South African Marine Pollution Survey Report 1979-1982

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A report to the Marine Pollution Committee of the South African National Committee for Oceanographic Research (SANCOR)

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SYNOPSIS

The main objectives of the Marine Pollution Programme initiated in 1974 were to discover sources of marine pollution, assess their magnitude and institute a national data centre where the information could be collected and collated most effectively. Most of the known impact areas and important estuaries as well as many beaches were surveyed between 1974 and 1979. The data have been summarised in the previous reports [20, 50]. This report, which covers the period 1979 to 1982, includes resurveys of the major impact areas and surveys of some estuaries in Natal and the south eastern Cape which have not been previously covered. The impact areas were Tongaat, Durban and the Natal south coast beaches, East London, Algoa Bay, Mossel Bay, False Bay, Hout Bay, Camps Bay, Table Bay and Saldanha Bay. The estuaries were Siyaya, Umgababa, Buffalo, Sundays, Great Fish, Kowie, Kariega, Sundays, Gamtoos and Kromme. There were also a number of general studies including those on metal concentrations along the Cape coast, further studies of beach recovery following an oil spill, and a study of colonisation of an artificial reef.

The research has been conducted by small teams of researchers, based at the Sea Fisheries Research Institute (SFRI) in Cape Town, the National Research Institute for Oceanology at Stellenbosch, the University of Port Elizabeth and the National Institute for Water Research in Durban. Apart from SFRI, all these projects have been funded by the Foundation for Research Development (formerly Cooperative Scientific Programmes) of the Council for Scientific and Industrial Research (CSIR), as part of the South African National Committee for Oceanographic Research (SANCOR) programme. The kind cooperation of all these groups has made the compilation of this document possible.

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OPSOMMING

Die vernaamste doelstellings van die Seebesoedelingsprogram wat in 1974 tot stand gebring is, was om die bronne van seebesoedeling vas te stel, hul omvang te bepaal en om 'n nasionale databasis daar te stel waar inligting op die effektiefste wyse versamel en saamgestel kon word. Die meeste reeds bekende trefgebiede en belangrike getyriviere, sowel as 'n hele aantal strande, is vanaf 1974 tot 1979 ondersoek. Die data wat tydens hierdie ondersoeke verkry is, is in voorafgaande verslae [20 en 50] opgesom. Hierdie verslag dek die tydperk 1979 tot 1982 en sluit herondersoeke van die belangrikste trefgebiede, sowel as ondersoeke van sommige getyriviere in Natal en die suid-oostelike Kaapprovinsie wat nie voorheen aandag geniet het nie, in. Die trefgebiede is Tongaat, Durban en die Natalse suidkusstrande, Oos-London, Algoabaai, Mosselbaai, Valsbaai, Houtbaai, Kampsbaai, Tafelbaai en Saldanhabaai. Getyriviere is die Siyaya, Umgababa, Buffels, Sondags, Groot-Vis, Kowie, Kariega, Gamtoos en Kromme. Daar is ook 'n aantal algemene ondersoeke uitgevoer wat metaalkonsentrasies langs die Kaapse kus, verdere ondersoeke na die herstel van strande na 'n oliestorting en 'n ondersoek oor die kolonisasie van 'n kunsmatige rif insluit.

Navorsing is deur klein groepe navorsers van die Navorsingsinstituut vir Seevisserye (NISV) in Kaapstad, die Nasionale Navorsingsinstituut vir Oseanologie in Stellenbosch, die Universiteit van Port Elizabeth en die Nasionale Instituut vir Waternavorsing in Durban onderneem. Behalwe dié deur NISV, is al die projekte deur die Stigting vir Navorsingsontwikkeling (voorheen Koöperatiewe Wetenskaplike Programme) van die Wetenskaplike en Nywerheidnavorsingsraad (WNNR), as deel van die Suid-Afrikaanse Nasionale Komitee vir Oseanografiese Navorsing (SANKON)-program gefinansier. Die welwillende samewerking van al die groepe het die samestelling van hierdie dokument moontlik gemaak.

DANKBETUIGINGS

Die grootste gedeelte van die werk is onder beskerming van SANKON met finansiële steun van die Hoofdirektoraat Omgewingsbewaring van die Departement van Omgewingsake onderneem, en hierdie steun word met dank erken. Waardering gaan aan deelnemers in die program van regeringsinstansies, WNNR-laboratoriums, universiteite en ander navorsingsorganisasies wat bydraes tot hierdie publikasie gelewer het.

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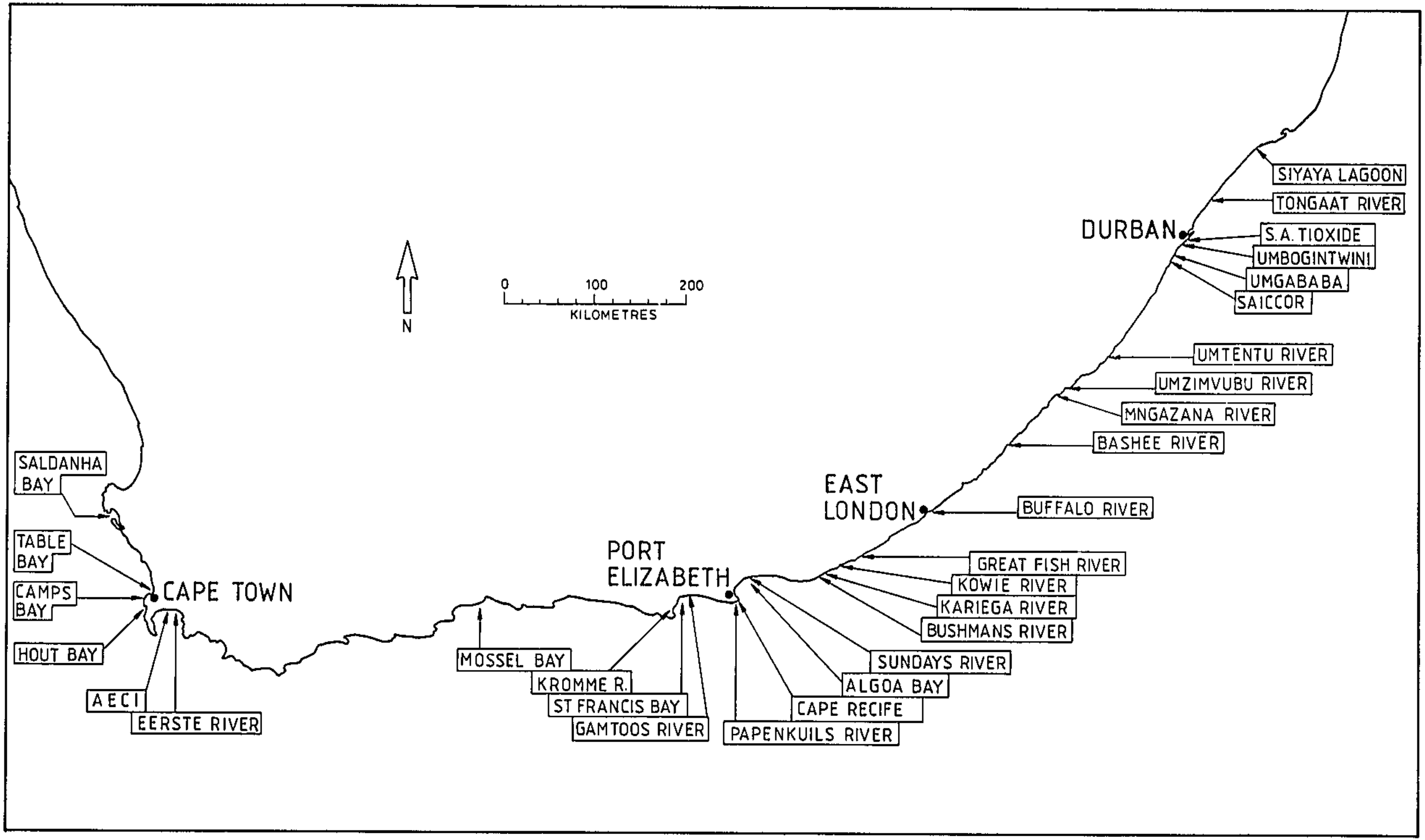

FIG. 1. MARINE POLLUTION SURVEY AREAS
1979—1982

AREA SURVEYS

SIYAYA LAGOON

The Siyaya lagoon is a small system about 120 km north of Durban, just east of Mtunzini (Figure 2). The catchment area is small (1 600 hectares) and consequently the system is blind, only opening during periods of heavy flooding. Although almost the entire catchment area is under sugar cane, the lagoon is surrounded by undisturbed indigenous forests [10]. During the last 15 to 20 years soil erosion due to poor farming practice has caused the Siyaya to become badly silted. Recently an interdisciplinary study has been commenced, "Siyaya Catchment Project" [86], to determine whether the catchment can be restored. This involves the implementation of a farm plan by the Sugar Association, the rehabilitation of stream banks and the regeneration of the original wetland areas.

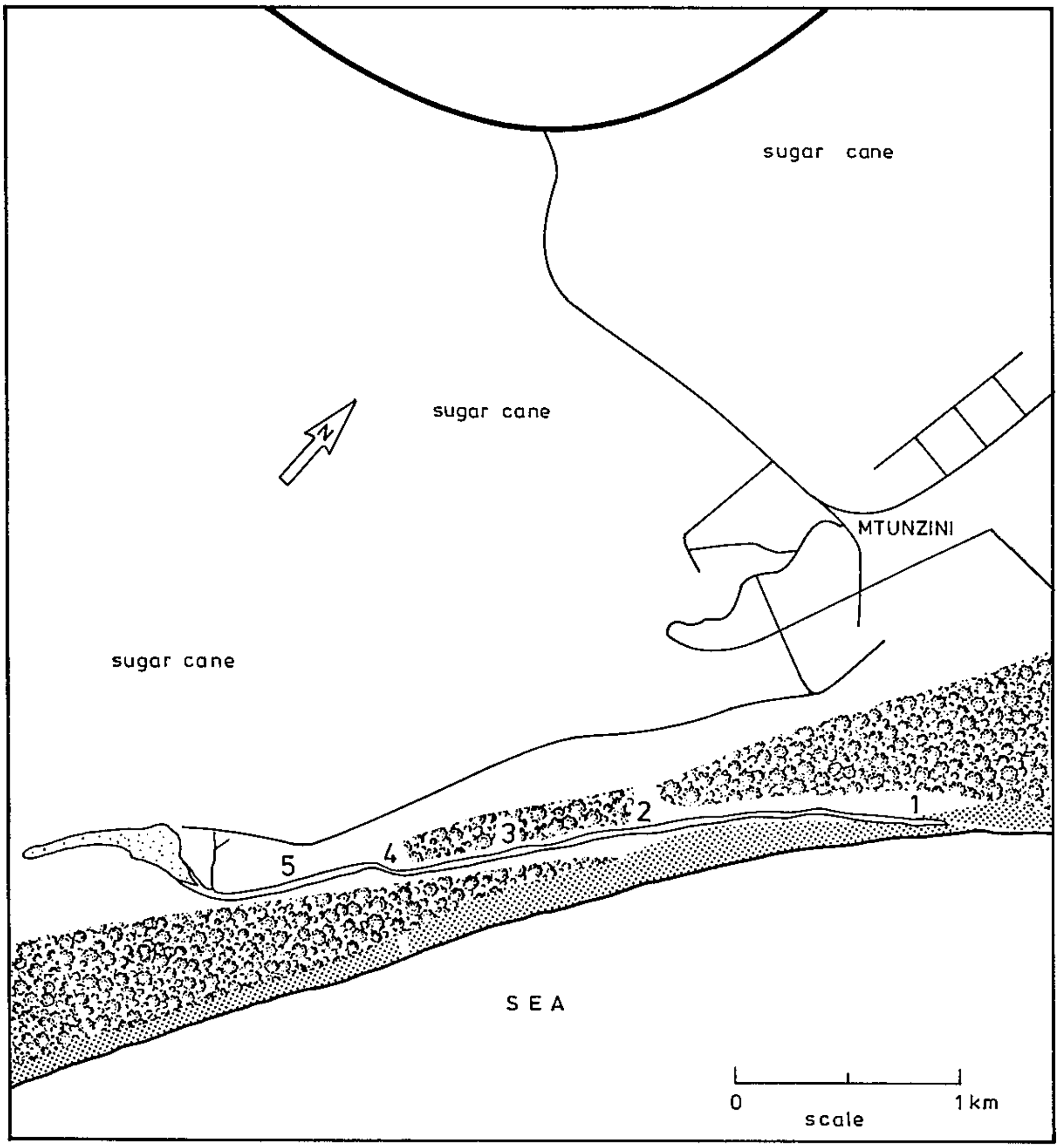

FIG. 2. SIYAYA LAGOON.

Nutrients and heavy metals

The lagoon was surveyed in September 1979 [27] before the project commenced. The water was virtually fresh throughout the length of the lagoon but the dissolved oxygen was surprisingly low (2,3 mg $O2\ \ell^{-1}$) in subsurface waters, probably due to the amount of leaf-litter from the surrounding swamp and dune forests. The nutrient concentrations were markedly higher at the head of the lagoon (nitrate 135 umol ℓ^{-1}) than at station 1. In bottom water nitrate (4 umol ℓ^{-1}) was down 30-fold, ammonia down 7-fold and phosphate 3-fold suggesting that the nutrients are being taken up by the plant material and contributing to the vigorous growth of *Phragmites*. None of the metal concentrations were particularly high compared with those in other Natal Estuaries [50] or the Bashee [21].

Meiofauna

Diversity and abundance of meiofauna were low in the sediment of the central and upper reaches of the lagoon (Station 3, 4 and 5). Towards the mouth there was a trend towards increased abundance and diversity. Impoverishment of the benthic faunal communities was probably due to the low oxygen concentration in the bottom waters. The presence of chironomids at most stations is indicative of the low salinities prevailing at the time of the survey.

Zooplankton

There was a marked drop in zooplankton numbers from the mouth to the head of the lagoon. The zooplankton was found to be an unusual mixture of estuarine and freshwater forms. Only three estuarine forms were found, namely the copepod *Pseudodiaptomus hessei* and *Branchyuran* and *Macrobrachium* larvae. All three were found only at station 1 (Figure 2) while a few *P. hessei* were collected at station 2.

At stations 1 and 2 the freshwater cladocerans *Moina* and *Ceriodaphnia* were common, as was the cyclopoid *Thermocyclops emini*.

Together with *P. hessei*, these contributed to the moderate settled volumes recorded for these two stations. Further up toward the head of the estuary these forms also became scarce, however, resulting in very poor counts for stations 3 to 5. The low oxygen levels probably contributed substantially to this.

TONGAAT RIVER MOUTH

The Tongaat river mouth which is 20 km north of Durban has been indentified as a site of pollutant input to the sea [20]. The river receives secondary effluent from the local sewage works and drainage from sugar cane fields. At the river mouth, a pipeline discharges effluent from a textile factory into the surf zone.

At low tide on 20 March 1980 two beach transects, with stations at high water, mid-water and low water, were established 50 m north and south of the pipe [65]. The estuary mouth was closed at that time.

General chemistry

The effluent was of fairly neutral pH but had a high OA (oxygen absorbed from alkaline potassium permanganate) value (54 mg ℓ^{-1}) indicating the presence of large quantities of easily oxidisable organic material. A northward drift of effluent was evidently predominating at the time of sampling as the northern water samples were less saline and yielded consistently higher OA (1 mg ℓ^{-1}) and Kjeldahl nitrogen (700 ug N ℓ^{-1}) values. Despite this large organic input, dissolved oxygen concentrations were consistently high and there was no evidence of oxygen depletion. Some of the OA results (1 mg g^{-1}) for sediments may be regarded as moderately high and indicate some build up of organic material.

Meiofauna

The interstitial meiofauna was diverse and abundant at all stations. Although the populations were somewhat less dense to the north of the pipe, an absence of long term observations precludes attributing this to the effects of effluent.

Trace metals

The trace metal results for water samples show that, apart from a moderately high copper concentration, the effluent contained generally low concentrations of trace metals. It should be realised, however, that these results are for a single "snap" sample and may not be representative of the overall long term situation. The trace metal concentrations in surf and sediments were similar to levels found in unpolluted beaches [77]. The interstitial water samples, on the other hand, yielded some surprisingly high results for lead, zinc, cadmium and copper (Table 1). A possible explanation is that an earlier batch of effluent contained high concentrations of these elements and that residues had not yet purged from the interstitial environment.

Most of the trace metal concentrations in mussels *(Perna perna)* and oysters *(Crassostrea cucullata)*, gathered from reef in the discharge area were similar to levels in unpolluted areas [94, 95]. The Mn concentrations were however up to ten times higher than those in unpolluted areas, Cu levels in *C. cucullata* were about five times the average levels reported for *C. margaritacea* but this could be due to the different species since the Cu concentrations in the *Perna perna* were similar to those in unpolluted areas [94].

Chlorinated hydrocarbon residues

No chlorinated hydrocarbons were detected in mussels from the study area.

Bacteriology

A south-going longshore current was flowing at the time of sampling. The *Escherichia coli I* index at the southern station was 128 000 per 100 ml, [65] coagulase positive mannitol positive staphylococci were present and the effluent was grossly contaminated by sewage.

The area receives a considerable input of organic matter. This does not appear to be having any long term adverse effect on beach fauna but the presence of sewage presents a health risk. Trace metal concentrations were generally low at the time of sampling but scattered high results in the interstitial water samples suggest that higher levels may prevail on occasions. As this was the first survey at this locality it is not possible to judge whether conditions are improving or deteriorating. Subsequently however the sewage has been diverted to the Tongaat sewage works.

TABLE 1: Trace metal concentrations (ug ℓ^{-1}) in water and effluent samples from Tongaat beach - 20 March 1980.

Station	Hg	Cu	Cd	Pb	Zn	Fe	Co
North surf	< ,0015	4,89	0,691	ND	1,49	337	0,086
North HW	,071	10,2	7,98	1,59	37,1	401	0,229
North MW	,023	16,7	30,6	ND	38,3	291	0,057
North LW	,026	10,9	13,6	0,229	43,3	291	ND
South surf	< ,0015	1,99	1,15	ND	19,7	471	ND
South HW	,023	321	38,6	7,23	236	345	0,029
South MW	,019	29,1	38,2	0,227	58,9	347	0,057
South LW	,008	61,9	14,0	0,652	59,2	165	ND
Tongaat estuary	< ,0015	4,89	0,155	0,667	9,66	1 890	5,46
Effluent	,011	163	1,05	ND	33,9	513	0,286

ND = Not detectable HW = High water
MW = Mid water LW = Low water

S A TIOXIDE (PTY) LTD EFFLUENT DISCHARGE

S A Tioxide discharges 1 800 m^3/day through a pipeline about 2 km offshore from Umbogintwini which is 14 km south of Durban. The effluent, comprising sulphuric acid and iron sulphate, is extremely acidic with a pH of less than 1. The pipeline has been in operation since April 1962.

The area in the vicinity of the discharge was resurveyed in February 1981 (Figure 3) to determine whether the effluent was causing any deleterious ecological effects [64]. The last detailed study of the area took place in May 1970 [49] when no adverse effects due to the effluent were noted.

General chemistry

The pH and sulphate results fell within the range normally found in sea water. Trace metal concentrations in the water and sediment were generally low and consistent with normal background conditions. No sulphides were detected in the sediments at stations 1, 2, 3, 5 and 6 and only a trace (0,11 mg g^{-1}) was found at station 4. The macrofauna was diverse and abundant at all stations indicating an absence of chronically toxic conditions.

The effluent appears to be having no deleterious ecological effects.

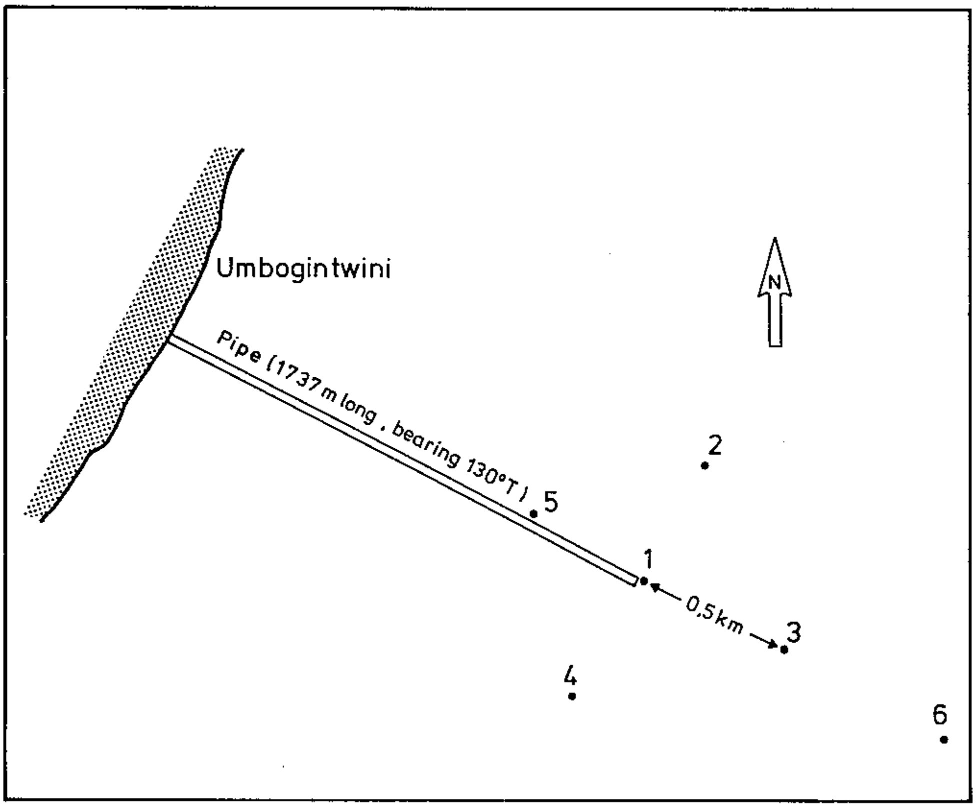

FIG. 3. S.A. TIOXIDE OUTFALL.
SCHEMATIC LAYOUT OF STATIONS.

UMBOGINTWINI OUTFALL

Effluent from a large industrial complex is discharged by two pipes at Umbogintwini beach about 16 km south of Durban. The smaller pipe from the ammonia plant discharges about 1 000 m^3d^{-1} just outside the backline of the surf while a further 3 000 m^3d^{-1} from the rest of the factory is discharged into the surf.

Apart from a slightly depleted oxygen concentration in one of the interstitial water samples there was no evidence of organic enrichment in the beaches at Umbogintwini. The OA values were consistently low in the water and sediment. The Kjeldahl nitrogen results showed a distinct trend in that those to the north of the outfall were consistently higher than those to the south, probably due to ammonia in the effluent. The effluent was drifting northwards at the time of the survey. The meiofauna was diverse and abundant on both sides of the discharge and gave no indication of gross toxic effects. The bacteriological results showed this region to be unpolluted by sewage.

Trace metals

There was no distinct trend in most of the results for trace metals in water, sediment and biological tissues. The exception was mercury. The concentration of 1,56 ug Hg ℓ^{-1} for surf water 100 m north of the discharge point was one order of magnitude higher than the normal background for sea water and is potentially toxic. The mussels *(Perna*

perna) collected from the area contained a mean of 4,75 ug Hg g^{-1} dry mass. This is the highest concentration of mercury that has been found in mussels from the Natal coast. It is significant that previous mercury highs recorded in *Perna perna* were also at Umbogintwini. These were 0,09 ug Hg g^{-1} dry mass in 1974 and 1,52 ug Hg g^{-1} dry mass in 1975. These data suggest that mercury concentrations have been building up in mussels in the area. Subsequent to these surveys effective steps have been taken to remove mercury from the effluent.

To place these results into perspective on a health risk basis it should be noted that 0,5 ug Hg g^{-1} wet mass appears to be the acceptable limit for mercury in aquatic organisms that are destined for human comsumption. The dry mass value of 4,75 represents 0,476 ug Hg g^{-1} wet mass which borders on the safe limit. The mussels analysed [64] were small (10 to 20 mm in length), and were collected from a concrete pylon on the beach opposite the pipe outlet. This pylon has subsequently been demolished. The results may thus not be representative for the larger individuals which are normally harvested several kilometres to the south at Inyoni Rocks.

UMGABABA ESTUARY

Umgababa estuary which is 35 km south of Durban (Figure 4), was resurveyed in January 1979 and again in February 1981 [29] after high mercury levels had been recorded previously [22]. High mercury levels were also found in the fish *Acanthopagrus berda* from the estuary and in the rock lobster *Panulirus homarus* from the surf zone at the mouth of the estuary. However fish from Umzimkulu and Bashee estuaries [21] have also contained high mercury levels compared with those from areas north of Durban, suggesting a possible natural enrichment of the mercury.

Meiofauna and zooplankton

The meiobenthos were diverse and abundant indicating that there had been no gross deterioration of conditions on the bed of the estuary. Zooplankton was also similar to that of February 1977 [22] again showing the numerical dominance of *Acartia natalensis* (98%). The *Pseudodiaptomus* numbers (21%) would likely have been considerably higher had the samples been taken at dusk instead of at midday.

TABLE 2: Concentration of Hg.
Units: Water - ug ℓ^{-1}; Sediments - ug g^{-1}

Stations		1A	1	2	3	4	5
June 1976	Sediments		0,016	0,014	0,013	0,013	0,013
February 1977	Sediments		0,04	0,131	0,115	0,122	0,067
January 1979	Sediments	0,008	0,023	0,016	0,023	0,018	0,023
February 1977	Water		1,01	0,624	0,767	0,836	0,871
January 1979	Water	0,856	0,888	0,662	0,824	0,694	0,614
February 1981	Water	0,034			0,086		0,007

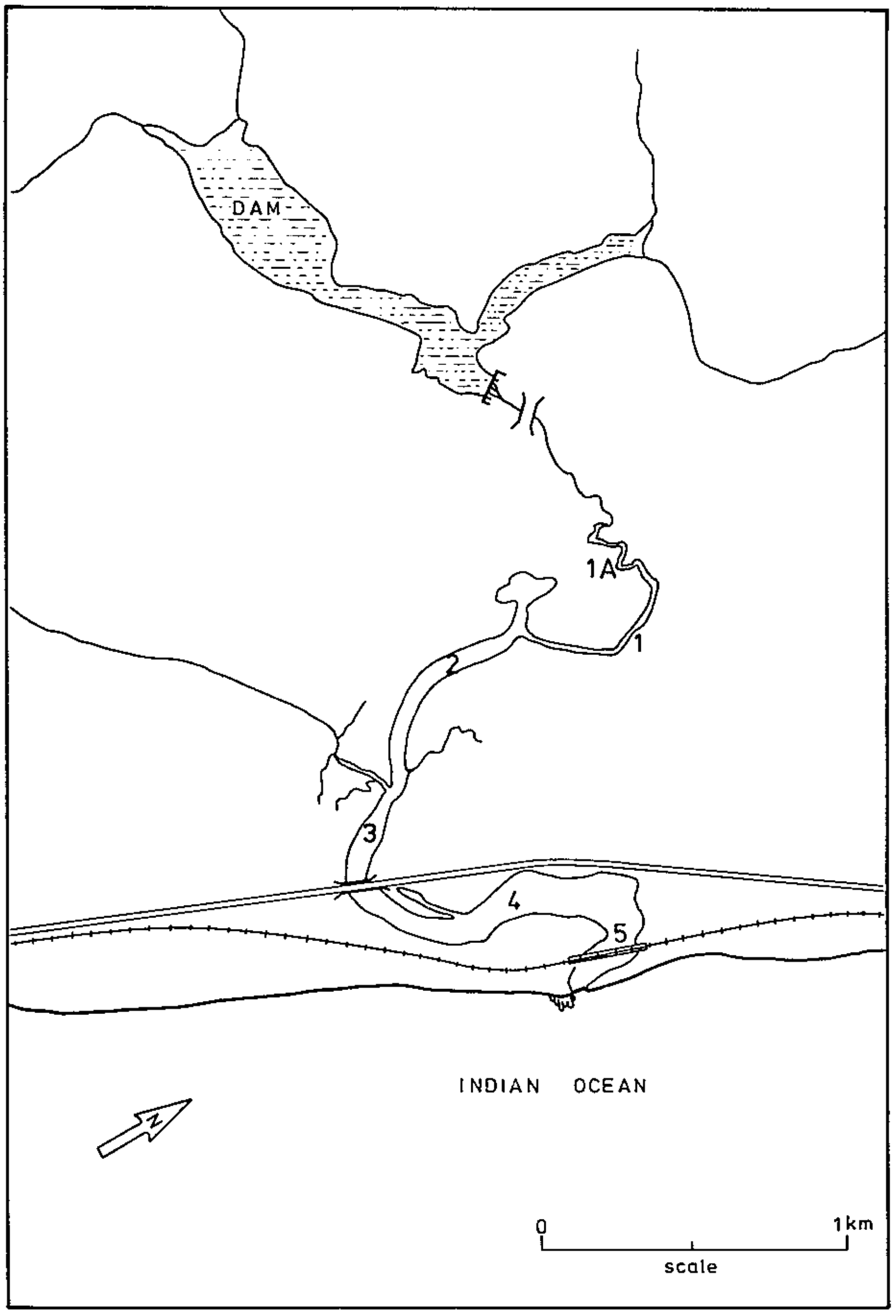

FIG. 4. UMGABABA ESTUARY

Metals in the sediments sampled on 18 January 1979 were very similar to those recorded in June 1976 [22] with no evidence of high mercury levels as recorded in sediments of 1 February 1977 [22]. To add to the confusion, the water samples taken in January 1979 showed consistently high mercury levels, similar to those of February 1977 (Table 2). Water samples for June 1976 were not analysed due to contamination. Since both sets of water samples had yielded high mercury levels a further set of samples, water only, was collected in February 1981. The mercury concentrations recorded on all the surveys are shown in Table 2. The mercury concentrations in the most recent survey were consistently low and this adds to the puzzle of the origin of the high levels of mercury in the Umgababa estuary.

SAICCOR OFFSHORE OUTFALL

SAICCOR discharges 80 000 m^3d^{-1} effluent through a pipe about 1 km off-shore from Umkomaas about 40 km south of Durban. The discharge is a very darkly coloured (coffee-like) rayon factory effluent containing calcium ligno sulphate. The effluent is warm (30 - 45 °C), is high in total dissolved solids (1,9 - 2,4%) and has a high oxygen demand (COD ca 50 000 mg $O\,\ell^{-1}$).

The beaches and off-shore area were intensively surveyed in the late 1960's after the pipe was commissioned in June 1966. No deleterious effect due to the effluent was reported [31]. The beaches were re-surveyed during low tide on 10 September 1980 and 21 January 1981 [67]. Station positions are shown in Figure 5.

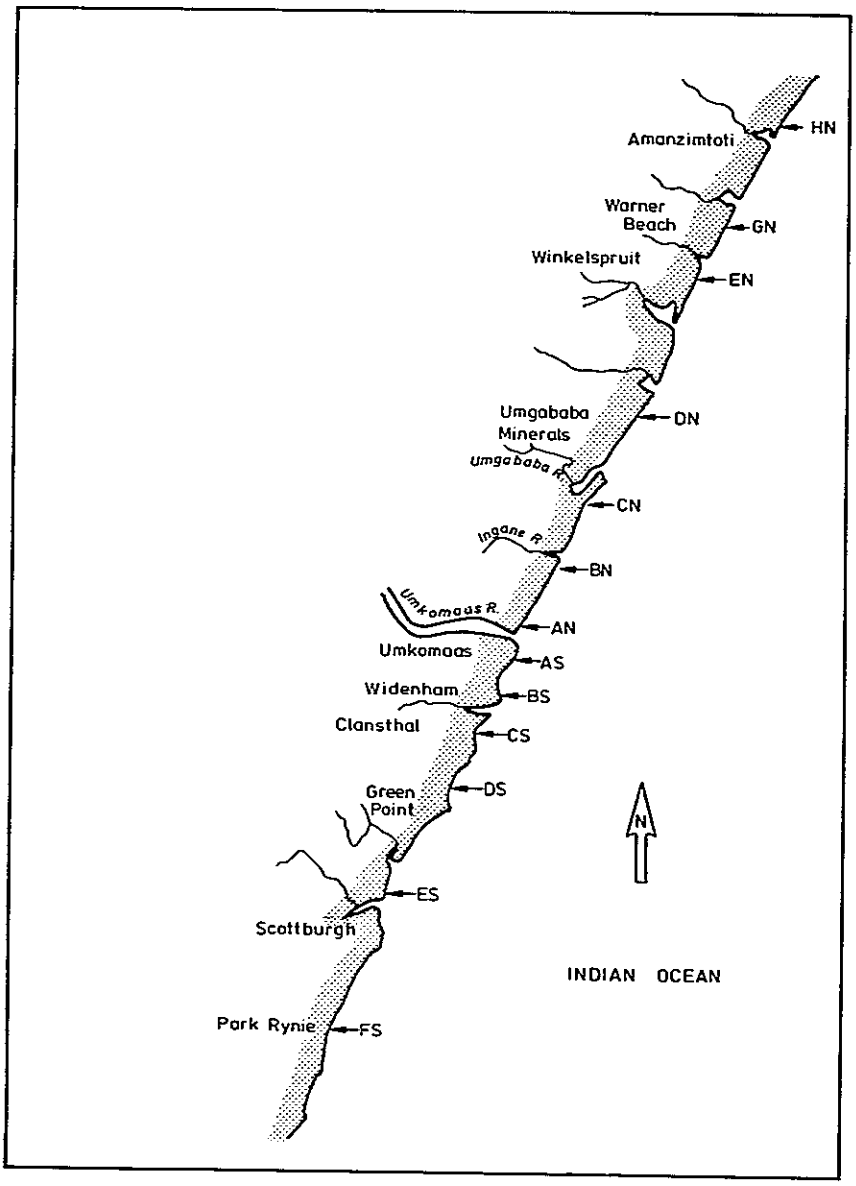

FIG. 5. LOCATION OF BEACH SAMPLING STATIONS. VICINITY OF SAICCOR OUTFALL.

General chemistry

Dissolved oxygen concentrations were consistently high indicating an absence of chronic organic build up within the sediments. The OA values and lignin concentrations were generally low. Although it is not possible to discriminate between natural levels of these parameters and those due to the effluent, the absence of a geographical trend suggests that the results reflected background conditions. The results for September 1980 were higher, on the whole, than those for January 1981. This appears to be unrelated to the effluent and is a reflection rather of differing general inshore conditions on the two occasions.

The interstitial meiofauna was found to be diverse and abundant in nearly all cases. The obvious exception was at station AN (Figure 5) where, on both occasions the sample contained fewer species and was dominated to a large extent by the archiannelid *Protodrilus*. This manifestation of stressful conditions can be attributed to the nearby discharge of the Umkomaas river.

There was thus no evidence of deteriorating conditions in the littoral zone.

MTENTU, UMZIMVUBU, MNGAZANA AND BASHEE ESTUARIES

Previous surveys of the Bashee, Mngazana and Umzimvubu estuaries had revealed a marked difference in the zooplankton- zoobenthos ratios of these estuaries. On the one hand the Mngazana, sampled in July 1977 showed a rich zoobenthos but relatively low zooplankton densities [25] with settled volumes of 0,4 to 6,3 cc for standard D net hauls. This was expected since in winter zooplankton biomass tends to decrease. For the Mngazana, this has been well documented [112]. On the other hand both the Bashee [21] and Umzimvubu [24] estuaries have consistently shown poor zoobenthos, and yet massive concentrations of zooplankton were present in the winter, the former when it was sampled in June 1975, and the latter in July 1977.

Since the Bashee had high zooplankton populations both summer and winter, compared with the Mngazana where it was high in summer but low in winter, it was decided to do a comparative study of the two estuaries in order to try and explain the observed difference. The Mtentu and Umzimvubu were included to provide additional data on estuaries similar to the Mngazana and Bashee estuaries respectively.

Since sampling four estuaries consecutively involved more than a week, it was decided to work over a neap tide period. The Mtentu (Figure 6) was visited from 15 to 16 March, the Umzimvubu (Figure 7) from 18 to 19, the Mngazana (Figure 8) from 20 to 21 and the Bashee (Figure 9) from 22 to 23 March 1979 [26].

TABLE 3: Settled volumes (in cm^3) of zooplankton from 50 m hauls with a sled-mounted plankton net.

Estuary	Date	Station					
		1	2	3	4	5	6
Bashee	8 6 75	17,0	69,0	35,0	86,0	51,0	8,0
Bashee	10 6 75	-	20,0	-	157,0	-	46,0
Bashee	6 12 75	-	0,6	25,0	80,0	82,0	2,2
Bashee	6 12 75	-	-	-	74,0	-	-
Bashee	22 3 79	-	-	-	47,0	51,0	-
Bashee	22 3 79	-	-	-	-	78,0*	-
Mngazana	15 8 79	6,3	5,6	2,4	0,7	-	0,4
Mngazana	20 3 79	-	110,0	31,0	11,0	-	-
Umzimvubu	13 8 77	3,5	138,0	71,5	60,0	30,7	-
Umzimvubu	18 3 79	-	-	30,5	27,5	36,5	-
Mtentu	16 3 79	46,0	45,2	87,0	-	-	-

* Slightly downstream of station 5.

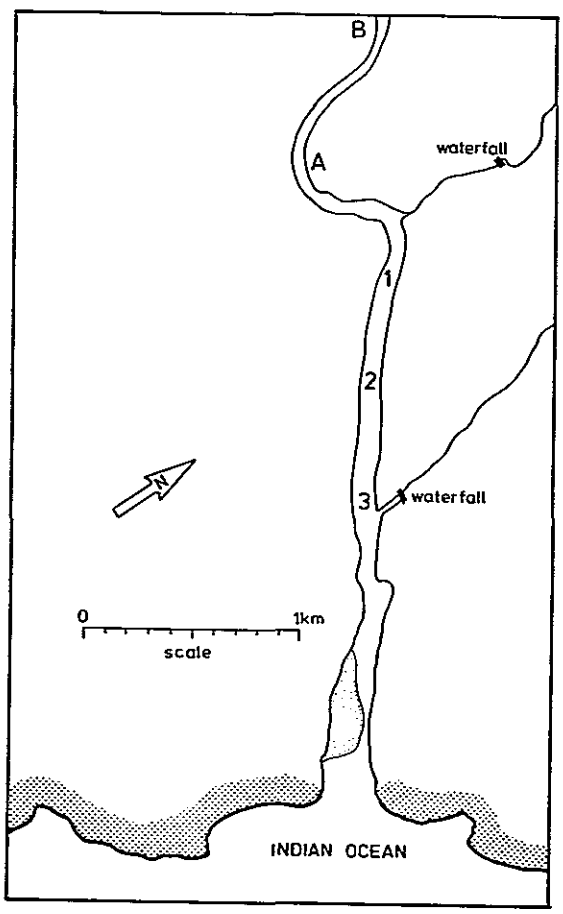

FIG. 6. MTENTU ESTUARY.

At the time of the visit, the Umzimvubu was unfortunately disturbed by a flash flood, and conditions were such that the results had no relevance to the study. The section of the estuary in which large concentrations of zooplankton had been located in July 1977 [24] was a swirling mass of totally fresh, muddy water during the 1979 survey.

All the estuaries were found to be well oxygenated, with relatively low phosphate and nitrate levels. The flooded condition of the Umzimvubu was reflected in the low surface salinities although a surprisingly high salinity was recorded in a deep hole below the road bridge at station 3A, (Figure 7).

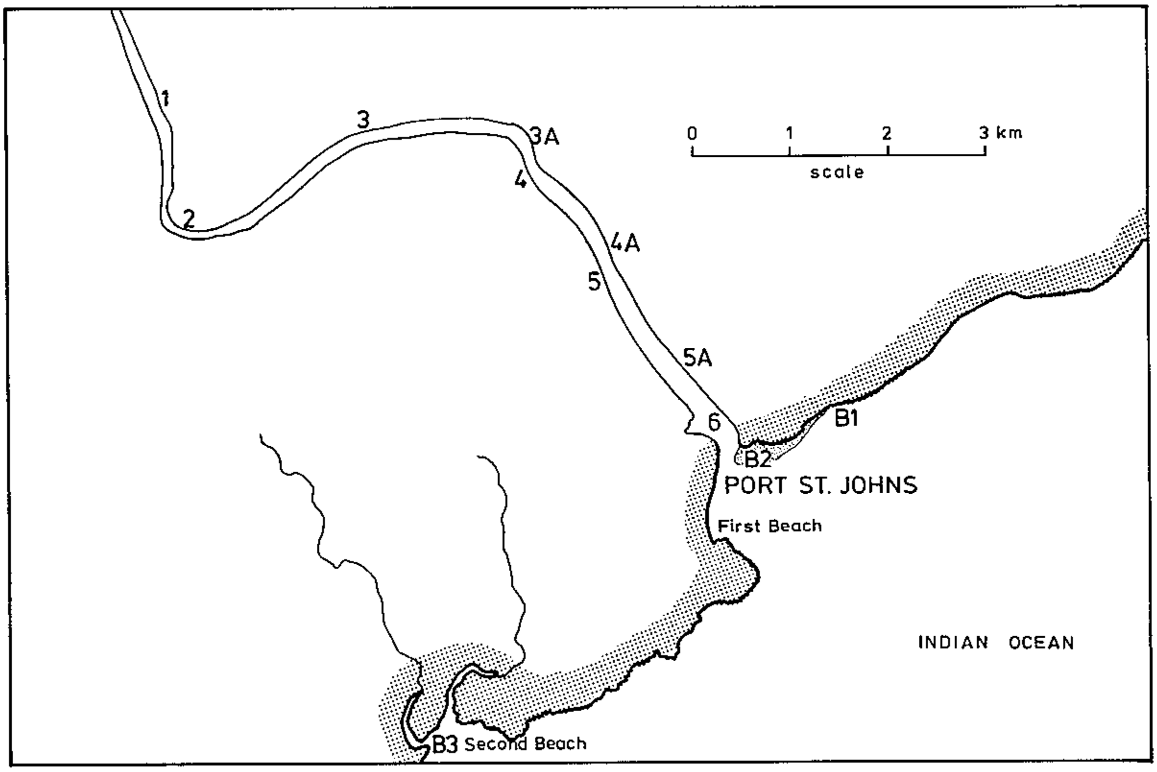

FIG. 7. UMZIMVUBU ESTUARY

Meiofauna

The results revealed that in all four estuaries most of the meiofauna was concentrated in the top 10 cm of sediment. There was a rapid decline in meiofaunal numbers with depth. The samples from the Mtentu and Mngazana estuaries yielded very high meiofaunal numbers indicating mean populations of 85 516 and 48 852 organisms per 100 cm^2 respectively.

The presence of a well developed meiofaunal community in the Mngazana estuary has already been documented. In comparing the meiofauna standing crops and production estimates for five southern African estuaries Dye [37] found the Mngazana sandy substrate to be the most productive and to support the highest standing crops. The Mngazana muds were exceeded only by those from the Knysna estuary in terms of meiofauna standing crop and estimated production. He found the meiofaunal numbers to be high throughout the year with an early winter maximum. The August survey [25] revealed a mean meiofaunal population of 31 623 organisms per 100 cm^2 at six stations along the estuary. This compares favourably with the 1979 [26] estimate of 48 852.

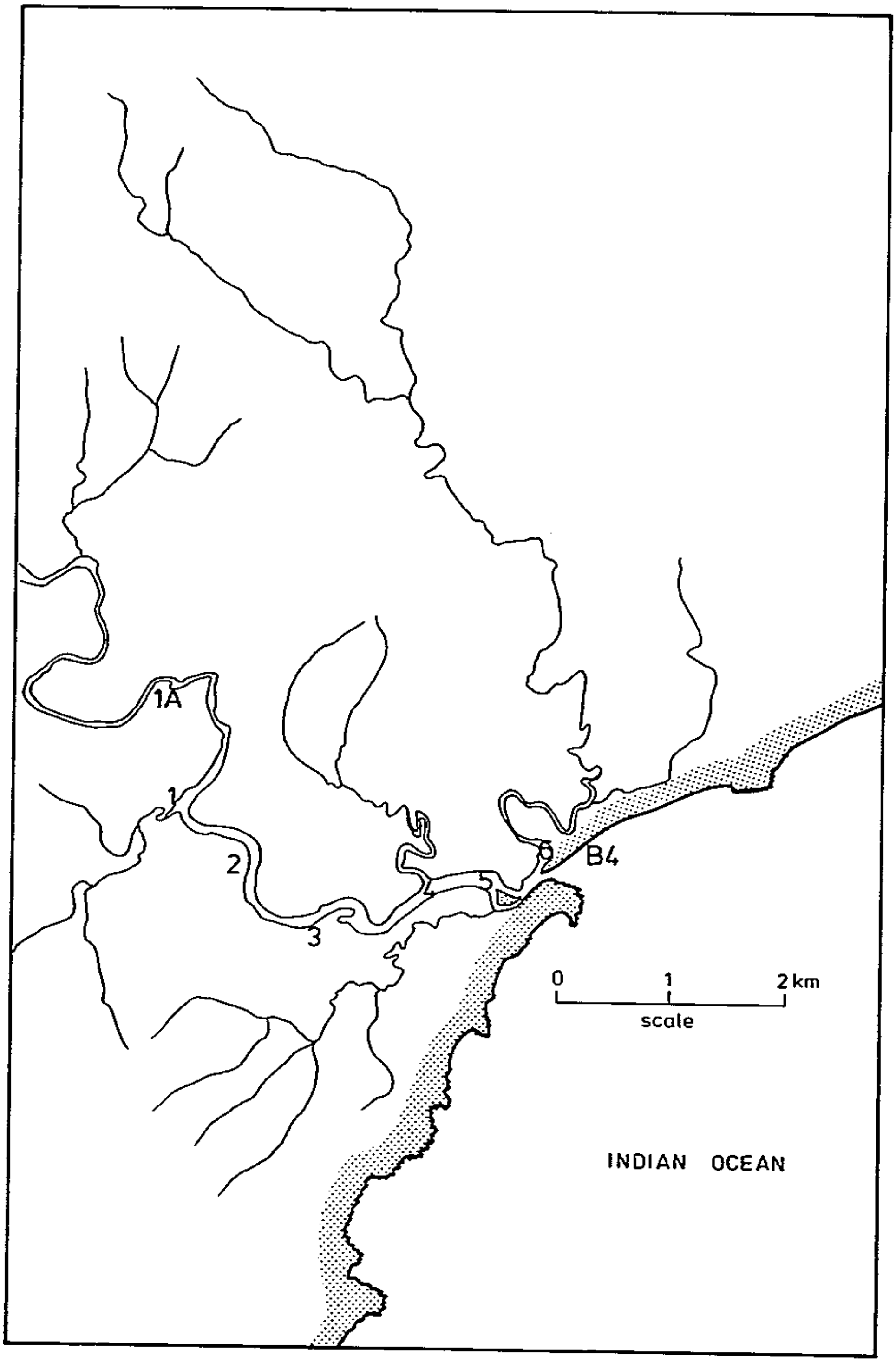

FIG. 8. MNGAZANA ESTUARY

In contrast to the high meiofaunal numbers recorded at the Mtentu and Mngazana estuaries, very low numbers were found in the samples from the Umzimvubu and Bashee. The Umzimvubu samples contained a mean of only 151 organisms per 100 cm^2 and the corresponding figure for the Bashee estuary was 823. The relatively impoverished meiofauna of these estuaries can be attributed to physical factors. The Umzimvubu is prone to flooding and can experience high current flows, as evidenced by the destruction of the road bridge in 1978. It is suspected that periodic erosion and deposition of sediments during periods of flooding hampers the development of stable meiofaunal communities. In the Bashee estuary the main factor limiting the development of meiofauna appeared to be the loosely compacted and fine nature of the substrate. At none of the stations was it possible to easily detect a definite interface between substrate and water column, while diving for samples using SCUBA.

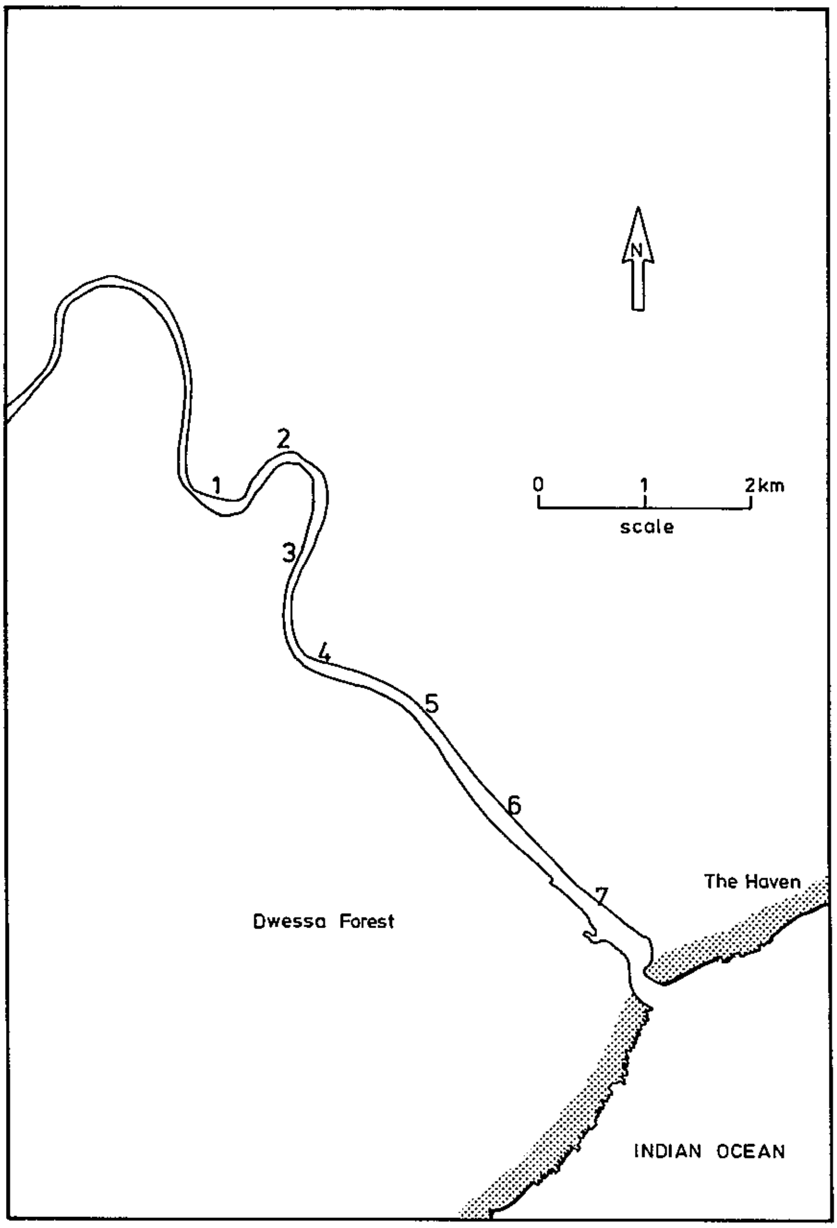

FIG. 9. BASHEE ESTUARY

It could be expected that such a substrate would smother benthic organisms and exclude gill breathing forms. Previous observations support the finding of impoverished benthic communities in the Umzimvubu and Bashee estuaries. In August 1977 the mean meiofaunal population at six stations in the Umzimvubu [24] was 1 726 organisms per 100 cm^2. Although this is appreciably higher than the figure of 151 obtained in the present survey it is far less than anything obtained in the Mtentu and Mngazana estuaries. It is probable that the higher values in August 1977 were due to the samples being taken towards the end of a dry season. Low water flows and an associated reduction in sediment transport during the preceding months might have enabled the benthic communities to consolidate. Although no other surveys of the meiofauna of the Bashee estuary have been performed, macrofaunal samples taken in June 1975 were similarly poor in terms of abundance and diversity [21].

The overall picture that has emerged is that the meiofaunal communities of the Mtentu and Mngazana estuaries are rich and well developed. In contrast, restrictive physical conditions in the Umzimvubu and Bashee estuaries have resulted in patchy and poorly developed meiofaunal populations. The Mtentu and Mngazana estuaries are likely therefore to have a relatively higher proportion of the available nutrients and energy tied up in meiobenthic communities. In the Umzimvubu and Bashee estuaries a lesser demand for nutrients and energy by the meiofauna would result in a larger proportion of these resources being available for exploitation by non-benthic communities.

Zooplankton

Except for the samples collected at the Umzimvubu during the time of flooding, the results showed all three estuaries had the typical summer dominance of the biomass by mysids, and the two estuarine copepods *Pseudodiaptomus hessei* and *Acartia natalensis* [26]. All three estuaries showed the typical high biomass expected in summer, although station 4 on the Mngazana was evidently too close to the mouth of the estuary (Figure 8).

The winter samples of zooplankton collected from the Mngazana estuary [25] in August 1977 were notable for the almost total absence of mysids and the accompanying drop in biomass. In contrast to this the samples taken in the Bashee in June 1975 [21] showed the mysids *R. terranatalis* and *M. slabberi* to be present in large numbers, and settled volumes of the standard D net samples were very similar to those encountered in the March 1979 samples (Table 3).

The data collected in the present survey, along with data collected on previous trips to these estuaries, do not show any marked external input of nutrients into the estuaries which might account for the differences. All evidence points to the fact that both the Bashee and the Umzimvubu estuaries, due to the nature of their estuary beds, do not support rich benthic communities. In the Bashee this is attributed to the very liquid nature of the muds, while in the Umzimvubu, frequent flooding and the subsequent unstable nature of the estuary bed, is the probable cause.

Estuaries such as the Mngazana typically have a very rich macrobenthos, in the form of *Upogebia* beds in the intertidal and shallow subtidal mud banks. They also have a very rich meiofauna, as shown by the present study and the work of Dye [37]. In such estuaries, the zooplankton is usually rich in summer and relatively much poorer in winter [112].

BUFFALO ESTUARY

The Buffalo was visited in April 1977 [23] and revisited in July 1980 [28]. The findings of the 1977 visit were included in the previous report [50] which also adequately described the area. The July 1980 visit, during which samples were taken at the same stations as previously, was planned to correspond with a full spring tide period.

On the previous visit [23], bacteriological contamination of the estuary was found to be high, and the metal levels were stated to be moderately high. The aim on the return visit was to look at these aspects again, both in the estuary and on the beaches, and to assess the level of metal contamination, which caused problems on the previous visit.

Station positions are shown in Figure 10. Oxygen levels were good throughout the estuary, and while some water OA values showed moderate organic enrichment, neither they nor the Kjeldahl nitrogen levels were particularly high for an estuary. Some of the OA levels in sediments were high, confirming organic enrichment, but the good oxygenation of the overlying waters confirm that these were not detrimental.

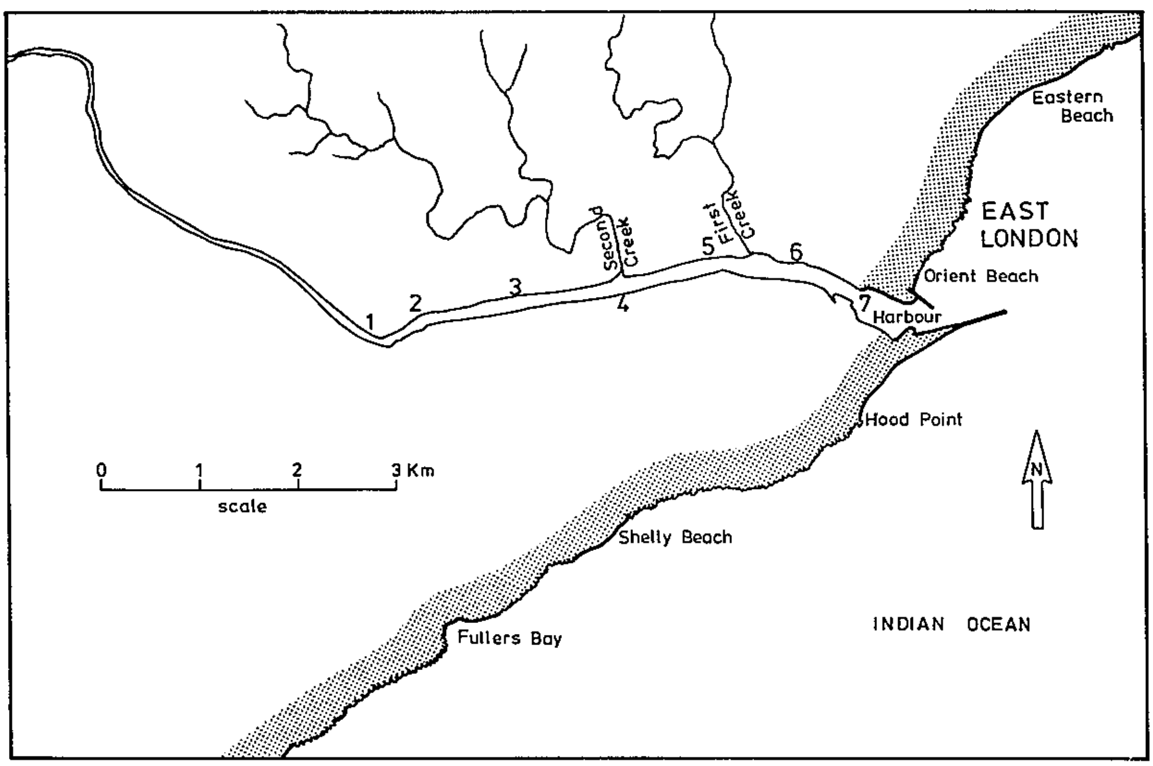

FIG. 10. BUFFALO ESTUARY

Bacteriology

The bacteriogical counts, provided by the East London City Engineers Department [28], show a considerable drop in faecal pollution indicator organisms. This confirms the chemical results, and points to an improvement in the degree of faecal contamination of the esturay.

Benthic meiofauna

Sediment cores for meiofaunal analysis were collected by means of scuba diving at stations 2 to 7. The cores penetrated to a depth of 10 cm and covered a surface area of 50 cm^2 at each station. The results revealed diverse and abundant meiofaunal communities to be present at all stations. The results were generally similar to those obtained in the previous survey of the estuary [23]. Population densities tended to be lower in the 1980 survey [28], supporting the contention that pollution levels have been reduced.

Zooplankton

The dominance of the copepod *Acartia longipatella* was confirmed. The related *Acartia natalensis* was not found in any numbers, while *Pseudodiaptomus hessei* was more common than was found previously [23]. Biomass was much the same as recorded previously, [23] and compares favourably with similar estuaries during the winter.

Chlorinated hydrocarbons

Some pesticides were detected in some of the sediments but the concentrations were barely above the detection limits. The level of total DDT (DDT & DDE & TDE) in small *Mugil cephalus* ranged from 50 to 130 ug kg^{-1} with one exception of 680. This is higher than that found in the Bashee (0 - 10 ug kg^{-1}) but lower than that found in the Durban Umgeni (250 - 400 ug kg^{-1}) in similar size fish of the same species. The level in the *Elops machnata* liver (200 - 600 ug kg^{-1}) were similar to levels found in the same size and species in Richard's Bay (600 ug kg^{-1}) and Kosi (800 ug kg^{-1}) and higher than those from the Bashee estuary (80 ug kg^{-1}).

Comparing this survey with the earlier survey [23] there do not appear to be any gross changes.

Trace metals

In the sediments the mean mercury concentration (0,208 ug g^{-1}) had decreased to about half the concentration found previously, but was still about three times the levels found in sediments from remote areas [21, 24, 25]. By contrast lead concentrations were approximately double previous levels and more than six times levels in remote areas. The Cu and Fe concentrations were also more than double levels in remote areas but were similar to levels found previously. The heavy metal concentrations in the water were similar to the concentrations found in remote areas. The level of heavy metals in the tissues of various animals sampled in the estuary were also similar to levels found in remote areas. However three *Elops machnata* had mercury concentrations of between 0,4 and 0,6 ug g^{-1} dry mass in their muscle tissue.

EAST LONDON BEACHES

A pollution monitoring survey was performed at six beach stations (Figure 11) near East London at low tide on 30 July 1980 [67]. The aim was to determine if any major changes had occurred, since an initial background survey at East London in April 1977 [63].

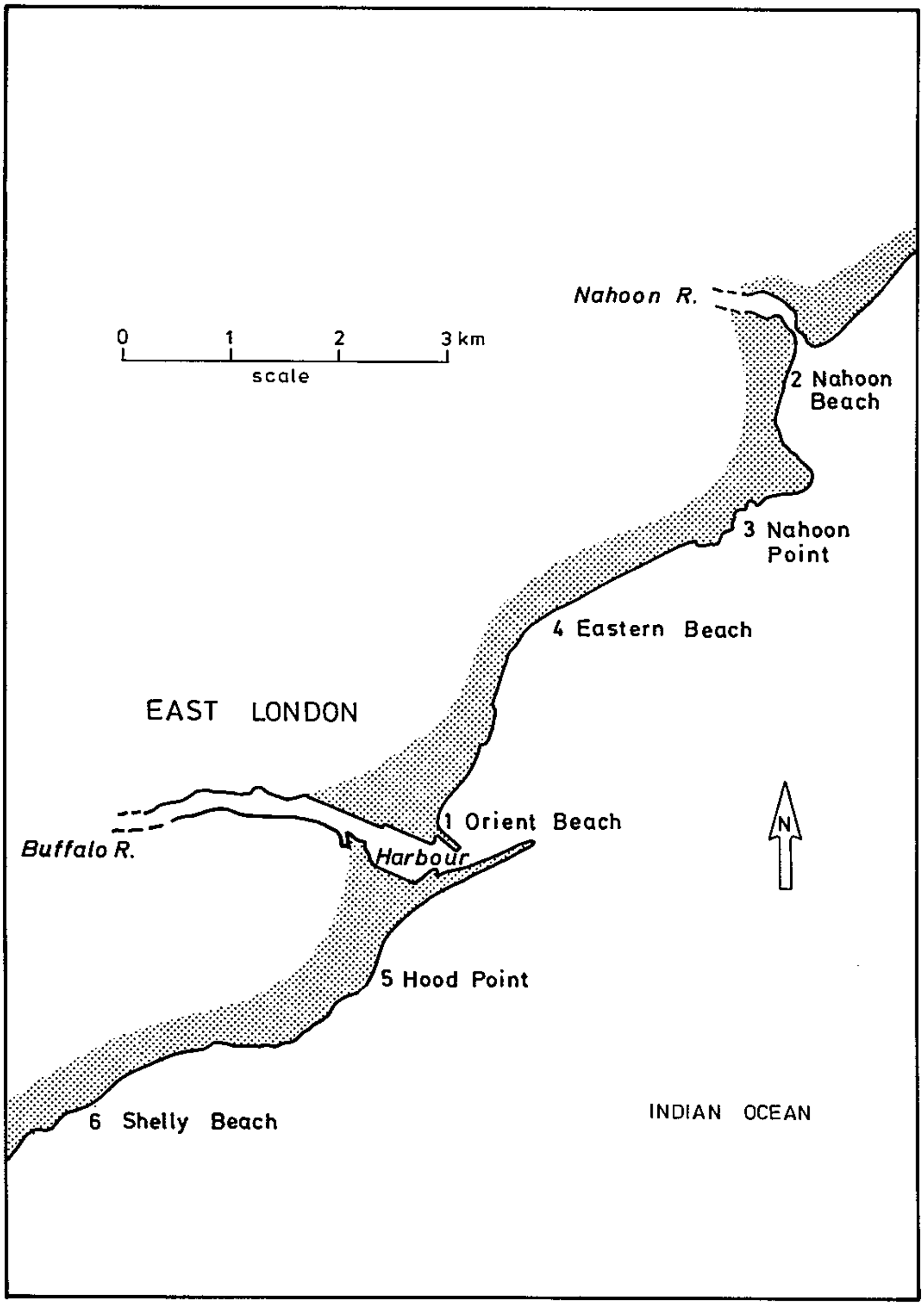

FIG. 11. EAST LONDON BEACHES.

General physics and chemistry

Apart from Nahoon beach (station 2), the salinities were all fairly close to 35 0/00 indicating minimal intrusion of fresh groundwater. There were some high OA and Kjeldahl nitrogen values but there was no clear indication of these being due to effluent. Dissolved oxygen concentrations were consistently high suggesting that rich organic effluents had not accumulated inshore. The sediments were generally fine grained at Orient beach, Nahoon beach and Eastern beach (stations 1, 2 and 4) whereas at Nahoon Point and Shelly beach they were considerably coarser.

Benthic meiofauna

The interstitial meiofauna was found to be fairly diverse and abundant at all stations indicating an absence of grossly toxic or organically enriched conditions. Species diversity tended to be slightly higher in the coarser sediments. The relatively high faunal density that was found at Nahoon Point in 1977 and attributed to the effects of sewage discharge was not evident on this occasion. This was probably a result of inherent patchiness in the meiofauna and does not conclusively imply that conditions have improved.

Trace metals

The trace metal results for the water and sediment samples were generally low and consistent with normal background conditions. However, in comparison with the 1977 results [63], a number of differences were evident. For example, cadmium and zinc concentrations in the water tended to be higher in 1980 [50]. Also, a relatively high lead concentration was found in the sediments at Eastern beach (station 4) in 1980, as was a higher mercury concentration in the surf water at Orient beach (station 1). There is insufficient data to conclude whether these differences represent real long term trends or whether they are simply due to natural spatial and temporal variability.

The mean mercury concentration in mussels *(Perna perna)* from Orient beach (0,723 ug g^{-1}) and Nahoon Point (0,444 ug g^{-1}) were far higher than in those from Eastern beach (0,127 ug g^{-1}) and Shelly beach (0,103 ug g^{-1}). This can be attributed to the Buffalo river in the case of Orient beach and to the sewage outfall in the case of Nahoon Point. It is relevant to note that in 1977, crayfish specimens *(Panulirus homarus)* from Orient beach were found to contain relatively high mercury concentrations. Furthermore, it should be noted that crayfish normally prey on mussels. Mussels were unobtainable near the Hood Point outfall so a direct comparison for that area was not possible. Limpets *Helcion pectunculus* collected in that vicinity did not yield high results for mercury but appeared to contain relatively high concentrations of lead, zinc and iron. As this species of limpet has not been used previously as an indicator of trace metal pollution the significance of this finding is presently uncertain.

Bacteriology

The bacteriological results [66] show that all three areas investigated are periodically subject to fairly heavy sewage contamination. The incidence and severity of contamination at any site is a function of the prevailing winds and currents. These findings are similar to those for 1977 and are the usual result of discharging sewage into the surf zone.

General assessment

Conditions were essentially similar to those found in 1977 and there has been no gross deterioration. Areas for concern are the periodic contamination of beaches by sewage and the accumulation of mercury in biota.

BUSHMANS, KARIEGA, KOWIE AND GREAT FISH RIVERS

The rivers surveyed during this investigation [105] all flow into the Indian Ocean on the southeastern Cape coast between the two industrial centres of Port Elizabeth and East London. This part of the coast is relatively underdeveloped, there being only a few holiday resorts and the small town of Port Alfred. The aim of these preliminary surveys [105], carried out in the period 1978 - 1979, was to determine the current metal levels in the sediments and water of the four rivers. The data obtained will not only serve as a baseline for future monitoring surveys of these rivers, but will also provide a useful comparison with the data obtained from the two industrial centres.

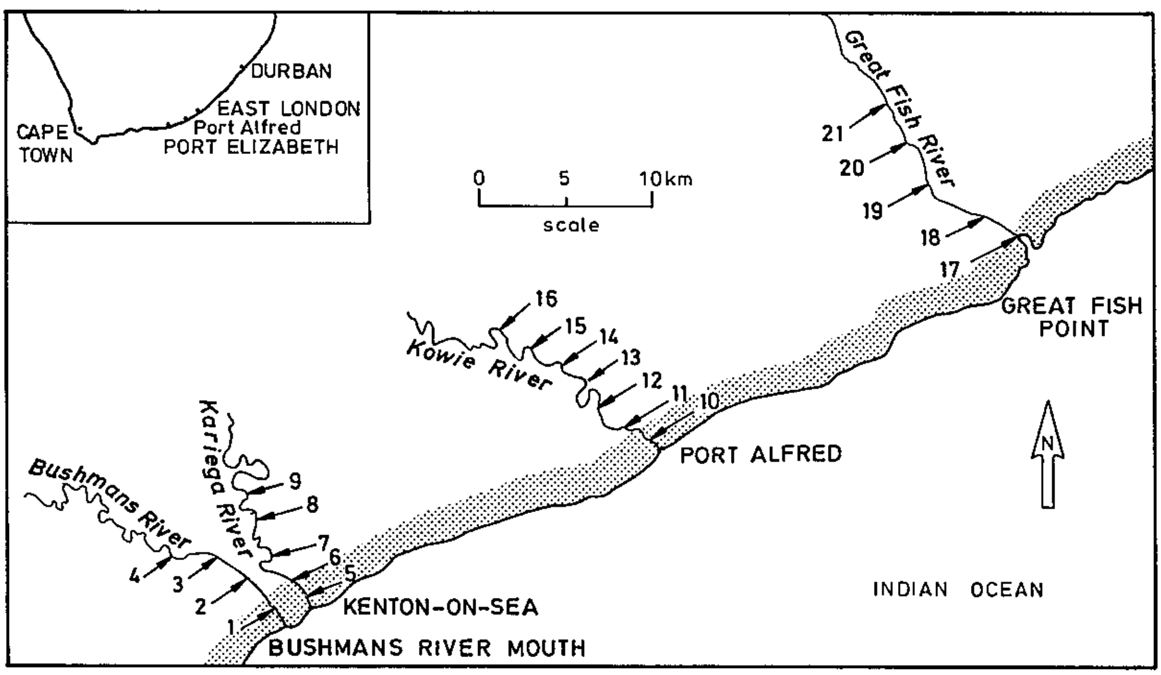

FIG. 12. LOCATION OF STUDY AREA AND SAMPLING POINTS.

BUSHMANS RIVER

The Bushmans river rises near Webster about 60 km south of Somerset East and enters the sea to the east of the town of Bushmans River Mouth, about 24 km west of Port Alfred.

The estuary is about 400 m wide but narrows upstream to a width of about 180 m (Figure 12). The catchment area is about 2 700 km^2 and the region is fairly dry.

Trace metals

The low concentrations in water samples from the Bushmans river indicated that the river was uncontaminated with respect to metals. Concentrations in the surface sediments of the Bushmans river were average for an uncontaminated Eastern Cape river [106, 107]. Concentrations in samples collected up-river were consistently low with very little variation along that part of the river surveyed. The only exceptions were a general increase in the levels of iron, aluminium and potassium and a decrease in the levels of calcium and strontium with increasing distance from the river mouth [105].

KARIEGA RIVER

The Kariega river rises to the west of Grahamstown and enters the sea 2 km to the east of the Bushmans river (Figure 12). The estuary is about 370 m wide near the sea but becomes much narrower upstream. The river mouth area is very shallow and the river is tidal for about 24 km [34]. The river banks are low in the lower reaches of the estuary but become steeper and higher upstream. The river catchment area supports some agricultural activities and a large part of it is covered in forest or indigenous bush.

Trace metals

The low concentrations in the water confirmed that there was no metal contamination of the river. Many of the element concentrations determined for the surface sediment samples were higher than those in samples from equivalent sites in the Bushmans river. Levels of copper, lead, zinc, cobalt, nickel and chromium increased significantly in the upstream samples [105] but both the cobalt/nickel and iron/aluminium relationships indicated that the metals were derived from the weathering of catchment rocks [108]. These metals are being trapped in the riverine sediments and it is unlikely that they will be released to the water column.

KOWIE RIVER

The Kowie river rises to the south of Grahamstown and flows into the sea at Port Alfred (Figure 12). It has a catchment area of about 580 km^2 with an average rainfall of 640 mm a^{-1} [34]. The estuary extends about 19 km upstream from the mouth; it is relatively narrow in the upper reaches but about 150 m wide near the mouth where the river banks have been canalised. In general, there is a paucity of flora and fauna which could be due to the fast tidal exchange rate and to the canalisation at the mouth which has resulted in a reduced saltmarsh and *Zostera* bed area [34].

Trace metals

Metal concentrations in water samples were similar to those from the Bushmans and Kariega rivers. The levels of mercury at sites 15 (0,216 ug ℓ^{-1}) and 16 (0,131 ug ℓ^{-1}) and nickel at site 14 (2,70 ug ℓ^{-1}) (Figure 12), were relatively higher, probably resulting from catchment leaching of metal-rich soils. It was not possible to collect sediment samples in the canalised section of the Kowie river as the small amounts of sediment which have been deposited from the fast flowing water have collected between the boulders on the bed of the canal. Mean concentrations (in ug g^{-1}) of copper (15), lead (30), zinc (96), cobalt (18), nickel (24), cadmium (0,06) and chromium (63) in surface sediments were higher than would be expected from an unpolluted river [103, 107, 108]. The high concentrations of iron (32 mg g^{-1}) and aluminium (39 mg g^{-1}) indicated the presence of clay and hydrated iron minerals. The relative concentrations of iron and aluminium and of cobalt and nickel suggest that for the most part, the trace metals are derived from the leaching of a mineralised catchment [108].

GREAT FISH RIVER

The Great Fish river is approximately 180 km by road from Port Elizabeth (Figure 12). Background information about this river is almost non-existent, probably because of its relative remoteness from a major town. The river drains a large area of the eastern cape lying between Cradock and Queenstown and supports an extensive irrigated agricultural scheme; the catchment area of the river and its tributaries is 30 500 km^2 [34]. The river mouth has not been closed in recorded history, although the suspended sediment load is particularly great. The northerly limit of the mouth is fixed by an outcrop of calcareous consolidated dune sands of the Ecca Group. The south bank is flat, muddy and low-lying with several creeks draining wide saltmarshes.

Trace metals

The higher metal levels present in water samples from the Great Fish river are partly due to the high concentration of suspended materials carried by this river. Metal concentrations in filtered and unfiltered water samples collected during two further surveys (Table 4) indicated that with the exception of iron and manganese, there were only relatively small differences in the metal concentrations in filtered and unfiltered samples. The levels of iron and manganese were considerably lower in the filtered samples, confirming that these elements were present mainly in the suspended particulate phase.

The higher copper, cadmium and mercury concentrations found in the summer (low flow) compared to winter samples (high flow) indicate an input of metal-rich seepage water to the river. Even during these periods, the overall metal concentrations are average for eastern Cape rivers [106, 107].

Metal concentrations in the Great Fish river sediments [105] indicated an unpolluted river. Slightly increased metal levels occurred in the sediment from site 18 adjacent to a small stream.

Metal concentrations in sediment and water samples from the four rivers are thus indicative of unpolluted river catchments. Elevated metal levels were found at sites upstream from the river mouths but inter-element ratios for these samples suggest that the metals are not anthropogenic but are derived from weathering of catchment rocks. Metal levels in the sediment did not vary greatly with depth.

TABLE 4: Comparison of metal concentrations (ug ℓ^{-1}) in the Great Fish River. Filtered versus unfiltered surface water.

	Element									
	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Cr	Hg
WINTER 1980										
Unfiltered										
mean	2,9	1,3	5,5	1 380	57	0,5	1,9	0,08	3,2	0,109
std.dev.	1,3	0,4	2,2	924	26	0,2	0,7	0,03	1,9	0,071
Filtered										
mean	3,3	0,7	4,1	31	11	0,2	1,4	0,05	1,2	0,072
std.dev.	1,2	0,2	1,0	35	13	0,1	0,4	0,03	0,4	0,055
t-value	-0,4	3,3	1,2	3,3	3,6	2,1	1,4	1,6	2,4	0,9
probability	0,70	0,11	0,27	0,03	0,01	0,07	0,19	0,14	0,07	0,38
SUMMER 1981										
Unfiltered										
mean	4,8	1,1	3,7	647	46	0,05	1,5	0,36	1,7	0,286
std.dev.	0,4	0,5	1,0	393	51	0,0	0,6	0,23	0,7	0,165
Filtered										
mean	3,2	0,6	2,6	6,1	4,4	0,05	1,0	0,18	1,0	0,267
std.dev.	0,3	0,2	2,5	2,0	0,8	0,0	0,4	0,10	0,5	0,148
t-value	7,2	1,7	2,2	3,6	1,8	0,0	1,7	1,6	1,9	0,2
probability	0,00	0,13	0,06	0,01	0,01	1,0	0,14	0,15	0,09	0,86

Conditions in these rivers are likely to be maintained in the absence of further urbanization or industrialization in the area, and the rivers do not need to be monitored on a routine basis.

SUNDAYS RIVER

The Sundays river enters Algoa Bay approximately 40 km east of Port Elizabeth (Figure 13). The river originates in the Karoo near Nieu Bethesda and flows over Karoo deposits (the Beaufort, the Ecca, the Table Mountain and the Witteberg geological groups). The river is dammed by the Mentz Dam near Jansenville from where a steady flow of fresh water is released. It drains the highly cultivated Sundays river valley but otherwise flows through undeveloped areas. Unlike the Swartkops river estuary, the Sundays river does not have any salt marshes or extensive mud flats.

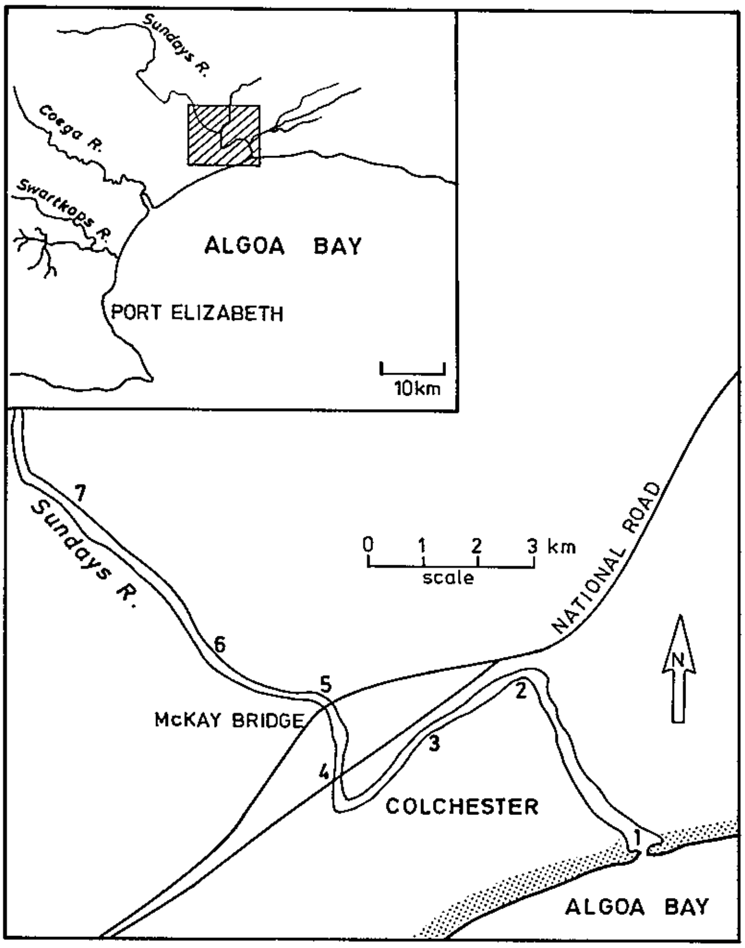

FIG. 13. SUNDAYS RIVER ESTUARY.

The estuary is channel-like for its entire course with a narrow intertidal zone and because of this, flushing of the estuary is virtually complete during floods. The water is approximately 2,5 m deep near the mouth but this increases gradually to a maximum of 5 m on the first bend of the lower reaches. It then becomes gradually more shallow and is 2,5 m deep at the limit of tidal influence approximately 20 km from the mouth. The estuary is about 200 m wide at its widest point near the mouth, from where it becomes progressively narrower to about 20 m at the head of the estuary.

This estuary is virtually unpolluted with respect to industry but it flows through an extensive orange-farming area and pollutants from this source can be expected. It should be possible, therefore, to assess the impact of agricultural activities up river on the estuary. The aim of these preliminary surveys carried out in August 1979 and August 1981 [99] was to determine the current metal levels in the sediments and water of the Sundays river. The data obtained will serve as a baseline for future monitoring surveys should urban development or industrialisation be planned for this region of the South African coast.

Trace metals

The metal concentrations in the water were generally low with slight but distinct increases of copper, lead, zinc, chromium and mercury in samples collected near the river mouth. These may be a reflection of the proximity of the town of Colchester. Higher concentrations of iron, manganese and chromium in unfiltered samples implies that these elements are present mainly in association with the particulate phase.

Metal concentrations in surface sediments of copper, lead, zinc, cobalt, nickel and chromium were elevated at all sites except in the river mouth. Analyses of core samples show that these elements are interrelated consistently with iron which suggests that they are derived from weathering of locally mineralized catchment rocks [108].

The Sundays river is at present unpolluted with respect to metals and unless further urban, agricultural or industrial developments take place it should not be necessary to monitor the area.

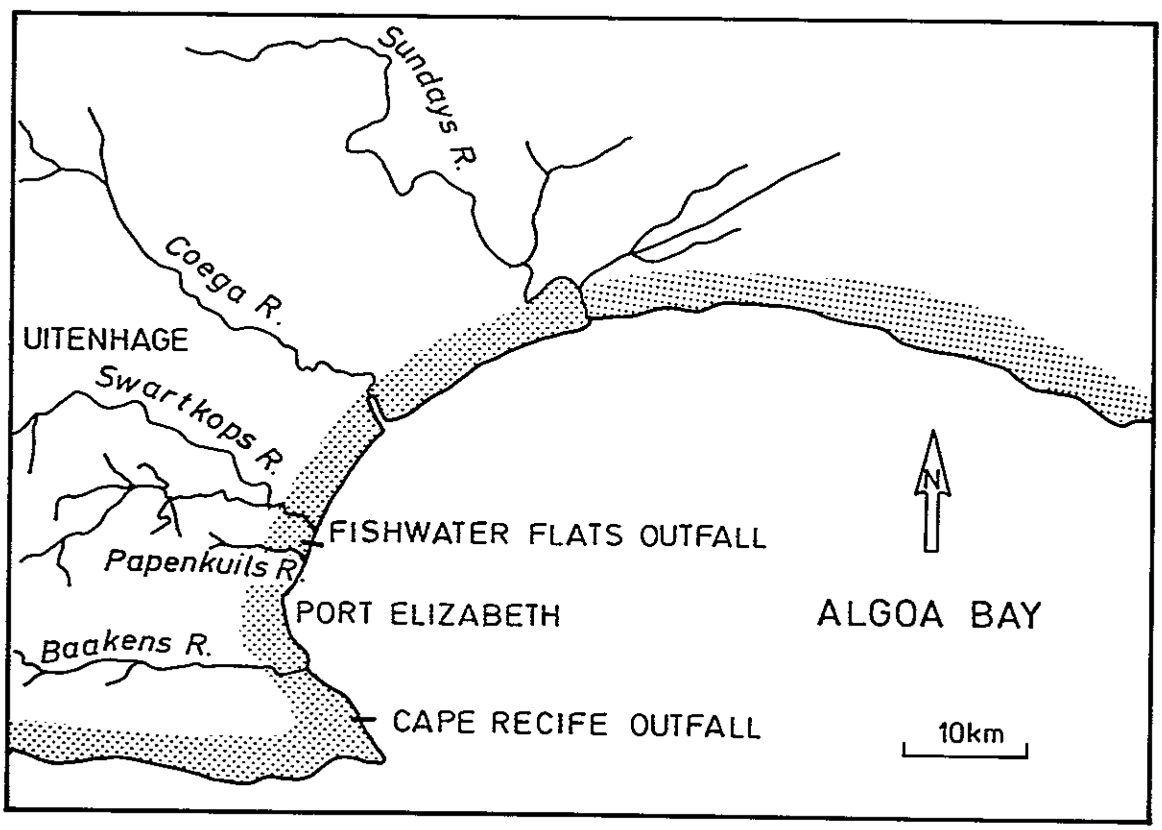

FIG. 14. LOCATION OF STUDY AREAS.

ALGOA BAY SEWAGE OUTFALLS (Figure 14)

Algoa Bay, bounded by Cape Recife and Cape Padrone on the southern coast of South Africa, is in the transitional zone for marine fauna between the warmer tropics and the colder temperate zone. It is in an important ecological position, and comprises open sandy beaches, rocky capes and several small islands. St Croix Island is one of the few breeding grounds of the Jackass penguin [85] and considerable importance must be attached to the preservation of this ecosystem. The two major rivers flowing into the bay are the Sundays and Swartkops rivers. The Coega river valley is utilised for the production of sea-derived salt for human consumption, and the river water is prevented from flowing into the evaporation pans by earth wall impoundments. The Baakens river flows into Algoa Bay in the dock area of Port Elizabeth; the volume of water is relatively small except during periods of flooding. Treated industrial and urban effluents from the towns of Uitenhage and Despatch and the Port Elizabeth municipal area are introduced to the bay via the Swartkops and Papenkuils rivers and the Fishwater Flats sewage outfall. Treated urban sewage also enters the bay via the Cape Recife outfall.

The sewage works at Cape Recife (Figure 15) receives from 8 000 to 32 000 $m^3\ d^{-1}$ of raw domestic sewage and has an average output of 12 000 $m^3\ d^{-1}$. Some of the water is lost by evaporation and a further volume is used to water the grounds of a golf course and the university campus, so that the average input to the bay via the Cape Recife outfall is 8 000 $m^3\ d^{-1}$. This input of enriched water causes considerable macro-algal (seaweed) production downshore, much of which is washed up onto the beach to form a driftline [43].

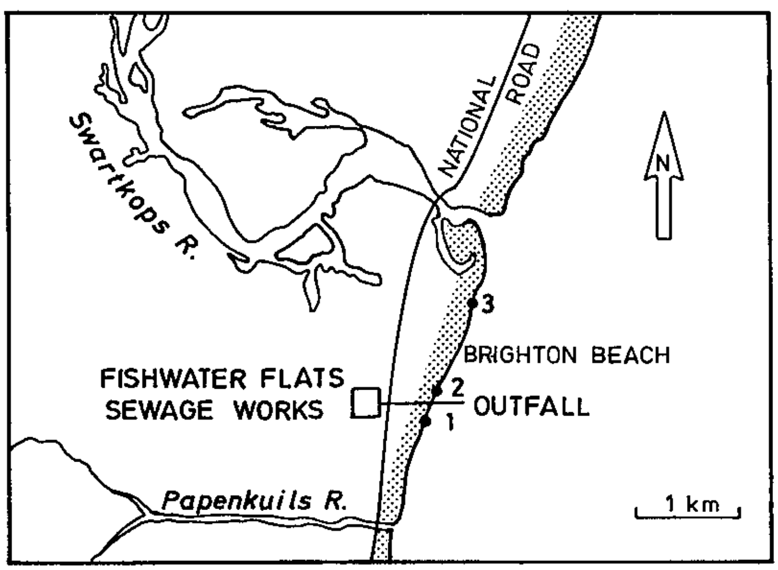

FIG. 15. FISHWATER FLATS OUTFALL.

The Fishwater Flats sewage works processes from 50 000 to 55 000 $m^3\ d^{-1}$ of mixed domestic and industrial wastewater. About 20 000 $m^3\ d^{-1}$ of mainly industrial waste is discharged into the Papenkuils river [97], while approximately 30 000 $m^3\ d^{-1}$ of processed domestic sewage is discharged through the pier pipeline near Brighton beach.

The nutrient, heavy metal and bacterial enrichment in these two areas (Figure 14), and their effects on the biota, with particular reference to macrofauna and meiofauna, have been investigated [43].

Bacteriology

The effluent discharged through the pier pipeline does not appear to impact with the adjacent beaches as is shown by the high salinities (35 0/00) and low *E. coli* counts (< 100 per 100 ml) at sites 1 and 2 (Figure 15) adjacent to the outfall. The nutrient concentrations [43] at sites 1 and 2 were normal for unpolluted beaches [77].

At Cape Recife nutrient concentrations [43] and *E Coli I* counts (960 per 100 ml) were higher at sites 4 and 6 near the outfall but were approximately at background levels 100 m north of the outfall (station 7), which was the direction in which the current was flowing. The salinity was 17 0/00 at station 6 and 34 0/00 at station 7.

Redox potential levels in the beach sediment close to the Cape Recife and Fishwater Flats outfalls were high (> +400 mV)[43], indicating oxygenated sediments. The concentration of metals in the water samples near both outfalls were low except for mercury which was slightly elevated at station 6 (0,092 ug ℓ^{-1})(Figure 16).

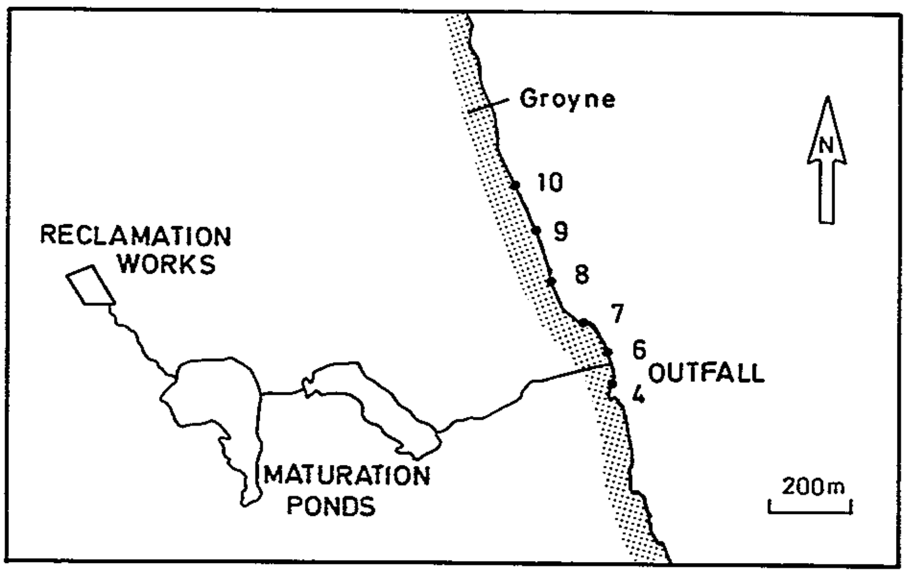

FIG.16. CAPE RECIFE OUTFALL.

Trace metals

Metal levels in sediments were slightly elevated near the Cape Recife outfall but approximated normal background levels within 200 m of the outfall (station 8). The metal levels in sediments near the Fishwater Flats outfall were similar to background levels [77].

The metal concentrations in *Perna perna* (brown mussels) collected at Cape Recife outfall were not significantly elevated compared with the concentrations in the same species collected elsewhere in Algoa Bay [94]. This suggests that the outfall is likely to have only a small sphere of influence on the rocky shore biota, particularly with regard to metal contamination.

Benthic meiofauna

In the meiofauna counts, nematode worms, harpacticoid copepods and turbellarian flatworms were dominant. There was a clear increase in numbers downshore from Fishwater Flats outfall which corresponded with the increase in nutrient levels reaching this beach. This increase in total numbers which included all taxonomic groups was five-fold from site 1 to 3 (Figure 15). This indicates that due to the northward inshore current and wave action, the effluent is swept inshore causing enrichment of beaches for at least 1 km north of the outlet. This enrichment does not seem to have had any adverse effects on the beach. Although high at site 3 meiofauna numbers are within the range recorded elsewhere along the south eastern Cape coast [72]. It is known that exposed beaches can tolerate a reasonable amount of organic loading without disturbing the equilibrium or developing adverse conditions providing oxygen concentrations remain high [74]. This appears to be the case here, where all that has happened has been a shift in meiofauna abundance to higher levels without the development of anaerobic conditions. Particularly important in this respect is the increase in harpacticoid copepods which are generally the most sensitive group to oxygen stress [58, 84].

Macrofauna

Fifty-three species of macrofauna were recorded at Cape Recife during the survey [43]. The area immediately adjacent to the treated sewage outfall was found to be devoid of macrofauna due to the freshwater input and the high nutrient levels especially of ammonia which is toxic. For example, Wickins [110] has shown that a level of > 5 umol ℓ^{-1} NH3-N adversely affects prawn survival and growth. The greatest numbers of macrofauna (372 m^{-2}) were recorded at site 6 (Figure 16) immediately downshore of the outfall although the smallest number of species was found at this site. Three species, *Pseudactinia varia*, *Chthamalus dentatus* and *Siphonaria capensis* not only survived the variable salinities and high nutrient levels but actually flourished under these conditions of low competition for the plentiful food supply; they may be considered as typical "indicator" species or polysaprobes [59]. Rocks were covered in blue-green algae at this site upon which *S. capensis* appears to thrive [60].

However, 100 m downshore (site 7) most of the effluent had been diluted by seawater thus enabling more species to survive at this distance from the outfall. Beyond 300 m down-current numbers and diversity increased to normal levels. The results of the survey indicated that the effect of the effluent tends to be one of biological enrichment.

PAPENKUILS RIVER

The Papenkuils river, with a catchment area of approximately 600 km^2, enters Algoa Bay 5 km north of Port Elizabeth on the south eastern coast of South Africa. For the last 3 km of its course, the river flows through the industrial areas of North End and Deal Party and for this entire region the river bed and banks have been canalised with concrete. The urban areas of Gelvandale and Algoa Park, together with the municipal rubbish dump, are situated at the head of the river, while industrial effluents contribute to the flow in the region of the mouth.

The early establishment of local industry in the area earned the river the appropriate title of "Smelly Creek" but conditions improved after canalisation in 1965. However, the increase in the number and diversity of industrial concerns in the area and the introduction of a 20 000 m^3 d^{-1} outfall at the river mouth in 1976 have caused considerable environmental stress in the system. Although every effort is made to monitor and control the quality of effluent entering the river, this is an almost impossible task and the final 4 km of the river are subject to a high pollutant load which has led to the complete loss of macrofauna.

A preliminary survey was undertaken in November 1980 [97]. The location of sampling stations is shown in Figure 17. The physico-chemical, nutrient and faecal *E. coli* I results are listed in Table 5.

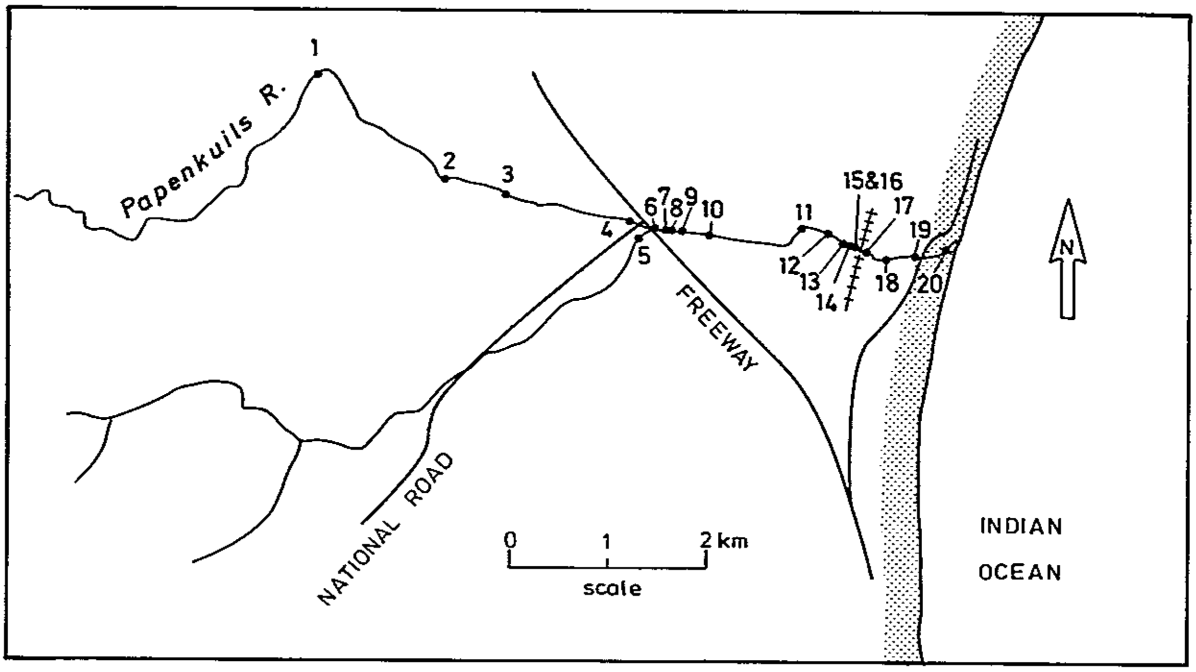

FIG. 17. PAPENKUILS RIVER, PORT ELIZABETH.

General conditions

Temperatures were stable at approximately 21 °C with the exception of station 8 where temperatures greater than 10 °C above local ambient were recorded. The effluents at stations 7 and 12 were alkaline, being pH 8,9 and pH 8,8 respectively.

Bacteriology (Table 5)

Faecal *E. coli I* concentrations were generally low (< 9 000 per 100 ml) upstream of the railway bridge (stations 1 - 14). However, an exceptionally high count of 4,76 million per 100 ml was obtained at the railway bridge (station 15) and this was accompanied by a dissolved oxygen concentration of 5,4 mg ℓ^{-1}. Effluent from the Fishwater Flats sewage works, which enters the river at station 17, was also low in dissolved oxygen (3,0 mg ℓ^{-1}) and had an elevated faecal *E. coli I* count of 0,69 million per 100 ml. Faecal *E. coli I* counts remained greater than 0,1 million per 100 ml between the effluent input at station 17 and the mouth of the river and a significant drop in dissolved oxygen concentrations was also recorded for this region. The source of the exceptionally high *E. coli I* levels found at station 15 was found to be a double stormwater drain with a flow of about 29 $m^3\ d^{-1}$, less than 0.2% of the main effluent outfall at station 17 which delivers from 19 000 to 20 000 $m^3\ d^{-1}$. However, the daily *E. coli I* contribution from stations 15 (1,4 million faecal *E. coli I* per day) was about 1% that from station 17 (140 million faecal *E. coli I* per day).

The *E. coli I* level recorded at the river mouth during November 1980 was 0,225 million per 100 ml while in September 1979 and 1980 counts of 0,2 million and 0,12 million per 100 ml respectively were obtained. It is worth noting that the Brighton beach bathing area is only about 3 km downshore of the Papenkuils river mouth and that an inshore current flows in the direction of this beach. There is also another effluent discharge from the Fishwater Flats plant through a pipe under the pier at Brighton beach.

Counts of $<$ 100 and 14 per 100 ml were recorded for Brighton beach in September 1979 and 1980 respectively which are well under the "recommended" limit of 100 per 100 ml for *E. coli I* in bathing water. Therefore there must have been considerable dilution, dispersion and mortality of the faecal *E. coli I* in the area between Papenkuils river and Brighton beach. Nevertheless this could be affected significantly by current patterns and the situation must be monitored to ensure that these levels remain low.

Chemistry

Ammonia levels remained below 7 umol ℓ^{-1} in all samples except those collected from stations 1, 4, 5 and 11 (Table 5). These stations were situated in the main stream rather than in effluent channels. Nitrite levels were generally low above station 15 but increased markedly towards the mouth in both main stream and effluent channel samples. Nitrate concentrations showed a similar trend although concentration fluctuations between samples were greater, particularly in the upper reaches of the river. Phosphate concentrations also increased in the lower reaches of the river, the highest value being recorded at station 18 just below the railway bridge. A three-fold increase in phosphate concentrations was observed between the effluent outfall at station 17 which is the main source of phosphate in the river, and station 18 (700 umol ℓ^{-1}). This result was surprising and lead to the suggestion that there was an accumulation of sludge downstream of the outfall and that bacterial degradation of this sludge released phosphate into the water column. Phosphate and total phosphorus concentrations decreased between station 18 and the mouth of the river.

TABLE 5: Nutrients and faecal *E. coli* concentrations in water from Papenkuils river, Port Elizabeth [97]

Station	Oxygen $mg\ell^{-1}$	Ammonia $ug\ell^{-1}$	Nitrate $ug\ell^{-1}$	Phosphate $mg\ell^{-1}$	Total Phosphorus $mg\ell^{-1}$	*E. coli* /100m
1	6,4	540	470	0,30	0,45	1400
2*	5,0	< 1	13	0,30	0,60	< 10
3*	7,8	2	350	0,05	0,25	40
4*	9,8	100	17	0,15	0,60	20
5*	6,5	160	720	0,50	0,80	2000
6#	9,2	< 1	100	8,0	8,4	7000
7*	8,0	< 1	49	0,50	0,80	190
8#	9,0	29	790	0,05	0,30	50
9#	8,2	< 1	1500	0,90	3,4	**
10#	6,4	60	71	3,5	4,3	4200
11*	4,5	430	250	0,60	1,0	50
12#	7,8	3	3080	2,0	2,8	**
13#	10,0	23	2200	0,70	1,0	9000
14#	10,4	33	2400	2,2	2,7	600
15#	5,4	33	120	9,5	11	4800000
16*	9,6	53	1500	0,90	1,1	2000
17#	3,0	27	2100	6,1	7,8	690000
18*	6,0	30	1800	22	30	130000
19*	4,2	37	1700	11	11	130000
20*	5,4	41	1600	5,0	6,8	230000

\# Drain sample
* Main stream sample
** Interference from non-lactose fermenti

Both nitrate and ammonia concentrations were relatively low in all samples collected during this survey. The maximum nitrate concentration recorded there was 220 umol NO3 N ℓ^{-1} which is well below the WHO recommended limit of 800 umol NO3 N ℓ^{-1} for drinking water [81]. These low nitrate levels may be explained by the fact that at the Fishwater Flats sewage treatment plant, the aerators were switched off routinely and anaerobic denitrification with the consequent lowering of nitrate levels can occur (J. Vail pers. comm.). Furthermore, as a completely anaerobic zone is required for the bacterial [33] or chemical removal of phosphate [73], and as the Fishwater Flats plant is not designed for biological phosphate removal this would explain the high phosphate and total phosphorous levels recorded during this survey.

Trace metals

The concentrations of ten elements in water samples are listed in Table 6. Metal concentrations were elevated along the entire length of the river. In the canalised section of the river the introduction of large amounts of copper, lead, zinc and nickel via drains at stations 12 - 15 and 17 is partly responsible for the absence of invertebrate macrofauna. Zinc concentrations were more than 500 times greater than the highest concentration of 8 ug ℓ^{-1} found in the nearby Swartkops river [100] while lead and nickel concentrations were more than 50 times higher. With the exception of nickel, metal concentrations in the effluent entering the river at station 17 were not elevated for this type of medium. However, nickel concentrations in this effluent were high, as were those in all the remaining samples collected downstream.

TABLE 6: Metal concentrations in water from the Papenkuils River, Port Elizabeth

(concentration ug ℓ^{-1})

Station	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Cr	Hg
1*	5	3	169	950	790	<0,1	2	0,14	1	0,084
2*	1	1	191	1260	320	0,7	2	0,10	1	0,009
3*	19	69	184	24400	290	6,1	7	0,36	35	0,032
4*	11	7	31	2800	650	1,6	3	0,16	3	0,032
5*	6	20	28	560	41	<0,1	5	0,13	4	0,029
6#	18	7	470	730	510	0,7	4	0,49	83	0,009
7*	4	16	38	540	41	<0,1	6	0,02	5	0,016
8#	13	5	17	360	208	0,2	3	0,17	1	0,082
9#	9	7	690	440	33	0,1	2	0,17	14	0,026
10#	9	10	75	1160	82	0,3	2	0,16	4	0,021
11*	3	9	29	850	185	0,1	4	0,08	15	0,035
12#	17	33	62	160	14	<0,1	2	0,57	6	0,153
13#	67	212	2190	1480	87	1,6	13	0,88	30	0,068
14#	42	326	3600	880	78	1,4	16	0,72	18	0,026
15#	26	104	800	1780	223	1,2	8	0,71	22	0,015
16*	20	32	56	1340	191	0,8	5	0,15	6	1,047
17#	3	8	144	550	224	1,1	106	0,03	8	0,032
18*	2	7	150	230	221	0,8	106	0,02	5	0,044
19*	9	26	390	440	169	0,8	44	0,18	7	0,126
20*	11	41	430	680	170	0,8	52	0,22	9	0,215

* Main stream sample
\# Drain sample

Sediment samples were collected from the same locations as the water samples with the exception of stations 8, 11 and 16 where no sediment was available. The ash contents of the dry samples varied between 37,9 and 97,2% (Table 7). No recognisable pattern in this variation could be discerned but in the lower regions of the canalized zone the loss in mass of these samples could be attributed almost entirely to the oxidation of sewage sludge.

Metal concentrations in sediment samples are also shown in Table 7. These concentrations are elevated along the entire length of the river, but notably between stations 5 and 17. Exceptionally high concentrations of zinc (2%) and chromium (4%) were recorded for station 6, these being the highest found in the sediments of any of the southeastern Cape rivers so far studied. In general, the concentrations of copper, zinc, lead, cadmium and mercury are considerably higher than those determined for the nearby Swartkops river [100]. Sedimentation occurs to a greater extent in the lower reaches of the Papenkuils river, below station 17 and the results presented here indicate that metals are adsorbed onto and coprecipitated with this sediment. Therefore, metals which are currently being introduced into this river will be present for a considerable period of time and could represent a long-term pollution threat to the biota.

TABLE 7: Metal concentrations in sediment from the Papenkuils River, Port Elizabeth

(concentration ugg^{-1})

Station	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Cr	Hg	% Ash
1*	9	150	137	95 800	896	1,5	6	0,14	42	0,26	82,5
2*	1	5	7	1 150	7	0,3	1	0,19	7	0,04	97,1
3*	8	31	61	10 100	31	3,0	5	0,16	17	0,07	97,2
4*	16	36	86	17 900	91	4,1	9	0,24	33	0,08	93,9
5*	107	290	900	21 700	202	5,4	25	1,30	130	0,68	38,0
6#	740	360	22 400	27 500	253	4,9	96	15,00	40 000	2,00	37,9
7*	150	250	755	16 000	68	4,4	23	1,40	210	0,62	83,3
8#					No Sample						
9#	64	2400	436	25 900	207	2,7	12	0,47	60	0,08	96,8
10#	205	140	1 640	13 800	178	6,0	40	3,40	830	0,14	66,7
11*					No Sample						
12#	109	290	890	18 800	465	5,9	26	1,10	200	0,56	81,9
13#	172	1200	162	15 400	443	5,8	32	1,70	330	0,26	80,0
14#	87	420	1 390	7 440	97	2,4	20	1,40	110	1,80	85,5
15#	48	88	202	1 400	126	3,5	13	0,27	46	0,24	94,1
16*					No Sample						
17#	155	450	1 820	9 090	162	2,9	68	2,00	320	3,47	85,6
18*	7	33	95	2 240	24	0,1	2	0,07	14	0,12	35,3
19*	3	8	20	2 040	17	0,1	1	0,06	5	0,03	86,0
20*	2	10	9	1 980	23	0,1	1	0,06	10	0,01	83,9

\# Drain sample
* Main stream sample

Urban effluent and run-off usually contain a high pollutant load and the Papenkuils river is an example where this is especially true.

Nutrient input is relatively small, with the exception of that from the Fishwater Flats outfall near the mouth (station 17). However, there are obviously considerable quantities of different metals entering the river via the many drains which are to be found both in and above the canalized section.

Industrial and urban developments are abundant within the comparatively small catchment and, although every effort is made by local authorities to limit misuse of the river, nevertheless significant pollution is occurring along its entire length. All industrial effluent should be processed at the Fishwater Flats plant.

ALGOA BAY TRACE METALS

A variety of molluscs were collected from various beach and rocky sites (Figure 14) as their ability to accumulate metals in their tissues is a characteristic which can sometimes be used to indicate areas of pollution. Oysters growing in the mouth of Papenkuils river have accumulated zinc, copper, lead and chromium [97]. Specimens of *Crassostrea margaritacea* growing at the mouth of the Swartkops river were also found to contain considerably more zinc, copper and lead than had been determined for the same species growing at other locations on the

South African coast [100]. Again the results of the survey of this river indicate the presence of four areas of contamination by metals [100]. Oysters collected at Woody Cape (site 68) did not contain elevated metal concentrations. The relative levels of metals in molluscs from Mossel Bay, St Francis Bay and Algoa Bay were indicated clearly by the distribution of metals in *C.margaritacea* [109].

Concentrations of zinc, copper and lead, three commonly occurring anthropogenic metals in the southeastern Cape are between 5 and 10 times greater in *C. margaritacea* from the Algoa Bay industrial area than from the other areas.

Copper, lead, zinc and chromium concentrations in *Perna perna* from the mouth of the Papenkuils river were high, as might be expected. However, the differences in concentrations between the various samples were not as great as in the case of the oysters and it was concluded that, for the most part, Algoa Bay was not polluted by metals. It has already been noted that metal accumulation is generally not as great in mussels as in oysters [32], so that this species is perhaps less useful as an indicator of metal pollution.

Metal concentrations in seven *Patella* species differed between the species and were also variable within the same species from different sites [109]. For example, cadmium concentrations were generally higher in *P. longicosta* than they were in *P. oculus*. In most cases variations in metal concentrations for a single species did not seem to be related to metal concentrations in the water at that site. For example, concentrations in *P. oculus* from the mouth of the Papenkuils river were not elevated, as might be expected from the data obtained for both oysters and mussels. The problem here may be that *Patella* spp are herbivorous grazers so that metal accumulation is more likely to be related to the metal content of their substrate.

Specimens of *Donax serra* and *Bullia rhodostoma* were also collected during the beach surveys. These species are included in the South African Marine Pollution Monitoring Programme [20] but few comparative data are available. The data presented here are variable but in view of the results obtained for sediment and water analyses, it must be concluded that the metal concentrations found in these two sandy beach molluscs were normal.

In summary, Algoa Bay is relatively unpolluted with respect to metals. Five sites of metal input have been found. These were Cape Recife sewer outfall, the manganese ore dumps at Kings beach, Papenkuils river, Swartkops river and Coega river. The Papenkuils river had by far the heaviest load. A detailed survey has revealed that high concentrations of nickel, lead, zinc, copper, chromium and mercury are present in sediment and water samples [97]. Macrofauna was absent in the river but some molluscs living near the mouth had anomalously high tissue metal concentrations even though this area is subjected to a strong tidal sweep. Control measures are definitely required to improve the condition of this river and minimise further pollutant input to Algoa Bay.

The present level of industrialisation and urbanisation is not causing significant stress to the ecosystem, probably because there is considerable water movement. However, further industrialisation or urbanisation must be planned carefully in order to preserve the relatively unpolluted state of Algoa Bay.

GAMTOOS RIVER

The Gamtoos river flows into St Francis Bay 55 km west of Port Elizabeth and 13 km northeast of Jeffreys Bay (Figure 18). The Gamtoos river, together with its two main tributaries, drains the central part of the Karoo, but the 34 500 km^2 catchment is an area of low rainfall and both droughts and floods occur at intervals [34].

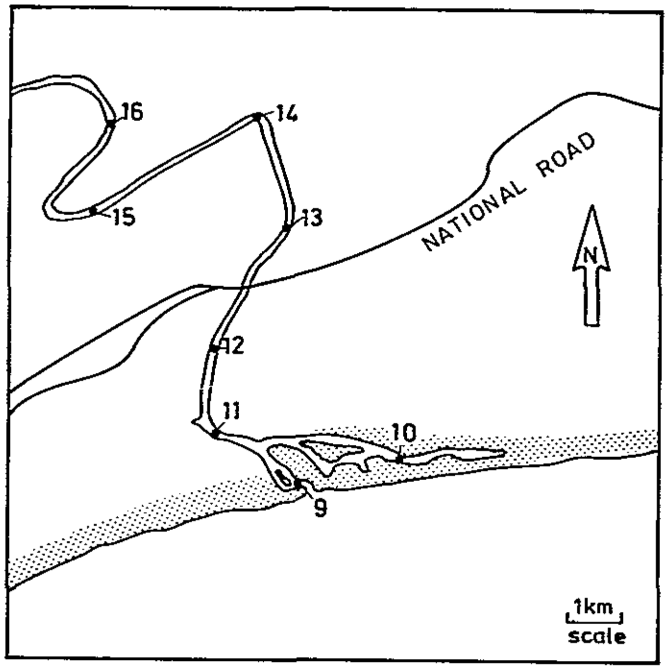

FIG. 18. SAMPLING IN THE GAMTOOS RIVER.

The eastern banks of the river are steep and a broad flood plain stretches from the western bank to steep banks more than 2 km away from the river. The length of the estuary is very variable depending on the rains but the river is often saline at the coastal road bridge about 7 km from the mouth [34]. The river mouth itself changes position frequently as there are no rocks on the coast to anchor it and there is substantial re-working of the eolean drift sand in the mouth region.

The aim of this preliminary survey undertaken during August 1979 was to determine the current metal levels in the sediment and water of this estuary. The data obtained will serve as a baseline for future monitoring surveys should urban development or industrialization be planned for this region of the South African coast.

Concentrations of major and minor elements in Gamtoos river water indicate that there is a significant marine influence up to and including site 16 (Figure 18). Although the position of the Gamtoos river mouth changes there is no record of it being completely closed for any prolonged period so that the water level in this estuary is determined mainly by the tide. Navigation by boat was impossible at locations upstream of site 15 (Figure 18) and hypersaline conditions could occur in this region of the river because of the warming influence of shallow sandbanks together with increased evaporation.

Trace metals

Trace metal levels in the Gamtoos river water [104] were average for eastern Cape rivers [100 - 103], with the exception of those found at site 10 (Figure 18) near the mouth of the estuary. Here, many metals were present at slightly higher concentrations and this was probably due to local input and the entrainment of a relatively high suspended solids fraction in the water column.

Generally, metal levels in surface sediments from the Gamtoos river were significantly higher than those found in the Kromme river [106]. The sample from site 10 was particularly interesting in that it contained the highest levels of copper, zinc, iron and manganese (21, 61, 28 600, 470 ug g^{-1} respectively) encountered during this survey. The reason for these higher concentrations may be due simply to a variation in catchment geochemistry. However there is also the possibility that these metals are being introduced to the river as a result of the extensive utilisation of the valley and that they are precipitating from the water column in this relatively calm estuary.

Overall metal levels in the Gamtoos river are slightly higher than those in the Kromme river [104] although no other significant source of metals was found. In the absence of urbanization or industrialization in these areas, it may be assumed that metals do not present a hazard in these estuarine environments.

KROMME RIVER

The two major rivers which flow into the bay are the Kromme and Gamtoos rivers, the mouths of which are open to the sea (Figure 19). The physical characteristics and general ecology have been described by Day [34] and a detailed community analysis of the estuary has been compiled from published and unpublished data [42].

The Kromme river has its origin in the Tsitsikama Mountains in the Blue-liliesbush Forest Reserve. The main tributary is the Dwars river which flows into the Kromme river above the Churchill Dam, approximately 43 km from the river mouth. About 14 km from the mouth, the river descends in a series of rapids which mark the limit of seawater penetration. Below these rapids the main tributary is the Geelhoutboom river which flows into the estuary about 9 km from the mouth. Other tributaries include the Klein, Boskloof, Sand and Brakfontein rivers which flow into the Kromme river 11, 5, 2 and 1 km from the mouth respectively.

The inflow of fresh water is regulated by the Churchill Dam. During the dry season (December - March) the sluices are kept closed with the result that little freshwater enters the estuary and a reversed salinity gradient can occur; this situation is then reversed in the rainy season [44] (April - November).

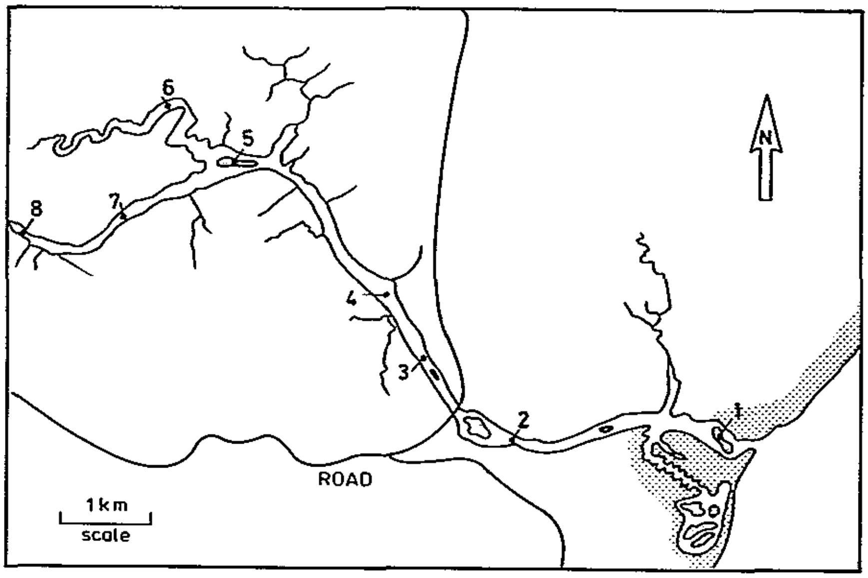

FIG. 19. SAMPLING SITES IN THE KROMME RIVER.

The estuary is bordered by rocky cliffs on both sides from the upper limits to the confluence with the Klein river. It widens downstream, particularly on the south bank of the river, into a broad flood plain. The north and south banks of the upper and middle reaches are overgrown with dense bush. Salt marshes occur on the south bank of the middle reaches and on the north bank of the lower reaches of the estuary. The substrate at the mouth area varies between medium- and coarse-grained sand with some silt. In the lower and middle reaches, mud and silt are encountered whereas the substrate of the upper reaches consists of a course silty sand and stones.

The estuary is one of the few relatively unspoilt estuaries in the eastern Cape. There is no industrial development along its banks and effluent disposal into estuarine waters is minimal. A marina, consisting of a network of canals with waterfront housing and mooring facilities for up to ten yachts, has been developed on the west bank of the estuary near the mouth. The results of two detailed surveys [5] indicate the marina canal system does not have an adverse effect on the ecology of the Kromme estuary.

Trace metals

The trace element concentrations in the water were generally low and there was no indication of contamination by these elements. This was to be expected as there was no industrialisation and very little urbanization in this area of the catchment. The marina complex at the mouth of the estuary apparently had no effect on trace metal input to the estuary.

Metal concentrations in the sediments were average for Eastern Cape rivers with the exception of those found at two sites. Chromium, cobalt and nickel (297, 7,8 and 15,6 ug g^{-1} respectively) were particularly elevated at site 6 in the Geelhoutboom river and also chromium (124 ug g^{-1}) at site 5 (Figure 19) on the northern side of a small island situated mid-stream at the confluence of the two rivers. It is likely that suspended material from the tributary enters the main river and is deposited on this island. Elevated levels of copper, lead and zinc were also encountered in the site 6 sample (12, 36 and 59 ug g^{-1} respectively). These metals were also elevated in a core sample taken at this site which implies that there has been continuous deposition of metal-rich sediment and that the metals are probably derived from weathering of mineralised rocks in the catchment. The extent of this metal-rich area in the Geelhoutboom catchment should be determined as it is possible that these metals could be remobilized during floods and may then affect the estuary to a greater extent.

Trace toxic metals were introduced into the Kromme river via the Geelhoutboom tributary as a result of the weathering of a local mineralised sequence. The effects of this input were distinguishable as far as the midstream island at the confluence of the two rivers. No anomalous metal levels are easily discernible downstream of this site.

In summary, the distribution of metals in water, surface sediments and sediment core samples from the Kromme and Gamtoos rivers indicated that both rivers drain essentially unpolluted catchments. However, unusually high metal inputs were found at isolated sites in each river [106].

ST FRANCIS BAY

St Francis Bay is an extensive, south-facing bay bounded by Cape St Francis to the south west and Cape Recife to the north east (Figure 20).

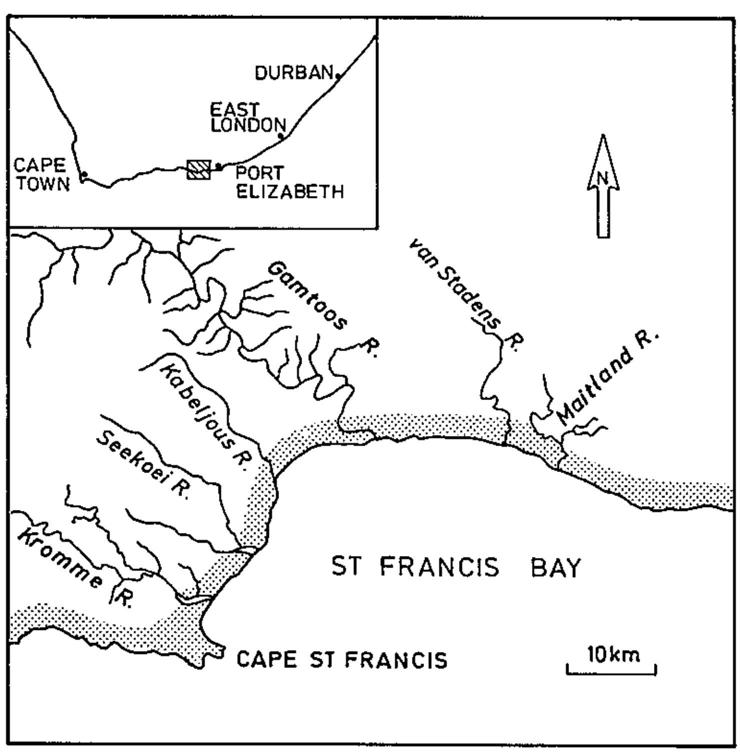

FIG. 20. LOCATION OF STUDY AREAS.

The town of Jeffreys Bay is the major urban development on the St Francis Bay coast but a number of small holiday resorts are to be found, often in the vicinity of the river mouths. A marina has been constructed on the west bank of the Kromme river near the mouth. The surrounding inland area supports a considerable variety of farming and agricultural activities.

Metal concentrations in the surface water from St Francis Bay were generally lower than those determined for Mossel Bay and the south-western part of Algoa Bay [109], as might be expected. However, the samples collected near the mouths of the Gamtoos and van Stadens rivers contained slightly elevated levels of several metals. The results obtained were very similar to those reported by Orren [77].

Metal concentrations in surface sediment were generally low, as might be expected for high-energy coastal environments.

There was some evidence of contamination by metals in the area of St Francis Bay between the mouths of the Kabeljous and Gamtoos rivers. High chromium concentrations (mean 205 ug g^{-1}) were determined in these samples but there were no corresponding increases in the concentrations of other elements particularly of cobalt and iron, which would be expected if this anomaly was of geochemical origin [108]. Metal concentrations in the sample from the mouth of the Gamtoos river were elevated (about 5 fold) relative to the levels determined in the other coastal samples. It is thought that these metals are derived from a combination of catchment weathering and also run-off from cultivated land which had been treated with fertilisers and seed dressings [106]. Metal concentrations in a variety of marine organisms from rocky shore sites and sandy beaches have been determined [93]. Oysters, in particular, have been found to accumulate very high levels if they are exposed to pollution [106] and *Crassostrea margaritacea* has been used for this purpose in Algoa Bay [100]. The concentrations found in this species growing in St Francis Bay were all low [109] suggesting the bay as a whole was not polluted significantly with metals. Low metal concentrations in brown mussel *Perna perna* collected from several sites in the bay confirmed that there was no indication of accumulation.

St Francis Bay [109] is presently unpolluted with respect to metals, the levels of which are generally lower than those found in equivalent samples from Algoa Bay. There is some evidence of metals input into the area between Kabeljous and Gamtoos rivers [106] where sediment chromium concentrations were considerably higher than those found in other parts of St Francis Bay. The source of this metal is unlikely to be entirely geochemical but may also be derived from the leaching of cultivated land. Although the chromium levels found to be about an order of magnitude above background, they do not represent a threat to the coastal environment.

MOSSEL BAY

A preliminary pollution survey of Mossel Bay and surroundings was undertaken in 1978 [50]. The follow-up survey in December 1980 [46] was concentrated around the discharge at Voorbaai and also on a sewage outfall, which was not included in the previous study (Figure 21).

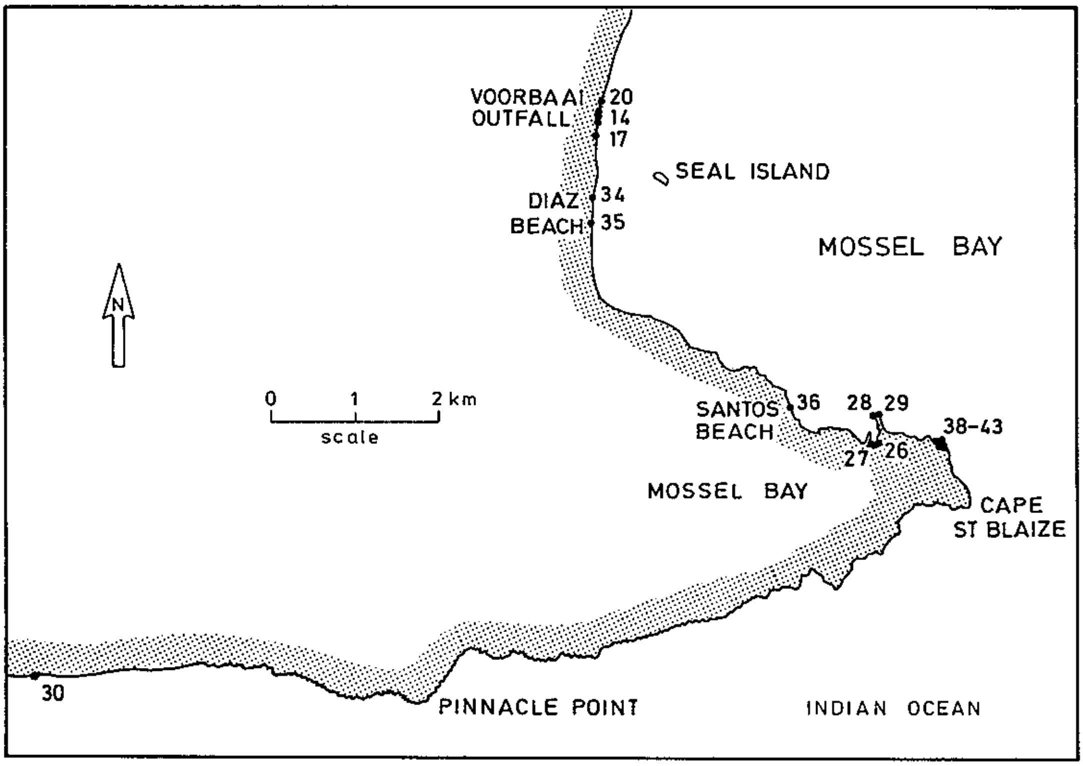

FIG. 21 MOSSEL BAY STATION POSITIONS

General chemistry and benthic meiofauna

The chemistry of the water and sediments of the beach at Voorbaai had changed very little in the fifteen months since the previous survey. Evidence of the factory discharge could be found on both sides of the outfall but was not wide-spread. The DO (dissolved oxygen) in the interstitial water 200 m from the discharge was still less than 5 $mg\ell^{-1}$ and the OA (oxygen absorbed from alkaline permanganate) values were slightly elevated but the nutrient levels were normal. There was no evidence of trace metal pollution from the outfall. Numbers of the three dominant taxa; nematodes, harpacticoid copepods and flatworms, were significantly lower on this occasion. However there was no evidence that this was a permanent trend and is probably the result of seasonal differences in the activity of the canning factory.

There was little observable effect of the sewage discharge on the chemistry of the seawater. However there may be evidence of some sewage pollution on nearby beaches. These should be monitored regularly in view of expected development.

EERSTE RIVER ESTUARY

The Eerste river runs from the Stellenbosch area through the Cape Flats and discharges east of Macassar township on the northern shore of False Bay. The northeastern corner of False Bay is considered to be a potential pollution impact area. Under certain oceanographic conditions current eddies exist which can concentrate pollutants as well as natural marine components in the area off Strand and Gordon's Bay [3].

The Eerste river receives treated sewage effluents from works at Stellenbosch and at Macassar (effluent from Somerset West and Strand) just upstream of the mouth. Effluents from various industries including wineries are also discharged at various times. After passing the sewage works, the river runs on to the wide (300 m) beach from between the sand dunes, it turns sharp west and flows for 300 m before turning south and flowing into the sea over the sand in a 5 m wide stream. During the westerly flow the channel is about 70 m wide and forms something of a lagoon (Figure 22).

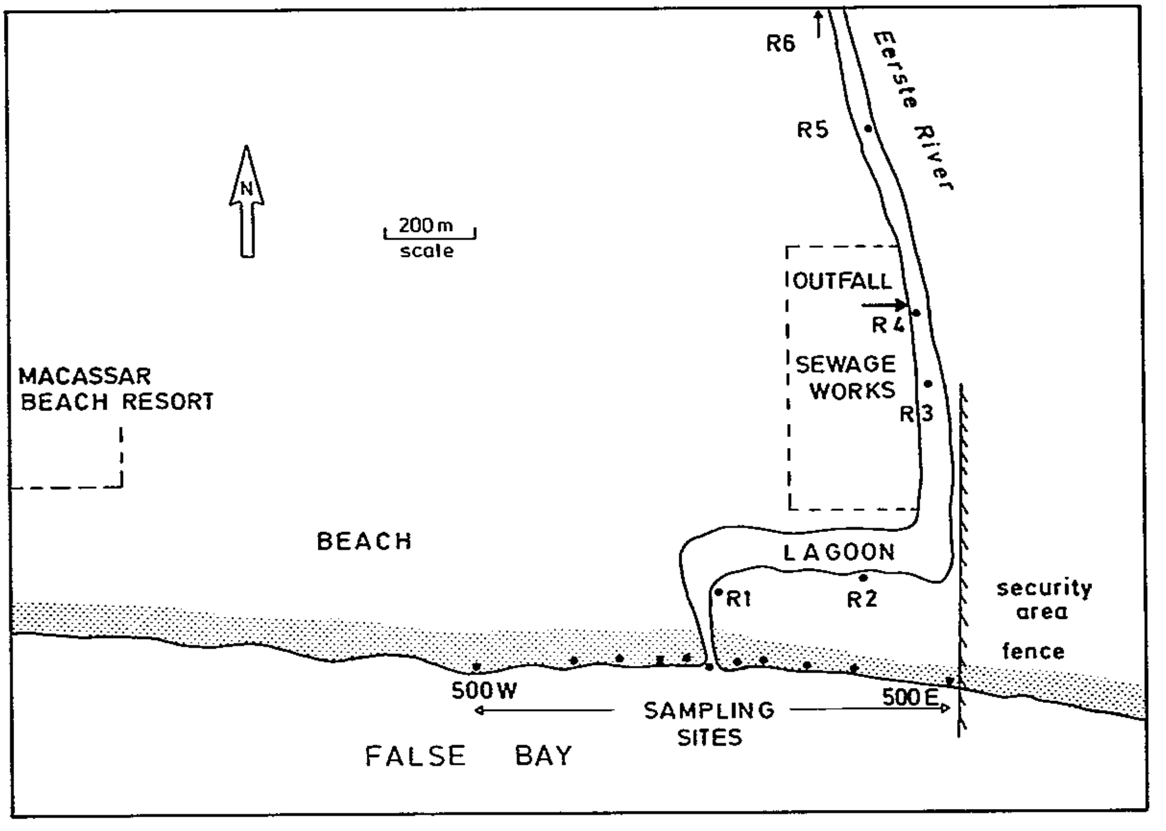

FIG. 22. FALSE BAY SAMPLING POSITIONS.

The area was surveyed on 10 December 1980 and again on 4 December 1981 [9]. The area surveyed included the estuary and 500m of the adjacent beaches.

The effects of the discharge of the Eerste river into False Bay were most noticeable in the nutrient chemistry and in the meiofauna data. Nutrient levels were high (up to 30 times background levels) and, although not as high as levels around AECI effluent discharge [6], probably represent the largest nutrient input to this area of False Bay by reason of the larger discharge from the river. Phytoplankton blooms were seen in the surf zone. The source of these nutrients is largely from the Stellenbosch and Macassar sewage works but agricultural run-off and other effluents could also increase the loading. In spite of this large loading the concentrations were diluted to near background within 500 m of the mouth, showing the overall impact on False Bay is, in fact, confined to a small area.

When considering the results from chemical and biological analyses together, some additional observations can be made. The chemical parameters showed unpolluted conditions at the times of sampling, while the meiofauna showed up a definite pollution history. This suggests that there is a periodic discharge of industrial and an organic (probably food based) effluent into the Eerste river. When considering the numbers of the more sensitive harpacticoids, it can be assumed that an industrial pollutant discharge had occurred within one month of sampling during 1980 (first visit). In 1981 (second visit) the periodic release of an industrial effluent had again severely reduced the meiofauna population around the river mouth. A longer period of less toxic conditions, possibly with organic effluent had allowed the populations to recover and recolonize the sand closer to the river mouth. These effluents were not apparent in the water chemistry at the time of sampling. The various authorities should examine these discharges and try to prevent any that are considered as hazardous.

Overall the Eerste river was not considered to represent any pollution threat to False Bay from the chemical viewpoint at the time of this survey. However, an assessment should be made of the nature of the periodic discharges. No bacteriological sampling was carried out at that time and this should be done to assess whether any public health threat exists particularly from the sewage discharges. As with the other discharges studied in this area of False Bay the impact of each is rapidly absorbed in the sea. A stage may be reached where cumulative effects of all the discharges pose a pollution problem and this should be examined in the future.

A E C I SOMERSET WEST

The AECI factory discharges liquid effluent into the sea via a small open rivulet and the adjoining beach is, therefore, regarded as a potential impact area. The beach was surveyed in 1976 [38] and again on 6 November 1979 [6].

The effects of this factory discharge were shown most clearly in the chemistry and biology of the interstitial water. The overall picture seems to have changed little since 1976 except for large increases in nitrate (20-40 times 1976 levels) in interstitial water at some sites, an increase in the OA values and a reduction in dissolved oxygen levels. These represent a slight worsening of the situation but may be accounted for by daily or seasonal variations. The parameters mentioned above, together with increased interstitial silicate, showed the site to be more at risk than the unpolluted reference beach at Swartklip which is also in False Bay. Other parameters, particularly surface water values, showed that the impact of the effluent was rapidly absorbed.

Overall, the beach was not excessively polluted and the effects appeared to be localised to within a few metres of the outfall and hence posed no serious environmental problem at that time. Additionally, there was little visual evidence of pollution.

HOUT BAY (Figure 23)

The third annual pollution survey [7] was made on 11 December 1980. The two earlier surveys [50, 40] showed the principal pollution problem arose from organic enrichment of the main beach. This was shown by the high values of oxygen absorbed from alkaline permanganate (OA), low dissolved oxygen levels in interstitial waters, and low numbers of interstitial meiofauna due to these chemical factors. The conditions have remained essentially unchanged or possibly have deteriorated slightly. The organic content of the beach has remained high as was indicated by the low level of dissolved oxygen (zero at stations 1, 4, 5 and 6) in the interstitial waters and the high OA (maximum 0,417 mg g^{-1} at station 5) values for sediments. The conditions tended to become more severe at the harbour end of the beach but not within the harbour itself. This may indicate that organic material present in, or introduced into, the bay may collect at that end of the beach. The stressed condition of the beach was clearly shown by the low numbers of meiofauna present.

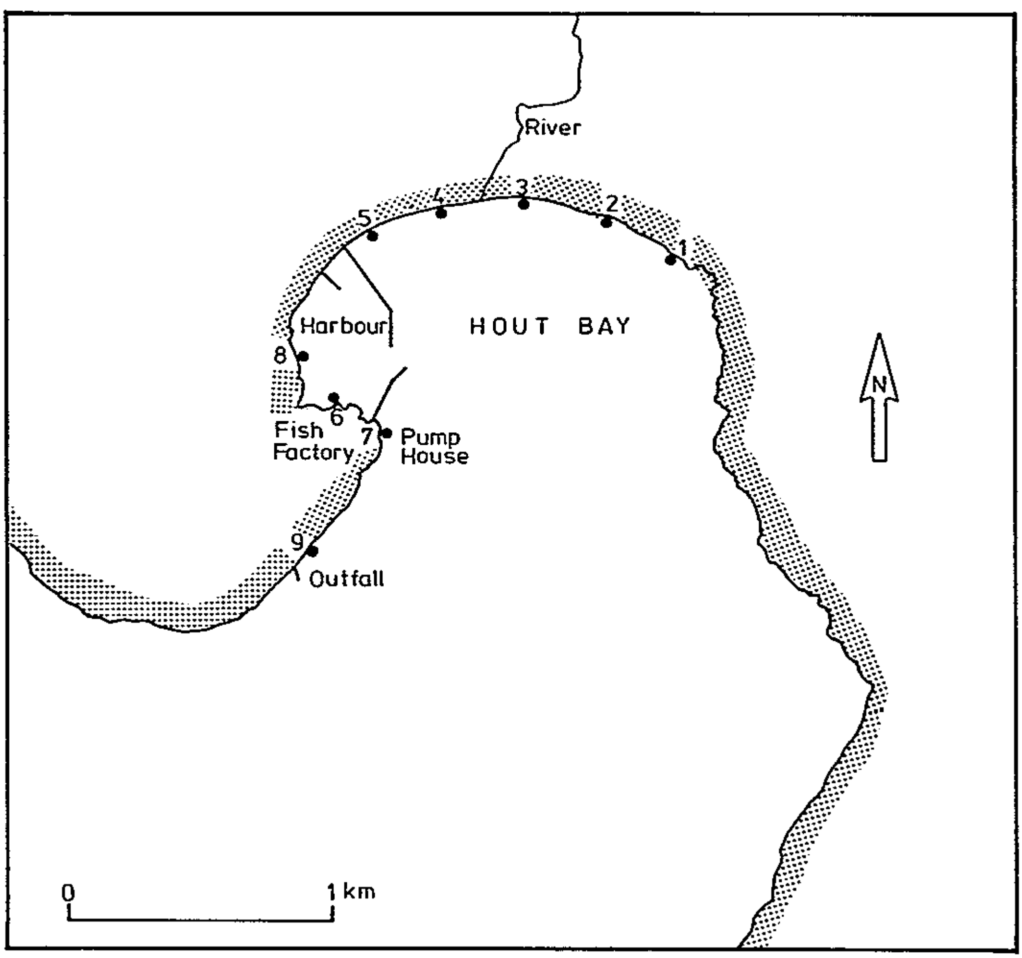

FIG. 23. SAMPLING STATIONS IN HOUT BAY.

Nutrient levels in the surface water were noticeably different in 1980. Silicate and nitrate levels were considerably less than they were in the two previous studies. The most likely explanation for this lies in upwelling. In 1979 the nutrient levels were similar to those in upwelled water and the water temperatures were lower. It seems that in 1980 no upwelling occurred prior to sampling so that the surface water became depleted in nutrients. The effect of the Disa river input with its higher silicate loading could be seen near station 4 from the 1979 and 1980 analyses. This may also have affected water chemistry slightly on the western end of the beach. The water chemistry at stations 6, 7 and 9 was affected by nearby effluent discharges which would in most cases raise the nutrient levels. Station 8 on a beach within the harbour seemed largely unaffected although the interstitial water there was less saline, indicating a fresh groundwater input. No metal pollution was apparent in the bay.

It should be noted that all three pollution surveys were made outside the peak season for fish factory operations at Hout Bay. A survey during the peak season when pollution problems could be worse, would be enlightening.

Since Hout Bay is an obvious impact area and is located in an area of outstanding natural beauty, a far more detailed study of the area has been planned for 1981/1982. This forms part of the basic research studies geared to obtaining an understanding of mechanisms in marine pollution. This study is initially concentrating on the beach and the characterisation of the organic contamination. When the methods have been developed the harbour sediment will be examined and it is hoped that the study will then be extended into the water column and subtidal sediments. It is hoped to be able to determine from which of the four sources, i.e. fish processing, mineral oil, sewage, or natural products the organic contamination is derived.

CAMPS BAY

A further pollution monitoring survey was carried out in October 1979, [8] to determine whether this popular recreational area has been affected by the new sewage outfall which was completed in 1977 (Figure 24). Previous surveys [39] had revealed that the beach was unpolluted and that it compared very favourably with other reference beaches [77] along the west coast.

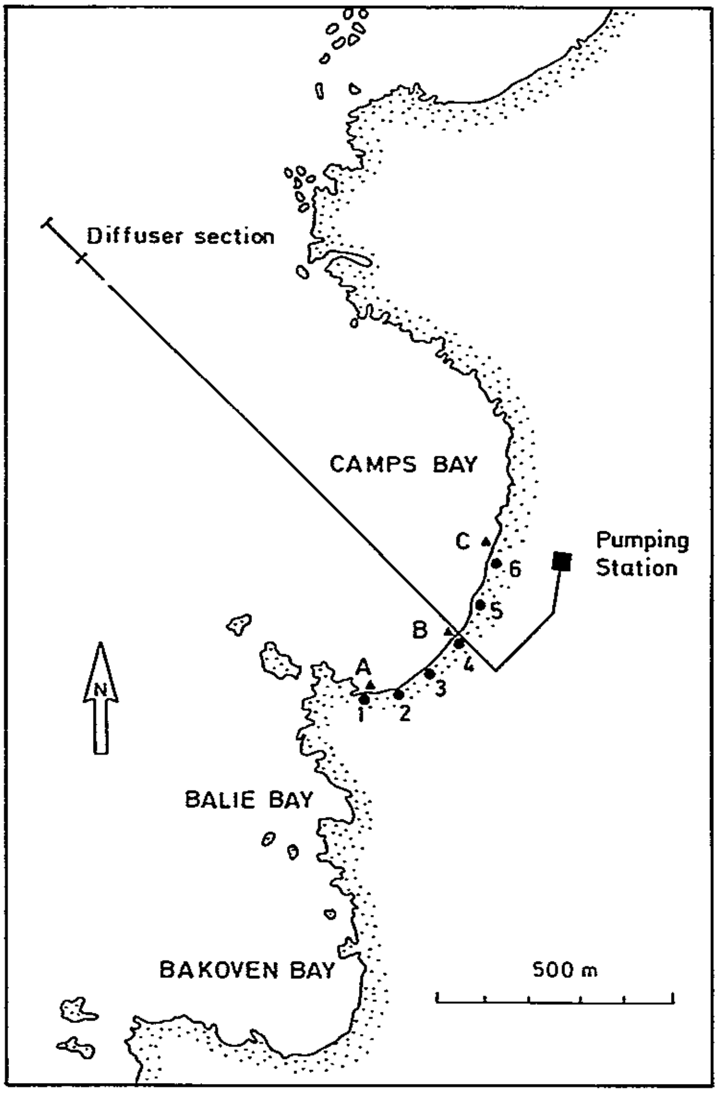

FIG. 24. CAMPS BAY SAMPLING POSITIONS.

The salinity and temperature were slightly higher and the nutrients in the surface water were lower than previously observed in the same season. This was probably because there was no upwelling due to the onshore northwesterly wind blowing at the time. The high phosphate (3 times the others) at the northern-most station is puzzling, particularly since it is coupled with a silicate concentration which was much lower than at all the other stations. The concentration of all nutrients in the interstitial water were highest at the southern-most station as had been observed previously. The OA and DO were in the range obtained on unpolluted Cape beaches [77].

Trace metal levels were higher at the station nearest the sewage pipeline which was probably due to metals leaching from the pipe itself. The meiofaunal population was normal for an unpolluted coarse grained beach [77]. The overall results show that there has been no deterioration since the outfall system was brought into use.

TABLE BAY

Table Bay is situated at the northern end of the Cape Peninsula. It is bounded on the south and east sides by the city of Cape Town and on the north and west sides by the Atlantic Ocean. The bay has a total surface area of 10 500 ha and a volume of approximately 2 km^3 [90]. The seabed is mostly rocky with occasional patches of sediment. The bottom slopes gently towards the west, reaching a maximum depth of 35 m between Robben Island and Green Point (Figure 25).

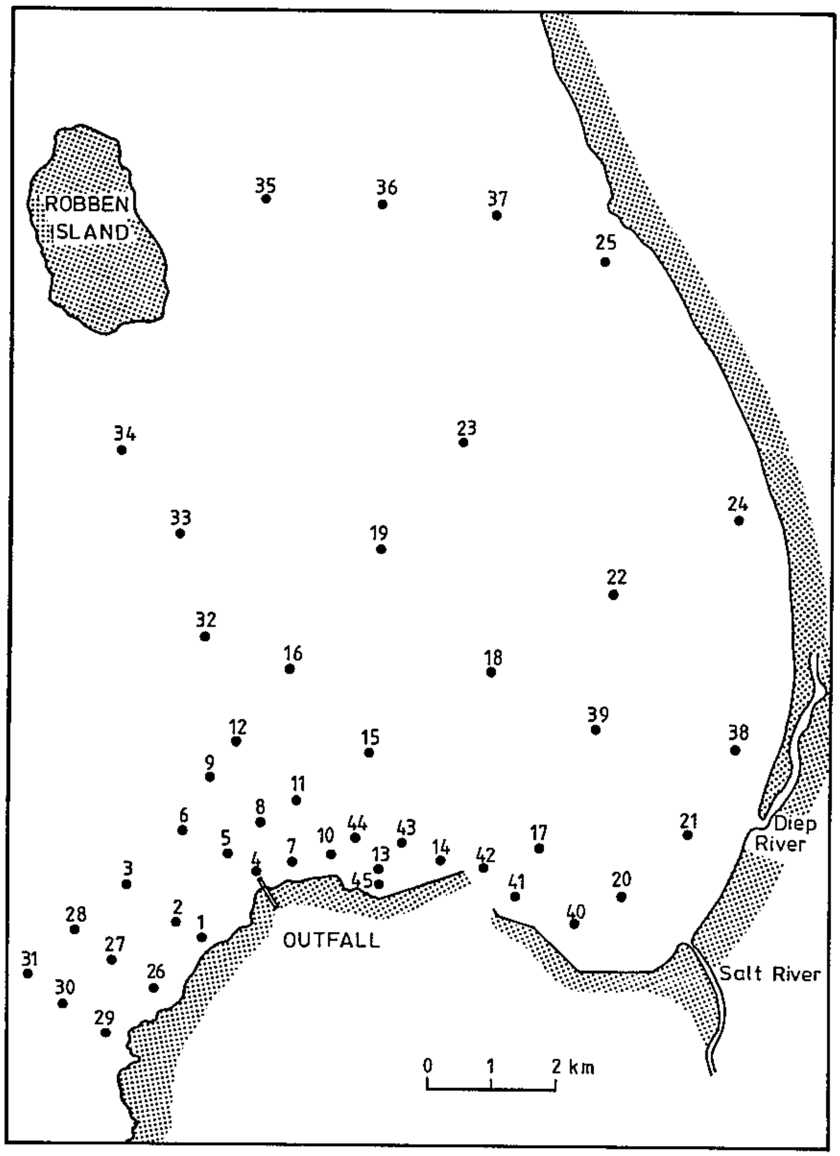

FIG. 25 TABLE BAY SEWAGE STUDY

Raw macerated sewage is discharged through the Green Point sewage outfall into Table Bay. The volume discharged is about 30 000 m^3 d^{-1}. This discharge is in shallow water just outside the surf zone. However, the pipeline is situated in a high energy part of the coast. Currents are strong, as shown by the clean-swept bottom in many places in the vicinity. This part of the coast is exposed to winter storms.

In addition to the sewage, the bay receives a number of other inputs. These include the water from the Salt and Diep rivers, power station cooling water, some industrial effluents and general inputs from the harbour and ships. The Salt river receives treated sewage from the Athlone Sewage Works [78].

To date, sampling has been carried out on two separate occasions, namely, in July 1980 (winter) and September 1980 (spring) [41]. During the first survey the weather was calm and had been for a few days previously. During the spring survey there was a southwesterly wind reaching 24 knots. On the first survey, 25 stations (1 - 25) were sampled and on the second survey, a further 20 stations (26 - 45) were added, based on the results from the first survey. These stations were roughly between Sea Point, Robben Island, Bloubergstrand and Table Bay Harbour, but were more closely spaced around the sewage outfall (Figure 25).

The salinity of the surface samples was generally about 35 0/00, decreasing slightly with depth. The minimum was 34,2 0/00 in the south east corner, probably due to water from the Salt and Diep rivers.

After a period of calm weather levels of dissolved oxygen were at, or near, saturation in the surface water at most stations. However at those stations near the outfall levels as low as 3,4 mg ℓ^{-1} were found at a depth of 8 m. After a southeasterly wind, levels in surface water fell as low as 5,6 mg ℓ^{-1} near the outfall, compared with over 8 mg ℓ^{-1} in the centre of the bay. Although this does not represent a critically low level of dissolved oxygen, the decrease is significant. At a depth of 10 m the low-oxygen plume surrounding the outfall was more extensive.

Nutrients in water

In the winter there was no clear plume emanating from the sewage outfall but the nutrient levels were higher near the Salt river mouth. In the spring, silicate and nitrate levels were elevated and ammonia slightly elevated at the surface close to the outfall while higher phosphates at the 10 m depth were observed. Higher nutrient levels also occurred along the eastern shore, probably due to imput from the rivers.

Trace metals in water

In winter only Hg had a distinct high point in the vicinity of the outfall. Elevated concentrations of Cu, Fe, Hg, Ni, Pb and Zn were observed near the river mouths. In the spring levels of Cu and Fe were elevated at the surface east of the outfall and west of the outfall at 20 m depth. Higher concentrations of Ni were found north of the outfall at the surface with lesser concentrations at 10 and 20 m depths. In the eastern section of the bay there was a large area of high manganese concentration in surface water possibly due to some factory effluents discharged in that area [41]. At 20 m, like Cu and Fe, the concentration of Mn and Zn were highest west of the outfall.

Trace metals in sediments

The picture for the trace metals in sediments is completely different from that in water. In all cases the metal concentrations in sediments were generally low in the bay. This is particularly obvious when metal concentrations from this survey are compared with those from other areas of sewage inputs. For example, Hershelman [56] reported concentrations of metals in Southern California which in all cases were two to four orders of magnitude higher than those observed in Table Bay.

However, there was one small area between the harbour entrance and Granger Bay in which there was a very sharp increase in the concentrations of all metals studied [41]. This applied even in the case of lead, whose distribution in water was different from those of all the other metals.

Oxygen absorbed from alkaline permanganate (OA)

This is a crude measure of the amount of easily oxidisable organic matter in the sediments. The OA results should therefore indicate areas in which the organic material from the sewage was accumulating. The most surprising feature was that the area of highest organic material did not correspond with the area of high metals.

Sediment particle size

Mean particle size ranged from 104 um to 1 014 um with 90% of the samples in the range 110 to 550. One third of the samples were a mixture of sand and gravel and 20% of those also contained mud. The rest of the samples were totally sand. No sediment could be obtained at seven of the sites. Most sediments were moderately to well sorted.

Bacteriology

Results for *Streptococcus fecalis* [41] and *E. coli* collected during winter show that there were high numbers in the vicinity of the outfall.

During the spring cruise there were also high numbers of coliforms around the outfall, spreading in an easterly direction. A high concentration was also found off the mouth of the Diep river. The high concentrations spread into Granger Bay. However, levels to the west of the outfall were low.

The water near the bottom definitely contained lower dissolved oxygen levels. There was also a large area at a depth of 10 m in which the oxygen levels were depressed. This depression was too great to be attributed purely to entrainment of bottom water in the plume. The decomposition of sewage must, to a certain extent, also account for the depletion of oxygen. Raw sewage inevitably contains a higher suspended organic load which increases the oxygen demand of the effluent.

There were large inputs of nutrients from both the sewage outfall and the Salt and/or Diep rivers. The input from these rivers was far more noticeable and extensive during the winter when land runoff is at its peak.

There was no depletion of surface phosphate during the spring. Phosphate was evenly dispersed through the entire water column. However, in the case of nitrate, the normal pattern of lower nitrate concentrations in the surface water was observed. In spring, surface levels were generally lower than those observed in winter, although the opposite was true in the deeper water.

In a preliminary investigation of the Green Point outfall, a very high correlation between trace metals and organic material in sediments was found [75]. This was different from the results obtained on these surveys. The high organic content occurred to the southwest of the outfall whereas the highest metal concentrations were all in Granger Bay. This suggests that the particulate organic matter in the sewage is carried to the southwest in a bottom current, and adds support to the findings on the trace metal concentrations in water which also suggested this type of process. This then raises the question of whether the high trace metal concentrations in the sediments are related to the sewage at all. The results of the preliminary survey indicate that they definitely are. Therefore it seems that the picture appearing from this survey may reflect a temporary state. Winter storms are likely to throw into suspension much material along the northwest shore of the Peninsula. This could then be carried along the shore and deposited in the much more sheltered area in the vicinity of Granger Bay.

The side-scan sonar survey of the bay has shown [111] that this is one of the few areas in which there are large amounts of fine sediment. These fine sediments will act as an organic detritus trap. The metals in these sediments could therefore have a number of sources:

1. Metals could be carried out of the harbour and deposited in this area. This probably contributes something to the metal loading in the adjacent area. However, high metal concentrations were not detected in the water near the harbour. In addition, metals from the harbour, if this was an important source, would probably have deposited on the eastern side of the harbour entrance since this is also an area of fine sediment accumulation. This was not the case.

2. Dredged sediment from the harbour has been dumped in this area. This could have contributed substantially to the high metal concentrations.

3. The particulate matter in the sewage could be trapped in the fine sediments in this area. Since this organic matter is rich in trace metals, this would increase the metal content in the sediments. In the preliminary study [75] there was a high correlation between organic matter and trace metal concentrations. However, in this larger, later study, the correlation was not good.

This question will have to be resolved by further sampling under different conditions. Emphasis will be placed on the metal-organic associations. In the meantime therefore, it cannot be conclusively stated that the high metal levels in the sediments of Granger Bay are related to the sewage outfall.

On the other hand increases in metal levels in the water around the outfall could be traced. This was the case for most of the metals studied. Lead was the only metal which did not conform to this pattern, indicating atmospheric fallout as the main source of lead. The actual lead concentrations (maximum 4,95 ug ℓ^{-1}) are higher than those currently quoted as the levels in seawater. Although a number of fairly recent reports quote lead values of the same order [57], the most recent figures are quoted as about 3 ng ℓ^{-1} [62]. This suggests that there is some lead contamination in the survey samples. A possible source of contamination could be the Niskin sampling bottles (M. Branica, Editor, *Lead in the*

Environment, pers. comm.). Nevertheless the relative values of lead obtained probably still illustrate the pattern of lead distribution.

Overall the metal distributions in the water on the two trips have illustrated some important points:

1. During winter when land runoff was high, there was a definite input of metals from one or both of the Salt and Diep rivers.

2. Apart from this, the water was far better mixed during the winter and there were few differences with depth. This is in contrast to the situation in spring where there were marked differences in metal distributions with depth.

3. During spring there was a clear plume of high metal concentrations in the surface water to the northeast of the outfall [41]. This was particularly noticeable for copper, iron, manganese and zinc, those metals which had the highest concentrations in the effluent itself.

4. However, in the deeper water the highest metal concentrations were invariably to the southwest of the outfall. There are two possible reasons for this:

   (a) The well-known upwelling process may bring metal-rich water close to the shore in this area.

   (b) There may have been a bottom current which was moving in the opposite direction from the surface currents. Although there was no mention of this in the work of Atkins [4] and van Ieperen [90], such currents are known to occur on occasions (City Engineer, Cape Town, *pers. comm.)*.

The question now arises as to whether the addition of trace metals to Table Bay via the sewage outfall is significant or not. Therefore some calculations have been carried out on the amounts of metals added to the bay daily through the outfall and these have been compared with the total amounts of metals in the bay. These calculations are, by their nature, very approximate, since large variations in natural and anthropogenic inputs occur from time to time. For example, large increases in trace metal inputs are known to occur with the first rains after the dry season. Nevertheless, these calculations should give some idea of the orders of magnitude of the metals. The results of these calculations are summarised in Table 8. These indicate that the amounts of most metals added to the bay daily through the sewage are insignificant in comparison with the amounts already there. In the case of iron and zinc, the amounts added daily are about 4% of the amounts present. Because of the low toxicity of iron in seawater, this is probably not serious. However, the zinc additions may prove to be significant under very calm conditions when residence times of water in the bay are longer than three or four days [90].

TABLE 8: Metal discharges into Table Bay via sewage.

Metal*	kgd^{-1}	Percentage of amount already present
Cu	5,6	1,4
Fe	67,8	3,8
Mn	1,8	0,3
Pb	1,6	0,1
Zn	51,5	3,7

* All other metals studied had a daily input of less than 0,1% of the amount present.

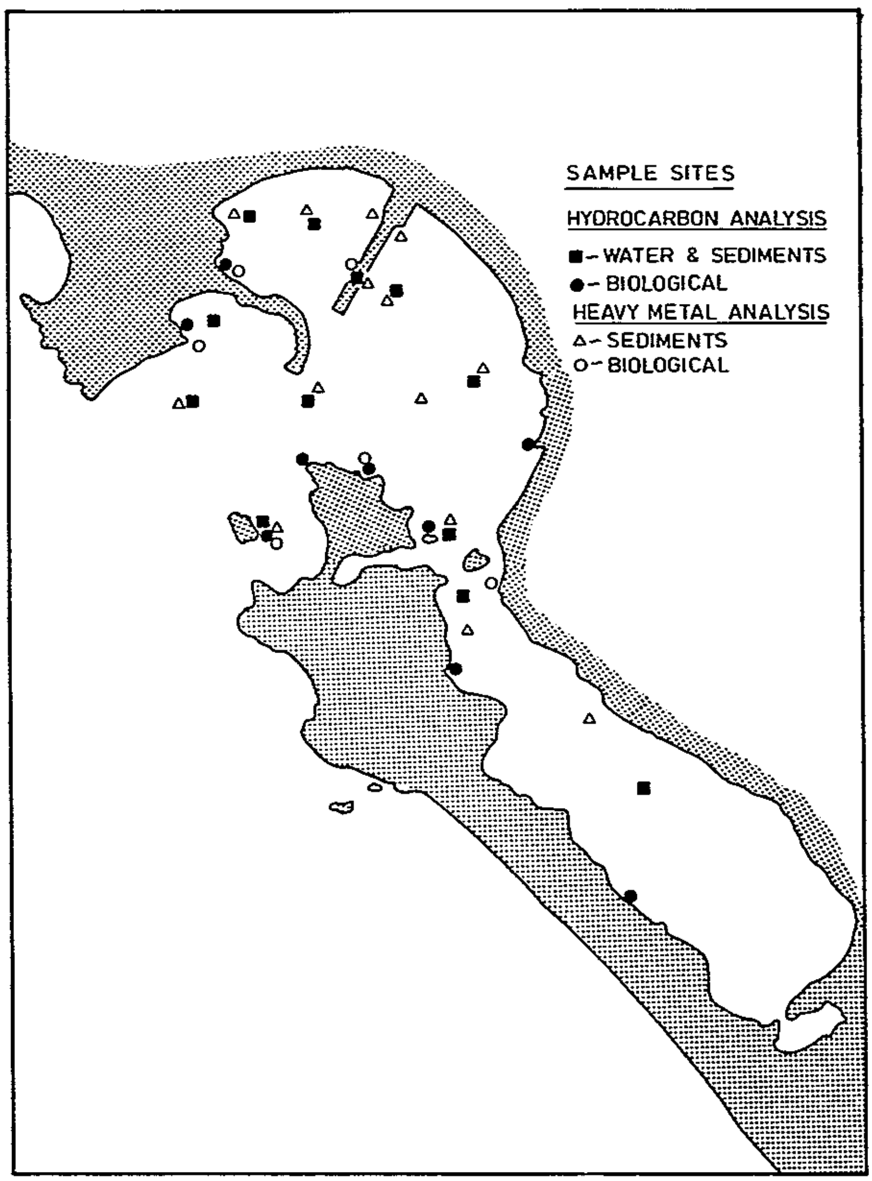

FIG.26. SALDANHA BAY SAMPLING SITES.

SALDANHA BAY

Saldanha Bay harbour has within its confines a jetty for the shipment of iron ore and ore concentrates, an oil transhipment terminal, a fishing harbour with fish processing plants and a small town. Each has the potential for producing a specific type of pollution. The quarterly pollution monitoring surveys conducted in the area by the Sea Fisheries Research Institute (SFRI) were designed to monitor these specific types of pollution [50].

The ore jetty began operations in September 1976 and the trade was at that time expected to be 12 to 18 million tons annually. In February 1980 the shipment of lead and copper concentrates began with an anticipated annual trade of 0,2 million tons.

Heavy metals

Cages of black mussels *Choromytilus meridionalis* and oysters *Crassostrea gigas* were anchored at nine stations to monitor any increase in metals. The mussels were obtained from a natural population at Boat Rock, a position remote from the ore jetty and the oysters from the Fisheries Development Corporation experimental farm at Churchhaven in Langebaan Lagoon. A summary of the heavy metal concentrations in these samples is given in Table 9.

TABLE 9: Metal concentration in black mussel and oysters from Saldanha Bay (1981 - 1983).

Concentrations ug g^{-1} dry mass

	n	Cu	Fe	Zn	Mn	Pb	Cd	Cr	Ni
BLACK MUSSELS									
1981	98	4,4	62	90	8	0,2	2,4	1,7	2,8
1982	115	4,9	52	90	7	1,0	1,8	1,2	1,1
1983	84	4,3	51	96	6	1,8	2,0	1,3	1,6
OYSTERS									
1981	69	27,7	135	520	9	ND		1,4	0,8
1982	102	18,7	115	520	8	1,3	5,7	1,2	0,4
1983	88	26,2	99	680	7	1,4	5,9	0,9	0,4

n = Number of determinations.
ND = Below detection limit.

The values tabulated are the arithmetic means of all analyses of each year. It appears that with the exception of zinc and lead in both oysters and black mussels, the concentrations of the remaining metals had decreased in the period 1981 to 1983. The increase in lead concentrations in both oysters and mussels is seen, not so much as an increase in the mean concentration but more obviously as the number of samples in which the lead concentration was above the detection limit; in black mussels from 8% of the samples in 1981 to 96% in 1983 and in oysters from no detectable levels in all 98 samples in 1981 to 90% in 1983. Lead concentrate shipments began in 1980 and it seems likely that this could, in part, explain the increase in lead in mussels and oysters. Further evidence to support this contention can be found in the sediment analyses. In the longer term there has been little if any increase in metal concentration in black mussels (see Table 10).

TABLE 10: Range of concentrations of heavy metals in black mussels from Saldanha Bay over the period 1974 - 1983. (Units: ug g^{-1} dry mass.)

Ref.	Cu	Fe	Zn	Mn	Pb
1974 [96]	4,2 - 16,7	44 - 222	41 - 122	3,2 - 27,8	0,6 - 11
1976 [45]	1,5 - 8,0	46 - 133	31 - 100	11,3 - 16,0	0,3 - 0,7
1981	0,1 - 8,9	17 - 86	62 - 138	4,0 - 11,5	<0,2 - 2,6
1983*	4,3	49	96	6	1,5

* Arithmetic means.

Samples of surface sediments were collected on each survey from twelve, then (in 1982 and 1983) fourteen positions within the bay. The results are presented as arithmetic means in Table 11. Copper, zinc, lead and manganese had apparently increased but these increases were not statistically significant and were probably due to data from positions close to the concentrate jetty (where copper, iron and lead concentrations were known to be high) being included in 1982 and 1983. The concentrations were low when compared to those found in other South African harbours such as Durban, Port Elizabeth and Richards Bay [55], and approximately half the levels in the Knysna surface sediments [101]. These differences were all statistically significant ($p < 0{,}001$). High levels of copper and lead were occasionally found close to the concentrate jetty but these levels were the result of identifiable operational spills rather than continuous accretion. In general the metal concentrations were low and the impact of the ore jetty operations has been small.

TABLE 11: Saldanha Bay sediments annual mean concentrations. (Units: ug g^{-1} dry mass.)

	Cu	Fe	Zn	Mn	Pb	Cd	Cr	Ni
1980*	0,9(11)	2 120(11)	12(11)	12(11)	1,5(11)	0,2(11)		1,1(11)
1981	2,9(55)	2 240(55)	10(55)	17(55)	2,6(18)	0,3(55)	16,8(43)	4,1(43)
1982	2,4(48)	2 740(48)	13(48)	18(48)	2,7(48)	0,2(48)	9,1(48)	2,6(48)
1983	3,8(56)	2 230(56)	15(56)	19(56)	5,8(56)	0,4(56)	8,4(56)	3,2(56)

* Single survey. Number of determinations in ( ).

Hydrocarbons

In January 1980 oil trans-shipments began at the ore jetty. Water and sediment samples were collected at twelve stations and biological samples at nine to monitor any pollution. The oil content was measured by spectrofluorimetry and expressed as equivalents of Qatar crude (see Table 12). Oil concentrations in water were uniformly low but were slightly elevated in the sediments near the ore jetty and in the fishing harbour [18]. Oil concentrations in biological material varied greatly between species but the apparently high values found in some of the fauna (see Table 12) may be due to naturally occurring substances. Since the fluorescence spectra of the tissue extracts differed markedly from that of the standard Qatar crude particularly in the region commonly attributed to 1 and 2 ring aromatics. Peaks in this region were found in the tissue but would not normally be present in oil which had been exposed to the elements even for a short time. Concentrations of oil found in Saldanha Bay water, sediment, and biological samples were low compared to those in samples obtained in the northern hemisphere [18]. Much of the fluorescent material observed in the samples may not have been derived from crude oil. The oil found in the water samples possibly originated from small inputs of marine diesel oil from ship operations within the fishing harbour. In normal operation the oil trans-shipment terminal does not appear to pose a serious threat to Saldanha Bay.

TABLE 12: Concentration of extractable hydrocarbons as equivalents of Qatar crude. (Units: Water - $ug\ell^{-1}$; Other - ugg^{-1} dry mass.)

Type	N	Arithmetic mean	Range	Geometric mean
Water	116	3,62	0,1 - 61,0	
Sediment	38	6,33	1,0 - 23,7	
Red bait	22		0,0 - 121,6	7,9
Brown mussel	2		0,7 - 1,2	1,0
Mactra	14		0,0 - 43,8	2,9
Black mussel	24		0,0 - 85,7	2,3
Perlemoen	35		0,0 - 17,7	1,9
Rocklobster	73		0,0 - 26,0	2,0

Organic pollution

Organic pollution as measured by oxygen absorbed (OA) from permanganate has as its main source in Saldanha Bay the effluent from the various fish processing plants situated in the fishing harbour. However, the effluent from these plants may supply only a small proportion, albeit a very visible part, of the total mass of suspended organic material in the waters of the bay; the rest being the living and dead biota. It would be reasonable to expect the OA levels to vary with the season, to be high during the fishing season and low at other times. This effect was observed in the inner harbour when, after calm weather, a marked thermocline had become established.

High OA values have also been found throughout the water column when surveys were conducted in the closed fishing season during and following periods of stormy weather. These high levels of OA presumably result from resuspended organic material. Table 13 shows arithmetic means and standard deviations of OA values for all samples taken throughout the year. During the period covered by the data presented in Table 13 the OA levels increased from 1974 to a maximum in 1979 and thereafter decreased. The OA values presented here are low suggesting a low level of organic pollution in Saldanha Bay but this conclusion should be treated with caution as short lived episodes of high organic loading have occurred which are not reflected in these data.

TABLE 13: The OA values at various depths in Saldanha Bay 1974 to 1983. Arithmetic mean, Standard deviations. Units: mg ℓ^{-1}. Number of observations in parenthesis.

Year	Depth M			
	0	5	10	20
1974/75	1,7 0,9 (175)	1,6 0,9 (156)	1,5 1,0 (89)	1,2 0,6 (34)
1976	1,7 0,6 (89)	1,5 0,6 (85)	2,3 1,3 (45)	1,0 0,6 (17)
1977	1,7 1,2 (69)	1,7 1,0 (82)	1,4 0,8 (39)	1,3 0,7 (30)
1978	2,6 1,6 (58)	2,9 1,7 (38)	3,1 2,3 (45)	2,6 2,1 (18)
1979	4,3 3,2 (83)	3,5 2,3 (54)	3,7 2,2 (52)	3,2 1,4 (26)
1980	3,5 2,1 (57)	4,0 2,4 (28)	3,4 2,5 (23)	3,7 1,8 (9)
1981	3,3 1,9 (65)	3,6 2,0 (59)	3,4 2,2 (39)	3,6 2,2 (14)
1982	2,6 1,8 (83)	2,4 1,7 (79)	2,3 1,6 (49)	1,6 1,1 (14)
1983	2,6 1,4 (106)	2,5 1,4 (102)	2,7 1,5 (66)	2,7 2,0 (17)

METAL CONCENTRATIONS IN MOLLUSCS FROM THE SOUTHERN COAST

The ability of many biological species to accumulate pollutants has been used with varying degrees of success to indicate and sometimes quantify metal pollution of the marine environment. The characteristics of monitoring organisms have been described in detail [17, 82].

A great variety of molluscs occur around the South African coast, extending as it does from the subtropical environment of Natal to the temperate environment of the Cape. The potential of many of these molluscs as bio-indicators has been discussed in general terms on the basis of the reported use of related species [32] and certain of these have been included in the National Marine Monitoring Programme [20], that is the Cape oyster *Crassostrea margaritacea*, the brown mussel *Perna perna*, the bivalve *Donax serra* and the gastropod *Bullia rhodostoma*. However, few data on the accumulative ability of these species or on their tolerance to metals are available.

The metal concentrations recorded for *C. margaritacea* from 25 sites along a 500 km stretch of the South African coast during a period July 1977 to August 1979 are summarised in Table 14.

The major portion of the coast from which samples were collected is undeveloped and as would be expected, the metal concentrations recorded are low. There is little available data for *C. margaritacea*. The metal concentrations quoted in Table 14 are generally low compared to results obtained for the Pacific oyster *Crassostrea gigas*.

C. gigas is grown and studied in many countries and comparative data on tissue-metal concentrations are available, particularly for locations where metal pollution is already a recognised problem. The metal concentrations in *C. Gigas* cultivated in Knysna estuary have been shown to be up to an order of magnitude lower than those reported for this species growing in seemingly unpolluted locations elsewhere [93]. These data, together with the results from comprehensive surveys of metal levels in water and sediment samples collected from the Knysna estuary, confirm that the area is unpolluted with respect to the study elements [101]. It is therefore suggested that *C. margaritacea* growing in the vicinity of Knysna estuary (Figure 27 sites 8 - 11) contain near background levels of these elements.

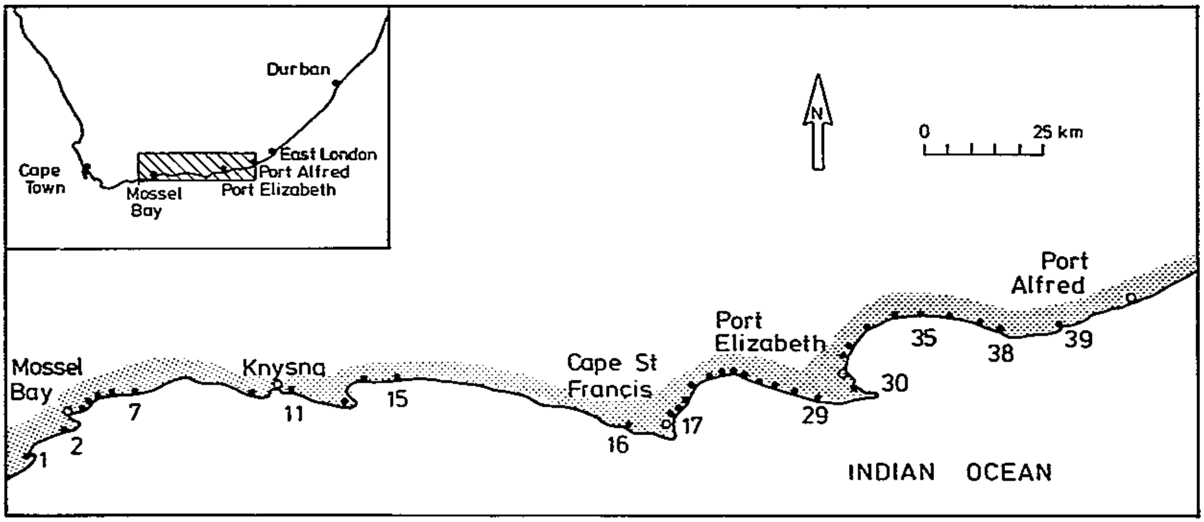

FIG. 27. STUDY AREA AND SAMPLING SITES.

Oysters from Victoria Bay (site 4, Figure 27) contained (in ug g^{-1} dry tissue) zinc (4 383), lead (3,2), nickel (5,1), chromium (13) and possibly cobalt (0,6). It is reasonable to assume that these metals are being introduced into the marine environment from the relatively large holiday resort situated along the shore of the bay. Some elevated metal levels were observed in isolated samples, for example copper in the samples from sites 11 (65), 12 (84), 13 (47) and 17 (63), cobalt in the sample from site 19 (1,3) and chromium at site 24 (11). No obvious common feature distinguishes these locations from the remaining survey sites, none of them being particularly near to urban developments, therefore it must be assumed that these metals are being introduced into the marine environment from natural sources.

Oysters growing at the mouth of the Papenkuils river (site 21) have accumulated zinc (6 516), copper (55), lead (10) and chromium (25). A recent pollution survey of this river [97] has shown that considerable quantities of a number of metals, most notably zinc and chromium, but also lead, cadmium and mercury, are entering the river via the many drains which are to be found both in and above the canalised section. *C. margaritacea* growing at the mouth of the Swartkops river (site 22) are also found to contain considerably more zinc (5 559), copper (34) and lead (1,2). Again the results of a survey in this river indicate the presence of four areas of contamination [100]. Oysters from the two extremes of Algoa Bay (sites 20 and 23) do not contain elevated metal concentrations which seems to indicate that the Bay as a whole is not polluted to any great extent. The results of a more detailed survey of the Bay indicate that the present level of industrialization and urbanization is not causing significant stress to the ecosystem, probably because there is considerable water movement [98].

TABLE 14: Metal concentrations in molluscs from sites on the southern coast.

ug metal g^{-1} dry tissue

	Zn	Cd	Cu	Pb	Fe	Mn	Ni	Co	Cr
C. margaritacea									
Mean	1536	8,3	27,7	0,59	174	5,91	0,61	0,18	4,60
S. dev.	770	2,9	19,5	0,51	106	3,75	0,95	0,31	3,58
No. of samples	411	411	411	386	411	411	386	401	382
P. perna									
Mean	92,6	3,1	6,95	1,16	433	7,67	7,83	0,64	3,56
S. dev.	19,6	1,2	1,79	0,89	118	2,57	3,08	0,31	1,39
No. of samples	1334	1334	1334	1334	1334	1334	1334	1334	1334
D. serra									
Mean	69,3	0,2	5,09	0,57	706	8,12	2,14	0,48	3,95
S. dev.	15,7	0,1	0,98	0,17	293	3,62	0,65	0,17	1,59
No. of samples	147	147	147	147	147	147	147	147	147
B. rhodostoma									
Mean	189	21,1	2,06	0,48	206	6,13	0,79	0,36	8,62
S. dev.	59	9,0	3,02	0,32	81	1,55	0,47	0,23	3,85
No. of samples	794	794	794	794	794	794	794	794	794

Copper (97), lead (1,5)and chromium (13) concentrations are elevated in *C. margaritacea* growing at the mouth of the Great Fish river (site 25). This result was unexpected as there are no urban or industrial developments along the river. It is therefore likely that these elements are derived from leaching of mineralized sequences in the catchment. In view of these results, a geochemical survey to establish the provenance of these metals should be undertaken.

PERNA PERNA

Metal concentrations recorded for *P. perna* [94] are summarised in Table 14. There is a lack of comparitive data for *P. perna*. The metal concentrations quoted in Table 14 are generally low compared to results obtained for the Pacific oyster, *C. gigas*.

These data, in conjunction with the results from a comprehensive survey of metal levels in water and sediment samples collected from the Knysna estuary, confirm that the area is generally unpolluted with respect to the study metals [101]. It is therefore suggested that, as *P. perna* growing in the survey area had similar metal levels to those growing in the vicinity of Knysna, this area may be considered to be essentially unpolluted with respect to these metals. Even in areas where industrial and urban development may have been expected to cause increased accumulation, tissue metal levels were not found to be significantly elevated above the regional mean.

The lead (1,6) concentration in *P. perna* from Mossel Bay harbour (site 4) was elevated. This is expected because of urban and industrial run-off in the area, together with the introduction of effluent from a fish processing factory. Chromium (5,5) was also slightly elevated in this sample and was probably of industrial origin. Nevertheless, the adjacent sampling sites were apparently not affected by the industrial and harbour complex.

Zinc concentrations were generally low, with the possible exception of the sample collected at the mouth of the Papenkuils river (180) (site 21). This river has become a canal for the industrial complex at Port Elizabeth, and a variety of effluents from manufacturing plants in the area are introduced into it. It is therefore not surprising that copper (22), lead (22) and chromium (9,4) concentrations in *P. perna* were the highest anywhere along the eastern part of this coast.

However, on the basis of these results, there is no serious metal pollution of urban or industrial origin in the survey area.

D. serra and *B. rhodostoma* were collected from sites along the same coast (Figure 27) during several surveys in the period August 1978 to August 1979. Two species of *Donax*, *D. sordidus* and *D. serra*, occur on eastern Cape sandy beaches. *D. sordidus* is small and undergoes tidal migration. *D. serra* is the largest species in the genus. The geographical range of *D. serra* is from Luderitz on the west coast to the Transkei on the east coast of South Africa. Its usual position on the beach is above the mid-tide level in the eastern Cape [35, 36]. In this region it does not undergo the normal tidal migration, but exhibits a semi-lunar pattern of movement up and down the intertidal zone [69]. Vast populations occur on some beaches.

Bullia are well represented on South African beaches with five intertidal and eight subtidal species. However they do not make ideal monitoring organisms, being both mobile and of a scavenging habit [15]. They have a wide geographical distribution and are abundant on many beaches. Brown [14] has reviewed the available data on the biology and physiology of *Bullia* species. *B. rhodostoma* is the common intertidal species of the southern and eastern Cape and is the dominant macrofaunal organism on many beaches [71]. It is long-lived, with a slow growth rate, reaching a length of about 40 mm after 10 years [70].

Variations in metal concentrations in *D. serra* and *B. rhodostoma* are apparent (Table 14). These variations are often accounted for by differences in size, the higher levels occurring in smaller individuals. Both zinc and cadmium in *B. rhodostoma* follow this pattern. In the case of cadmium, the concentrations are slightly higher for a given size of individual in the western part of the survey area, as has also been found for oysters. The concentrations of cadmium and zinc in *B. digitalis* have also been surveyed; these data indicate that *B. digitalis* from the west coast have higher tissue levels of cadmium and zinc than do south coast populations, and that metal concentrations do not increase with increasing size of individuals (K.C. Davies, unpubl. data). These findings tend to support those of the present survey. The results of a twelve month study to measure seasonal variations in metal concentrations were inconclusive, but indicated that differences due to size were dominant and masked any seasonal variations.

In summary, *D. serra* and *B. rhodostoma* fulfil many but not all the biological criteria for monitoring organisms. Practically, both species are of an adequate size for analysis; larger individuals should be collected so as to minimise concentration differences due to size. *D. serra* is often less abundant and more difficult to locate, but *B. rhodostoma* is more mobile and may, in fact, migrate out of a polluted area. Nevertheless, both may make a useful contribution to the coastal monitoring programme as a whole.

VARIATIONS IN TRACE METAL CONTENT OF THE MUSSEL *CHOROMYTILUS MERIDIONALIS* (KR.) WITH SEASON AND SEX [76]

Samples of *C. meridionalis* were collected in June and November from intertidal pools at Bloubergstrand, a few kilometres north of Cape Town. The rocky shore is exposed, experiences strong wave action and is sited in an area subject to extensive summer upwelling. The salinity of the water is normally just under 35 0/00. The beach is sufficiently far from Cape Town not to be influenced by pollution from the city; currents in the area are mainly wind driven and are thus variable, although the dominant current direction is northwesterly (81% in summer and 69% in winter)[53, 90].

From June to November the mean water content of the mussels increased significantly from 79 to 81.5% (99% < t < 99.8%). This increase suggests that some, but not all, of the animals had spawned during the period. The well developed gonads present in some of the mussels collected in November suggested that they were still in the process of spawning. This would account for the fact that the mean water content of this sample was lower than the mean determined over a long period [52], since it could be expected that the water content would increase after spawning.

The results of the trace metal analyses (Table 15) indicated that the mussels in the area had fairly low concentrations when compared with those from some other areas [16, 51, 80]. However the results were very similar to those obtained for *C. meridionalis* and *Perna perna* by other workers at unpolluted sites in the vicinity (Table 16).

TABLE 15: Trace metals in whole bodies of *Choromytilus meridionalis*. (ug g^{-1} dry mass, whole body.)

	Cd	Cu	Fe	Mn	Ni	Pb	Zn
Samples collected in June							
Female: Mean	0,28	5,84	21,4	8,50	0,85	0,82	75,3
std. dev.	0,05	1,29	7,7	3,17	0,21	0,23	14,1
Male: Mean	0,32	3,21	12,8	3,87	0,71	0,95	38,7
std. dev.	0,07	1,46	8,3	1,62	0,19	0,26	21,1
Sämples collected in November							
Female: Mean	1,11	7,17	51,0	9,63	1,16	2,57	90,8
std. dev.	1,12	1,31	20,1	1,69	0,40	0,67	13,1
Male: Mean	0,94	6,29	69,9	12,10	0,95	2,87	75,7
std. dev.	0,91	0,65	31,4	10,00	0,29	0,71	9,1

The results showed that there were significant increases in the concentrations of some metals from June to November, as follows:

males: copper, iron, lead, zinc (99% significance)
manganese (95% significance)

females: iron, lead (99% significance)
cadmium, copper, zinc (95% significance)

Increases in the concentrations of zinc, cadmium and copper from June to September have also been found in the common mussel *Mytilus edulis* [80] (sex not specified).

The reasons for these increases are not known but are probably not due to the development of the gonads since it has been found that in other species of molluscs the concentrations of most metals in the gonads and foot are lower, sometimes by a few orders of magnitude, than in some other organs [16, 88]. Highest concentrations normally occur in the kidneys if accumulation has taken place over a long period of time, while shorter term accumulation usually results in increased concentrations in the gills [80, 87]. Thus the seasonal fluctuations may be due to variation of wet mass of mussels with season. However, it has been noted that regression coefficients calculated using whole body metal contents against body mass show abrupt changes as the animals enter adulthood [30].

The seasonal variation may also be due to phytoplankton productivity and the availability of food. Highest productivity has been connected with low metal concentrations, since the ready availability of food would lead to a high metabolic and excretion rate [16]. However the present data do

TABLE 16: Summary of trace metal concentrations in mussels (ug g^{-1} dry mass.)

Metal	Location	Range (ug g^{-1})	Mean	Reference
Cd	Bloubergstrand	0,22 - 0,43	0,30	[76] (June)
	Bloubergstrand	0,37 - 3,65	1,04	[76] (Nov)
	Saldanha Bay	1,53 - 2,27		[45]*
	Saldanha Bay	0,73 - 21,87		[96]
	Knysna		6,1	[91]#
	South coast	0,25 - 9,2	3,3	[94]#
Cu	Bloubergstrand	1,49 - 8,14	4,60	[76] (June)
	Bloubergstrand	5,15 - 10,4	6,79	[76] (Nov)
	Saldanha Bay	4,53 - 8,00		[45]*
	Saldanha Bay	4,21 - 16,67		[96]
	Knysna		5,8	[91]#
	South coast	4,64 - 21,65	6,9	[94]#
Mn	Bloubergstrand	1,89 - 14,8	6,32	[76] (June)
	Bloubergstrand	5,51 - 33,9	10,7	[76] (Nov)
	Saldanha Bay	11,33 - 16,00		[45]*
	Melkbosstrand		18,00	[89]*
	Saldanha Bay	3,25 - 27,78		[96]
	South coast	4,88 - 11,50	7,67	[94]#
Ni	Bloubergstrand	0,39 - 1,09	0,78	[76] (June)
	Bloubergstrand	0,66 - 1,86	1,07	[76] (Nov)
	Saldanha Bay	0,67 - 2,00		[45]*
	Saldanha Bay	1,04 - 5,39		[96]
	South coast	2,97 - 14,3	7,7	[94]#
Pb	Bloubergstrand	0,07 - 1,43	0,84	[76] (June)
	Bloubergstrand	1,88 - 4,16	2,70	[76] (Nov)
	Saldanha Bay	0,27 - 0,67		[45]*
	Melkbosstrand		0,67	[89]*
	Saldanha Bay	0,65 - 11,11		[96]
	South coast	0,11 - 21,90	1,00	[94]#
Zn	Bloubergstrand	16,0 - 91,7	58,1	[76] (June)
	Bloubergstrand	67,1 - 118	84,3	[76] (Nov)
	Saldanha Bay	30,67 - 100		[45]*
	Melkbosstrand		106	[89]*
	Saldanha Bay	40,84 - 122,22		[96]
	Knysna		86	[89]#
	South coast	71,00 - 185	92	[94]#

* Calculated assuming water content of 85%.

\# *Perna Perna*, all others were *Choromytilus meridionalis*.

not support this suggestion, since phytoplankton productivity in this area is probably at its peak in November. There is, however, a tendency for metal concentrations to decrease in the warmer months because of the effect of temperature on the rate of excretion [16]. In scallops from the English Channel it was found that the highest concentration generally occurred in the winter months when the water was around 8 °C, while metal levels were lowest in the summer with temperatures around 15 °C. Along the west coast of South Africa, the opposite situation arises because of the extensive upwelling which occurs in summer. Measurements by this laboratory and others [1] indicate that this upwelling normally reduces the water temperature in inshore regions to about 10 °C, while winter temperatures are higher, in the region of 15 °C. This may account for the fact that higher concentrations occurred here in November, when the water would have been colder than in June.

It is interesting to note the low concentrations of cadmium obtained. These are not in agreement with some particularly high levels (up to 165 ug g^{-1}) which have been found repeatedly in the marine whelk *Bullia digitalis* from Ou Skip, 13 km north of Bloubergstrand. *Bullia* is not strictly comparable to *Choromytilus* since it is a secondary consumer and would be expected to have a higher concentration than a primary consumer. The results are nevertheless anomalous and will be investigated further.

The correlation matrixes for all metals are given in Table 17. For the June survey, the following strong correlations can be seen: Cu-Fe, Cu-Mn, Cu-Ni, Cu-Zn, Fe-Mn, Fe-Ni, Fe-Zn, Mn-Zn, Ni-Zn. Thus the five metals, copper, iron, manganese, nickel and zinc appeared to be all closely interrelated, although the nature of this relationship is not known. It is interesting to note the similarity of these correlations and those obtained by Watling [92] for *C. meridionalis*. For the November survey, however, only three strong correlations can be seen: Cu-Zn, Ni-Zn and Fe-Mn. In this case, copper, nickel and zinc as a group appeared to be closely related as did iron and manganese. In contrast to the June results, iron and manganese did not appear to be related to copper, nickel and zinc. However, since copper and zinc concentrations both showed significant increases from June to November while that of nickel did not, these correlations may have been coincidental.

TABLE 17: Correlation matrix.

JUNE SURVEY

	Cd	Cu	Fe	Pb	Mn	Ni	Zn
Cd	1,000						
Cu	,055	1,000					
Fe	,291	,909**	1,000				
Pb	- ,071	,263	,228	1,000			
Mn	,076	,800**	,752**	,204	1,000		
Ni	,042	,682**	,618**	,351	,427	1,000	
Zn	- ,011	,945**	,815**	,301	,811**	,753**	1,000

Number of observations: 17
Significant (r): ** (99%) 0,606
* (95%) 0,482

NOVEMBER SURVEY

	Cd	Cu	Fe	Pb	Mn	Ni	Zn
Cd	1,000						
Cu	- ,261	1,000					
Fe	,496	- ,205	1,000				
Pb	,087	,434	,448	1,000			
Mn	,561*	- ,056	,701**	,192	1,000		
Ni	,010	,496	- ,005	,280	- ,185	1,000	
Zn	,100	,786**	- ,062	,420	- ,103	,677**	1,000

Number of observations: 16
Significant (r): ** (99%) 0,623
* (95%) 0,497

No really significant correlations could be found between total metal content and dry body mass, although these have been found by other workers [12, 92]. The reason they were not observed in this work is probably because of the small size range of the animals used. The natural scatter would conceal any correlation over a small size range.

In the June survey, the females had higher concentrations than males of copper, manganese, zinc (99% significance level), and iron (95% significance level). There were no significant differences between males and females in November. The concentrations of some metals, particularly zinc, have been shown to be highly correlated with sex [92]; however it is felt that the sample taken in this work was too small for any definite relationship to be deduced.

Conclusion

The trace metal contents of the mussel *Choromytilus meridionalis* show significant variations between different individuals and with season. The seasonal variations may be related to water temperature. There may also be a significant relationship between the sex of the animal and the trace metal levels, since some differences were noted between males and females in June. Because of possible sexual differences, shown both in this and other studies, it may be advisable that, in order to avoid possible confusion arising from fluctuations due to the sexual cycle, only sexually immature animals, e.g. 10 to 15 mm shell length, be used for monitoring purposes.

RECOVERY POTENTIAL AND CHRONIC OIL POLLUTION ON THE SOUTH AFRICAN COAST [54]

The Venpet/Venoil tanker collision on 16 December 1977 focused attention on oil pollution around the South African coastline. About 31 000 tons of bunker oil were lost, some of which reached the shores of Victoria Bay and Klein Brak river on the south coast of South Africa, northeast of Mossel Bay. Major clean-up operarations were conducted at Little Brak River Beach while a sandy beach at Victoria Bay was left fairly undisturbed making these ideal study areas.

Several studies have shown [83] that environmental recovery following an oil spill can take several years and that many sites recovered only after about ten years [61]. Recovery cannot begin until the pollutant has been removed or diluted to an acceptable degree. Chemical, microbial and mechanical action together with degradation processes such as dissolution, evaporation and photo-oxidation cause the eventual breakdown and dispersal of the spilt oil. Primary biodegradation of beached oil is not as effective as had been thought previously and straight-chain hydrocarbons have often been found to persist for more than two years [11]. But evidence from the Arrow [79] the West Falmouth, Metula and Amoco Cadiz oil spills indicated a strong correlation between the degree to which an area is exposed to wave action and the longevity or persistence of oil within that area.

The southern Cape coast is fairly exposed to wave action and recovery of some beaches around Cape Town from a very small spill in 1973 took about four months [13] as judged by the stress symptoms of the sandy beach snail, *Bullia digitalis*. After the Venpet and Venoil disaster near Mossel Bay, large quantities of bunker oil reached the coast on 4 January 1978. When first washed ashore, the main oil sheet contained 85% water and sand. This water-in-oil emulsion (mousse) was stranded at the high water level and deposited during ebb tide. As the tide turned the oil tended to adhere to the sediments and subsequent tides buried it (Figure 28). The deposition of oil adhering to the sediments is clearly illustrated as a single narrow black band 24 cm below the surface.

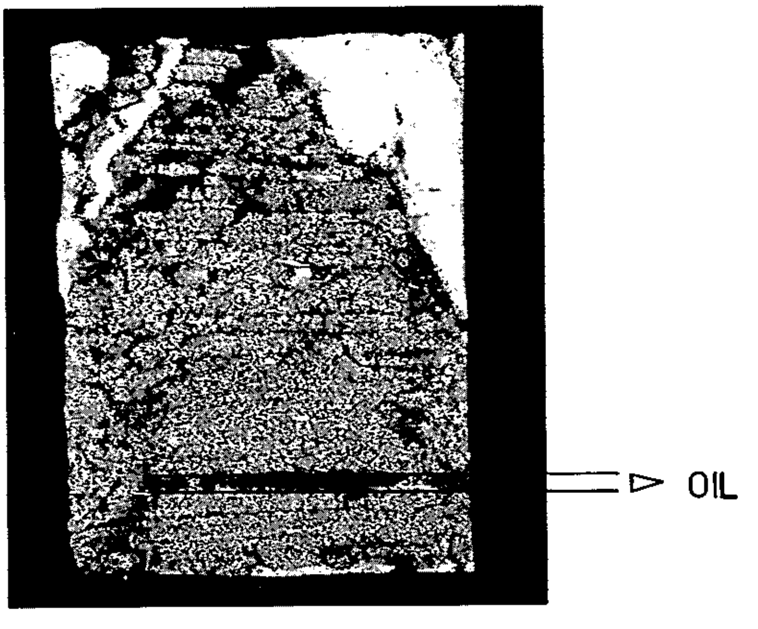

FIG. 28. RESIN CORE CAST FROM MARCH 1978.

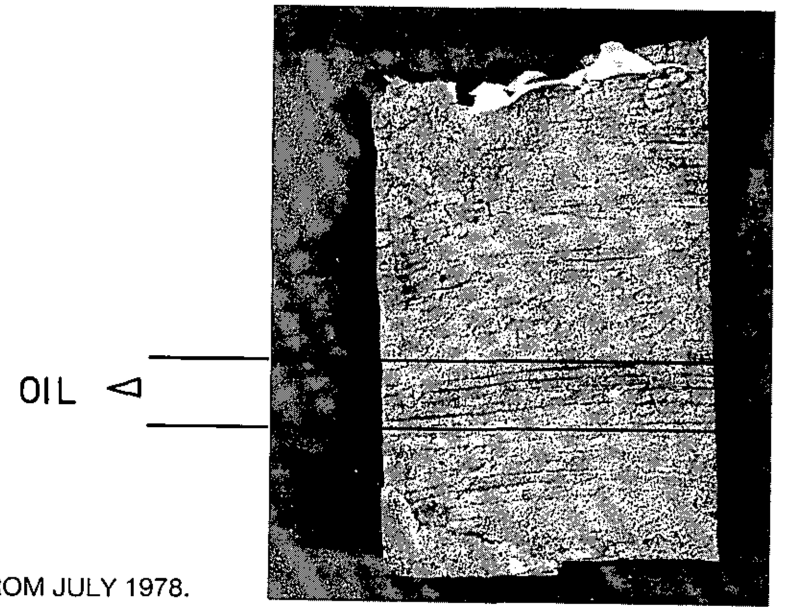

FIG. 29. RESIN CORE CAST FROM JULY 1978.

The contaminated beaches then underwent cycles of erosion and deposition depending on the onshore stress and the stage in the tide cycle. The vertical striations in Figures 28 and 29 are the results of the changing wave conditions. In April (Table 18), during a cycle of erosion, the oiled sediment particles were refloated and the oil concentration was reduced by 35%. By July during a deposition cycle, most of the oil had again been buried and was well mixed. A typical cast is shown in Figure 28. The previously narrowly-defined mousse band is seen to have spread visibly, but some reduction (2.8%) of oil contamination due to weathering and loss had taken place. The dilution of the oil mousse reduced the stress effect on many marine organisms and recolonisation had begun. At this stage the beaches appeared to have recovered and the psammolittoral meiofauna concentration rose to about prespill levels.

TABLE 18: Residual fuel oil in 100 g of sediment from the southwestern Cape coast.

Month	Year	Mean sediment oil concentration (mg)	Mean R-value (A256/A228)
March	1978	2,81	1,48
April	1978	1,83	1,45
July	1978	2,73	1,46
March	1979	6,29	1,62
December	1979	1,57	1,60

Unfortunately the fate of this particular oil could not be monitored any longer, because during a deposition cycle in March 1979 a higher average oil content was extracted from the beach sediment. These higher oil concentrations were characterised by a different R-value (ratio of absorption at 256 and 228 nm), indicating not burying of refloated oil but new, different oil and tar balls adhering to the sediment of the beaches. At the same time a decline in meiofauna populations was observed. During an erosion cycle in December 1979 the second batch of oil had been refloated and judging by the R-value, no new oil had been deposited during that time interval.

In view of these results it is reasonable to conclude that most south-western Cape beaches are chronically polluted with oil. This is not surprising, considering that in 1977, about 650 million tons of petroleum were transported around the Cape of Good Hope, constituting about 38% of the world movement of oil by sea [2]. This large amount of oil was carried by 3 279 tankers with an additional 3 631 vessels passing the Cape. The results indicate that the beaches can recover from accountable oil losses in about six to eight months. It is the unaccountable losses which make up the 678 tons (51,3 g m^{-3}) of oil estimated to be in the sand at any one time which causes chronic oil pollution.

In the case of sandy beaches this became apparent as a gradual darkening of the sand which earlier on was not recognised as chronic oil pollution. This suggests that throughout the world there may be many more undetected chronically polluted beaches.

RELATIONSHIP BETWEEN OIL POLLUTION AND PSAMMOLITTORAL MEIOFAUNA DENSITY OF TWO SOUTH AFRICAN BEACHES [47]

The effects of stranded oil from the tanker collision off the South African coast on the meiofauna ratio and density were monitored over a period of one year on two sandy beaches. The perturbation of two beaches was judged against reference beach meiofauna density behaviour. Major clean-up operarations were conducted at Little Brak River Beach while a sandy beach at Victoria Bay was left fairly undisturbed making these ideal study areas.

In the undisturbed beach, oil deposited in sediment depressed harpacticoid copepod numbers, while numbers of nematodes stayed similar to those of the reference levels. Removal of surface sand in the mechanically disturbed beach had a greater influence on the density of animals than oil. Both beaches showed recovery after six months, but later evidence of pollution by oil of unknown origin was found.

EFFECTS OF FLUORIDE, CADMIUM AND MERCURY ON THE ESTUARINE PRAWN *PENAEUS INDICUS* [68]

The acute toxicity of fluoride, cadmium and mercury was determined using conventional 96 h LC_{50} techniques. Fluoride was found to be relatively innocuous in terms of short-term exposure. The 96 h LC_{50} for fluoride was 1118+ or -302 mg ℓ^{-1}. It is unlikely that fluoride concentration of anywhere near this magnitude will occur in the field. Cadmium and mercury were considerably more toxic at low concentrations. The 96 h LC_{50} for cadmium was 2,07+ or -0,22 mg ℓ^{-1}, while that for mercury was 15,3+ or -2,4 ug ℓ^{-1}.

The chronic toxicity of all three elements was assessed using growth of young *Penaeus indicus* as the criterion for toxic effect. There was no significant reduction in growth with fluoride concentrations up to 11 mg ℓ^{-1}, cadmium concentrations up to 189 ug ℓ^{-1} and mercury concentrations up to 6 ug ℓ^{-1}. All three elements were readily accumulated by prawns from the water and there was good correlation between environmental and tissue concentrations after chronic exposure. Prawns from Richard's Bay, where there is an industrial source of fluoride, contained about 2,5 times as much fluoride as prawns from St Lucia Estuary (1 211 and 480 ug g^{-1} ashed mass respectively). In the chronic toxicity experiments there was a good degree of correlation between fluoride concentrations in the prawns and ambient concentration after 26 days exposure. Most of the uptake of fluoride and cadmium took place within five days, while the rate of mercury uptake increased after four days. Mercury and cadmium were deposited to varying degrees in both skeletal and non-skeletal tissues whilst fluoride was confined almost entirely to the skeletal tissue.

COLONISATION AND VIABILITY OF AN ARTIFICIAL STEEL REEF IN FALSE BAY, SOUTH AFRICA [48]

Colonisation of the wreck of an obsolete naval frigate scuttled in 34 m depth in False Bay, showed a characteristic pattern of early settlement, rapid growth and decline towards the end of the first year. Initial colonisation was by barnacles.

The large amount of detritus and later the muscle spat which settled on top of and inside barnacle shells impeded feeding and respiration. The smaller *Balanus algicola* were more effected than the larger *B. maxillaris*. Later mussels became the most important organisms reaching a biomass of some 790 g/m^{-2} wet mass) in places. Thereafter the mussel population decreased steadily, due partly to predation by large numbers of starfish *Marthasterias glacialis*.

After two years the mussel population had all but disappeared and the wreck appeared barren. A stable reef community has never been established and the small number of species present - 28 at its peak, declining to ten after one year - has been subjected to catastrophic events both biotic and abiotic, which periodically destroyed large sections of the community.

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