2,1	1,9	1,5	1,6	4,6	6,4	3,5	4,5
Nov	2,0	0,0	0,5	0,4	5,3	3,1	3,0	7,4
Dec	0,8	0,0	0,0	0,4	4,1	3,3	5,2	7,3
1976								
Jan	0,4	1,3	0,0	0,0	1,5	1,8	0,4	1,3
Feb	1,7	1,6	0,5	1,1	4,7	3,2	2,6	2,1
Mar	0,3	0,0	0,0	0,0	4,6	2,0	2,6	3,8
Apr	1,2	0,0	0,0	0,0	1,7	1,9	1,2	1,1
May	1,7	0,6	0,5	0,5	3,5	3,0	2,7	2,1
June	1,7	1,6	1,0	1,2	3,4	1,9	1,3	2,2
Mean	1,5	1,1	0,6	1,0	4,0	3,3	2,3	3,0

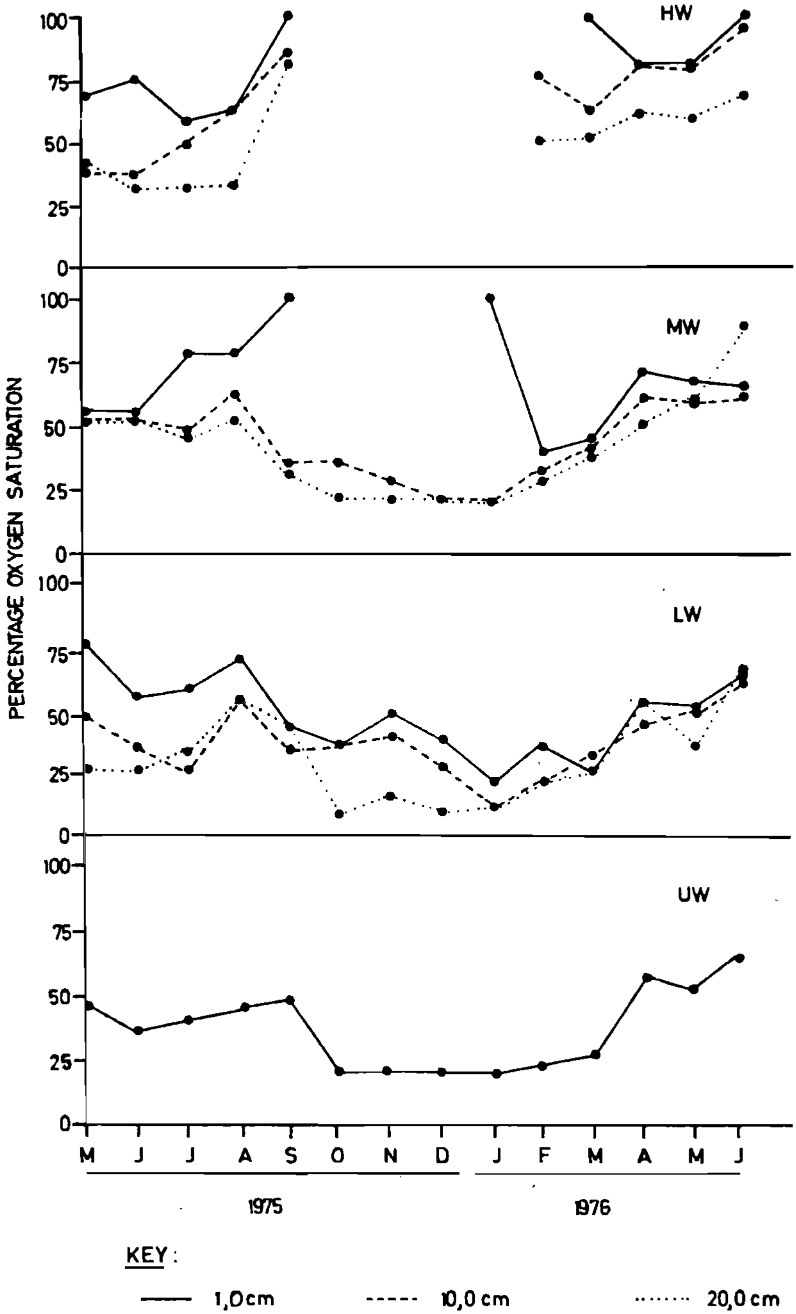

FIGURE 6
Seasonal fluctuations in percentage oxygen saturation in the substrate of Station A.

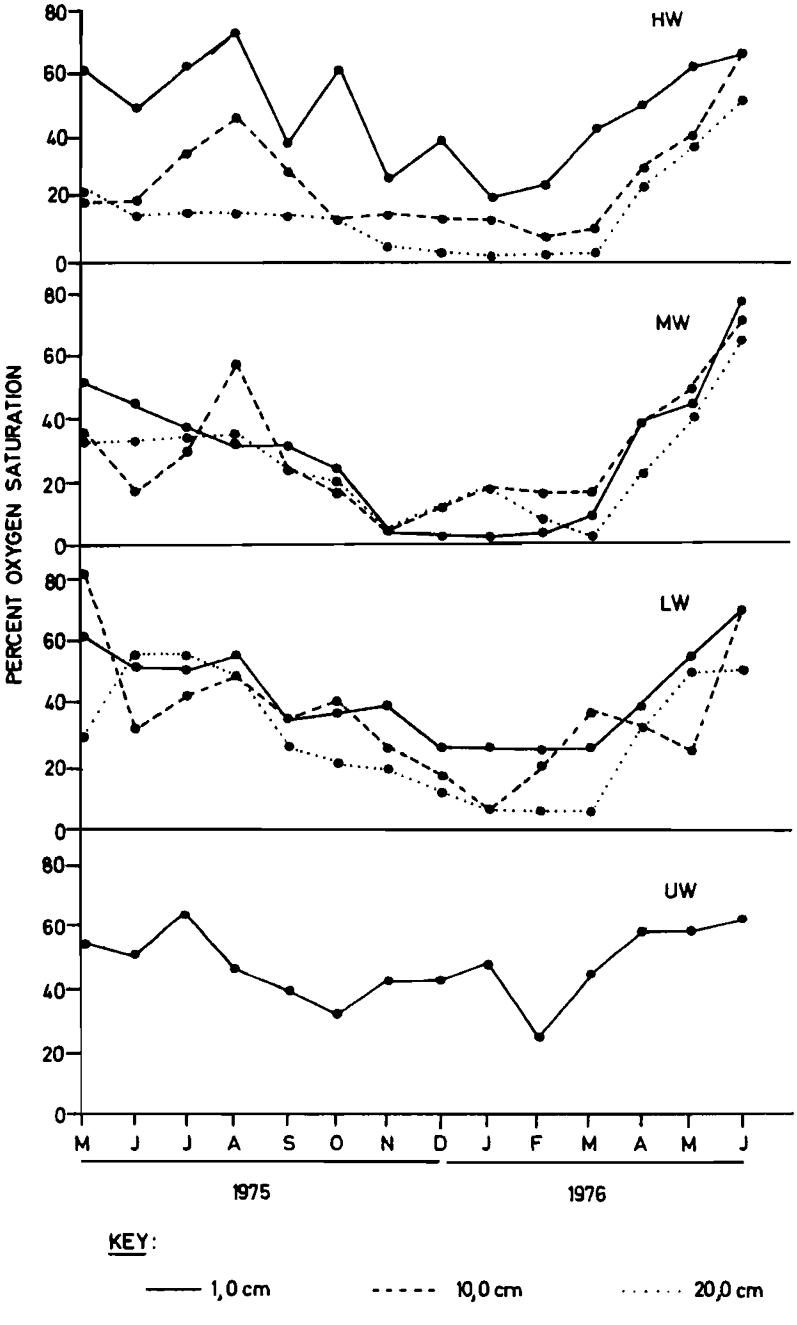

FIGURE 7
Seasonal fluctuations in percentage oxygen saturation in the substrate of Station B.

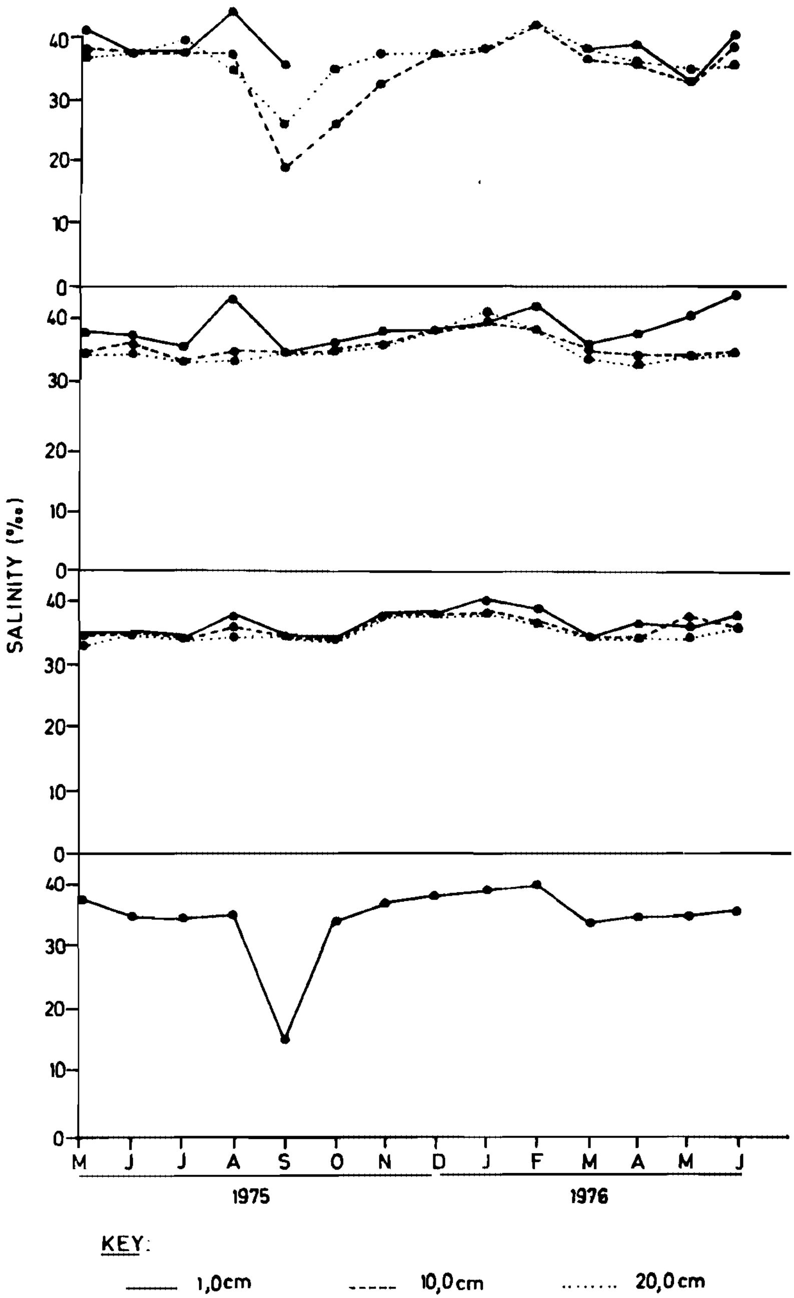

FIGURE 8
Seasonal fluctuations in salinity in the substrate of Station A.

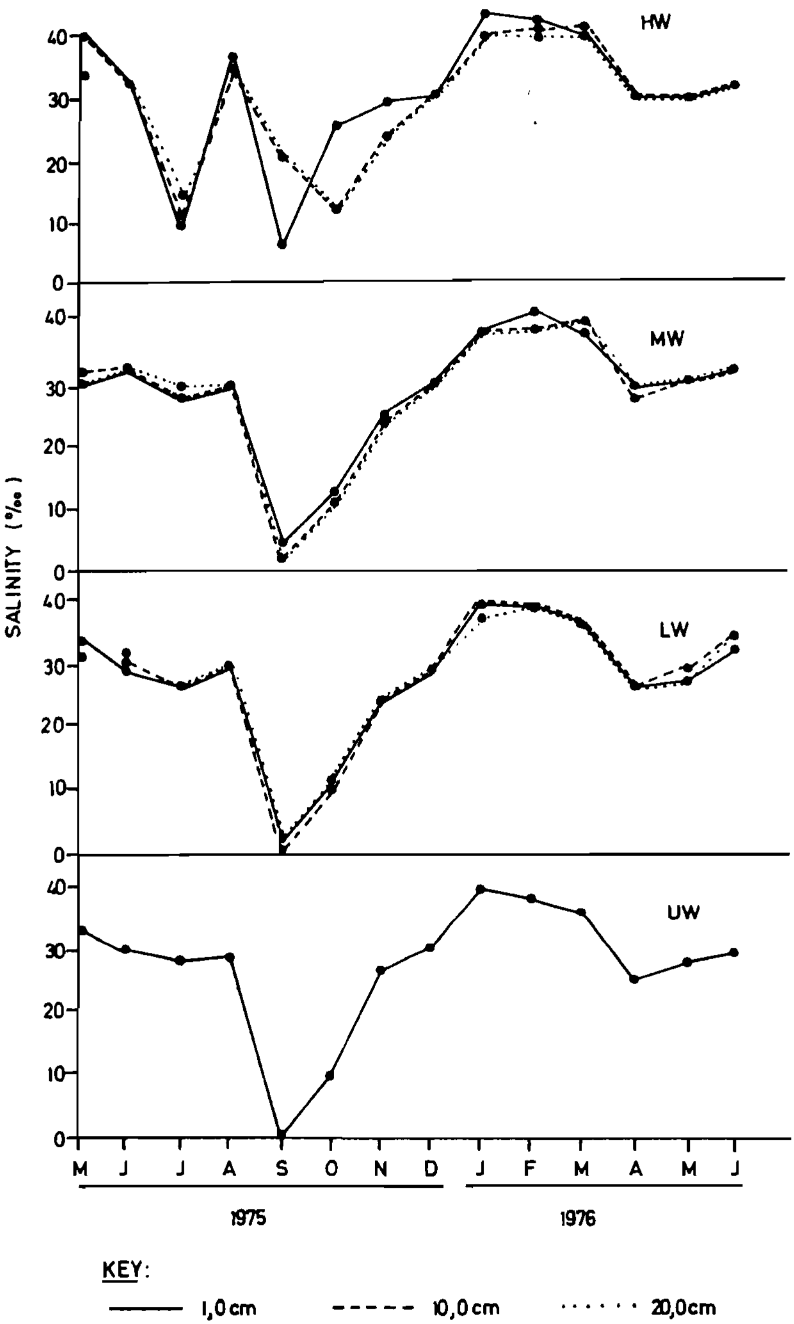

FIGURE 9
Seasonal fluctuations in salinity in the substrate of Station B.

DISCUSSION

The slopes of both beaches were characteristic of areas exposed to little or no wave action (Eltringham 1971). The increased gradient between LW and UW was probably due to scouring by ebb and flow tide currents. Bruce (1928) found that fine substrates trap silt which causes an increase in porosity while at the same time decreasing permeability. This was borne out in the present study and explains why the substrate of Station B was much less permeable than that of A. An increase in the percentage of fine particles towards the higher tidal levels has been reported by Brown (1971), Hanekom (1975) and McLachlan (1975) and appears to be due to selective transport of particles by incoming and outgoing tides.

As expected, temperature fluctuations were more severe near the surface of the substrate at the higher tidal levels, probably due to the absence of the buffering effect of the water (Bruce 1928; Johnson 1965). The effect of waterlogging, characteristic of Station B, was to reduce the temperature fluctuation in that beach. This is illustrated in the difference between the maximum and minimum recorded temperatures at the different tidal levels. Thus in the surface layers of HW at Station A, the difference was 26° C while at the same level at Station B it was only 22° C. Similarly the midwater level of Station A varied by 23° C while that of Station B varied by 20° C. The lower tidal levels varied to approximately the same extent at both stations, i.e. 15° C and 13° C at LW and UW of Station A respectively and 15,7° C and 14° C for the same levels of Station B. The same effect applied to the river itself, the lower reaches being more stable with regard to temperature than the upper reaches, due to the proximity of the former to the sea.

Although no clear seasonal pattern of nitrogen content was found, the determinations did reveal that the substrate of Station B had a higher nitrogen content than that of A. This was probably due to the trapping of detritus by the finer substrate at B resulting in increased bacterial populations (MacGinitie 1932). The greater permeability of Station A did not allow the trapping of detritus to the same extent and the bacterial populations were expected to be lower as a result. Tietjen (1966) measured both nitrogen and chlorophyll *a* on a regular basis in a North American estuary and concluded that such measurements have little value as indicators of food due to the large fluctuations which he found to occur. A similar situation was found in the present study.

In contrast, a clear seasonal pattern of oxygen was evident at both stations. Oxygen tension decreases with increasing temperature and it is not surprising that the substrate oxygen levels were much lower in summer than in winter. In areas subject to desiccation, however, air replaced water in the substrate and a gradual increase in oxygen concentration was found. This continued until a point was reached at which no more interstitial water could be obtained. The sand prawn *Callianassa kraussi* (Stebbing) appeared to play a major role in the oxygenation of the deeper sediments adjacent to their burrows. Since Station A had a coarser substrate than B it could be expected that oxygen concentrations would decrease with depth to a lesser extent at A than at B. However, when the two stations were compared it was found that, while oxygen decreased by an average of 26% from 0 to 20 cm at A, the decrease at B was only 15%. Furthermore, a closer look at Station B revealed that at HW, where few prawns occurred, the decrease in oxygen from the surface to 20 cm was 31%. At MW the decrease was only 3%. The only difference between the two areas was that MW had a high density of prawns. The decrease in the mud fraction of 0,3% from HW to MW could be ruled out as a significant factor as this did not affect the permeability. Apparently the prawns were pumping aerated water into the substrate. This is borne out by the fact that the HW level of Station B was nearly always anoxic below 1 cm whereas the rest of the beach remained oxygenated down to 20 cm. In addition, below the surface the sand in the vicinity of the burrows exhibited a yellow colour which became progressively darker with increasing distance from the burrow.

As with temperature, salinity fluctuations were most severe near the surface of the higher tidal levels. In addition, the range of salinity was greater at Station B than at A. The reasons for this are threefold. Firstly, the upper reaches of the estuary do not get flushed to the same extent as the lower reaches during the tidal cycle. Instead a "plug" of water moves up and down the estuary. This body of water has a low rate of exchange with the open sea and this results in hypersalinity in the upper reaches during the summer months. Secondly, temperatures tend to be higher in summer in the upper reaches for the same reason and evaporation is greater. Thirdly, the limited water circulation in the substrate of Station B results in pools of water lying on the surface during low tide and this evaporates to hypersalinity. The range is also extended to low values due to the proximity of the fresh water inflow. This, however, is only of significance during floods (Macnae 1957).

During the flooding of September 1975 the HW surface salinity at Station B dropped to $5{,}5^{0}/_{00}$ while the deep salinities remained at $21^{0}/_{00}$. A month later, after the floods, the surface salinity had returned to $25^{0}/_{00}$ but the deep salinities had dropped to $12^{0}/_{00}$. In contrast, all the depth zones of the MW and LW levels experienced a rapid decrease in salinity during the floods and returned equally rapidly to normal values afterwards. Again, the only difference between HW and the other tidal levels was the large population of prawns at the latter. These findings correspond closely to those of Forbes (1974) who found that the presence of prawns in the substrate greatly enhanced the circulation of water between the surface and deeper layers. Other macrofaunal organisms with burrows extending from the surface will probably have a similar effect. This effect on the distribution of meiofauna is considerable and will be reported elsewhere (Dye & Furstenberg in press).

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