

South African marine pollution survey report 1976–1979

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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

Marine Pollution surveys of the South African coast have been undertaken regularly since 1974. These surveys have been undertaken particularly at known impact areas and important estuaries, while simultaneously coastal reference lines and oceanic transects have been sampled.

This report contains information gained during the period January 1976 to March 1979, and follows on the previous report of Cloete and Oliff¹⁰. Impact areas covered by this report include East London and Algoa Bay, the Mossel Bay area, several points on the Cape Peninsula and Saldanha Bay. Estuaries visited included Kosi Bay, St Lucia, Richards Bay, Durban Bay, and the Umgababa, Umzimvubu, Mngazana, Bashee, Buffalo and Swartkops estuaries. Further south, Knysna and the Storms, Groot, Keurbooms and Bietou Rivers were studied, as well as the Wilderness Lakes. In addition information from the Berg, Olifants and Orange Rivers on the West Coast is included. Results from sampling undertaken along oceanic transects on the East Coast, the South Coast, and the West Coast are presented. Several general studies are also described, including oil spills resulting from the Goel 1 stranding on Robben Island, and the Venpet-Venoil collision, and a survey of chlorinated hydrocarbons in marine fauna of South Africa.

SINOPSIS

Opnames van seebesoedeling van die Suid-Afrikaanse kus is gereeld sedert 1974 onderneem. Hierdie opnames is veral by bekende impakgebiede en belangrike getyrviere onderneem, terwyl daar tegelykertyd monsters geneem is by kusverwysingslyne en diepseeelyne.

Hierdie verslag bevat inligting wat gedurende die periode Januarie 1976 tot Maart 1979 verkry is en volg op die vroeëre verslag van Cloete en Oliff¹⁰. Impakgebiede wat deur hierdie verslag gedek word, sluit Oos-Londen en Algoabaai, die Mosselbaaigebied, verskeie punte in die Kaapse Skiereiland en Saldanhaabaai in. Getyrviere wat besoek is, sluit Kosibaai, St Lucia, Richardsbaai, die Durbanse baai, en die Umgababa-, die Umzimvubu-, die Mngazana-, die Buffalo- en die Swartkopsgetyrvier in. Verder suid is Knysna en die Storms-, die Groot-, die Keurbooms- en die Bietourivier ondersoek, sowel as die Wildernismere. Boonop is inligting van die Berg-, die Olifants- en die Oranjerivier aan die Weskus ingesluit. Resultate van monsterneming langs diepseeelyne aan die Ooskus, Suidkus en Weskus word uiteengesit. Verskeie algemene ondersoeke word ook beskryf, insluitend oliestortings afkomstig van die stranding van die Goel 1 op Robbeneiland en die Venpet-Venoil-botsing, en 'n oorsig van gechlloreerde hidrokarbonate in mariene fauna van Suid-Afrika.

PREFACE

The preface to the previous report, edited by Cloete and Oliff¹⁰, outlines most adequately, the background to the research effort from which the present document arises. The editors refer readers to that report for more details.

The research featured in this report has been conducted by teams based in Durban and Cape Town, the latter including both the National Research Institute of Oceanography team at the University of Cape Town, and a team from Sea Fisheries Institute, studying Saldanha Bay. The Durban team, at the National Institute for water Research, was responsible for the area from Kosi Bay to Port Elizabeth. The areas between Port Elizabeth and Mossel Bay were studied by a small team based at the National Physical Research Laboratory in Pretoria, and largely dedicated to studying trace metals. The kind cooperation of all these groups has made the compilation of this document possible. Judicious use of the references cited will lead readers to more details of results. In addition all data from these studies is currently being prepared for storage in the National Oceanographic Computer Data Base at NRIO, Stellenbosch.

In the report that follows, each section has been presented in geographical order from East to West, with impact areas followed by estuaries, Oceanic Transects and some general studies.

TABLE OF CONTENTS	Page
Synopsis	(iii)
Sinopsis	(iii)
Preface	(iv)
List of figures	(vii)
IMPACT AREA SURVEYS	1
East London.....	1
Algoa Bay.....	2
Hartenbos, Little Brak & Great Brak Rivers, Mossel Bay.....	4
AECI, Somerset West.....	9
Green Point	11
Dido Valley Beach.....	14
Hout Bay.....	14
Saldanha Bay.....	17
South and West Coasts of the Cape Province.....	20
ESTUARIES.....	27
Kosi Bay.....	27
St Lucia Estuary.....	29
Richards Bay Harbour.....	31
The Southern Bay conservation area of Richards Bay.....	33
Durban Bay.....	33
The Umgababa Lagoon.....	35
The Umzimvubu Estuary.....	37
The Mngazana Estuary.....	39
The Bashee Estuary.....	40
The Buffalo Estuary, East London.....	42
The Swartkops Estuary.....	44

Keurbooms and Bietou Rivers.....	54
Groot River.....	58
Storms River.....	59
Knysna Estuary.....	60
Wilderness Lakes.....	67
Berg River (west coast).....	71
Olifants River (west coast).....	71
Orange River (west coast).....	73
OCEANIC TRANSECTS.....	74
East Coast Oceanic reference transects and coastal monitoring surveys.....	74
South and West Coast Oceanic reference transects.....	78
South Coast.....	80
West Coast.....	82
GENERAL STUDIES.....	84
Goel I.....	84
"Venpet-Venoil" Collision.....	84
Chlorinated hydrocarbon residues.....	87
REFERENCES.....	92
APPENDIX - Major Participants in the Programme.....	100
TITLES IN THIS SERIES.....	101

LIST OF FIGURES	Page
Figure 1. Location of East London sampling points.....	1
Figure 2. Map of Algoa Bay showing stations.....	3
Figure 3. Mossel Bay sampling stations.....	5
Figure 4. Sampling stations.....	11
Figure 5. Sampling stations - Hout Bay.....	15
Figure 6. Saldanha Bay station positions.....	16
Figure 7a. Currents at 5m (cm sec ⁻¹) Schematic 1972-1975.....	18
Figure 7b. Currents at 5m (cm sec ⁻¹) Schematic 1976-1978.....	18
Figure 8. Reference Beach Sites.....	21
Figure 9. Relationship between nematode and harpacticoid copepod populations (Number of animals per 100 cm ³ sediment)..	25
Figure 10. Kosi Estuary and lakes.....	28
Figure 11. St Lucia Estuary.....	30
Figure 12. Richards Bay Harbour and Sanctuary.....	31
Figure 13. Durban Bay.....	34
Figure 14. Umgababa Estuary.....	36
Figure 15. Umzimvubu Estuary.....	38
Figure 16. Mngazana Estuary.....	39
Figure 17. Bashee Estuary.....	41
Figure 18. Buffalo Estuary.....	43
Figure 19. Map of the Swartkops River showing sample sites.....	45
Figure 20. Scatter plots of Zn/Ni and Cu/Zn relationships.....	52
Figure 21. Scatter plots for the Fe/Al and Pb/Fe relationships...	53
Figure 22. Scatter plots of the Mn/Cd and Ni/Sr relationships....	53
Figure 23. Map of the study area.(Keurbooms and Bietou Rivers)...	55
Figure 24. Keurbooms and Bietou River sampling sites.....	55
Figure 25. Map of the Groot River showing sampling sites.....	58

Figure 26.	Knysna estuary.....	62
Figure 27.	Knysna lagoon.....	66
Figure 28	Location map of the Wilderness Lakes.....	67
Figure 29(A)	Bathymetric map of Swartvlei with transect line and position of profile samples	
29(b)	Cross section along transect line.....	69
Figure 30.	Profile in haloclinal section of Swartvlei.....	69
Figure 31.	Berg River Estuary.....	71
Figure 32.	Olifants River Estuary.....	72
Figure 33.	Orange River Estuary.....	74
Figure 34.	Location of sampling lines - Natal Coast.....	75
Figure 35.	Location of Transkei and Eastern Cape sampling lines..	75
Figure 36.	Location of South and West Coast Oceanic Transects....	79
Figure 37.	Temperature section - South Coast transect (summer)...	80
Figure 38.	South Coast transect - mean concentrations in the water above the thermocline.....	81
Figure 39.	Relationship between nitrate and phosphate concentrations South Coast transect - all autumn cruises combined....	81
Figure 40.	Relationship between nitrate and dissolved oxygen concentrations - South Coast transect - all autumn cruises combined.....	82
Figure 41.	Temperature section - West Coast transect (autumn)....	83
Figure 42.	Sampling stations.....	86

IMPACT AREA SURVEYS

East London

63

A brief survey was performed during April 1977 to assess the input of pollutants to the sea at East London. The survey was performed in conjunction with a more detailed study of the Buffalo estuary. Six stations between Nahoon Beach and Shelly Beach were visited (Figure 1). Measurements were made of the composition and density of the interstitial beach fauna, of trace metal concentrations in the beach sands and surf water, and of trace metal and pesticide concentrations in a variety of littoral marine organisms. A bacteriological survey of the coastal waters was undertaken on our behalf by the City Engineers Department of the East London Municipality during July 1977.

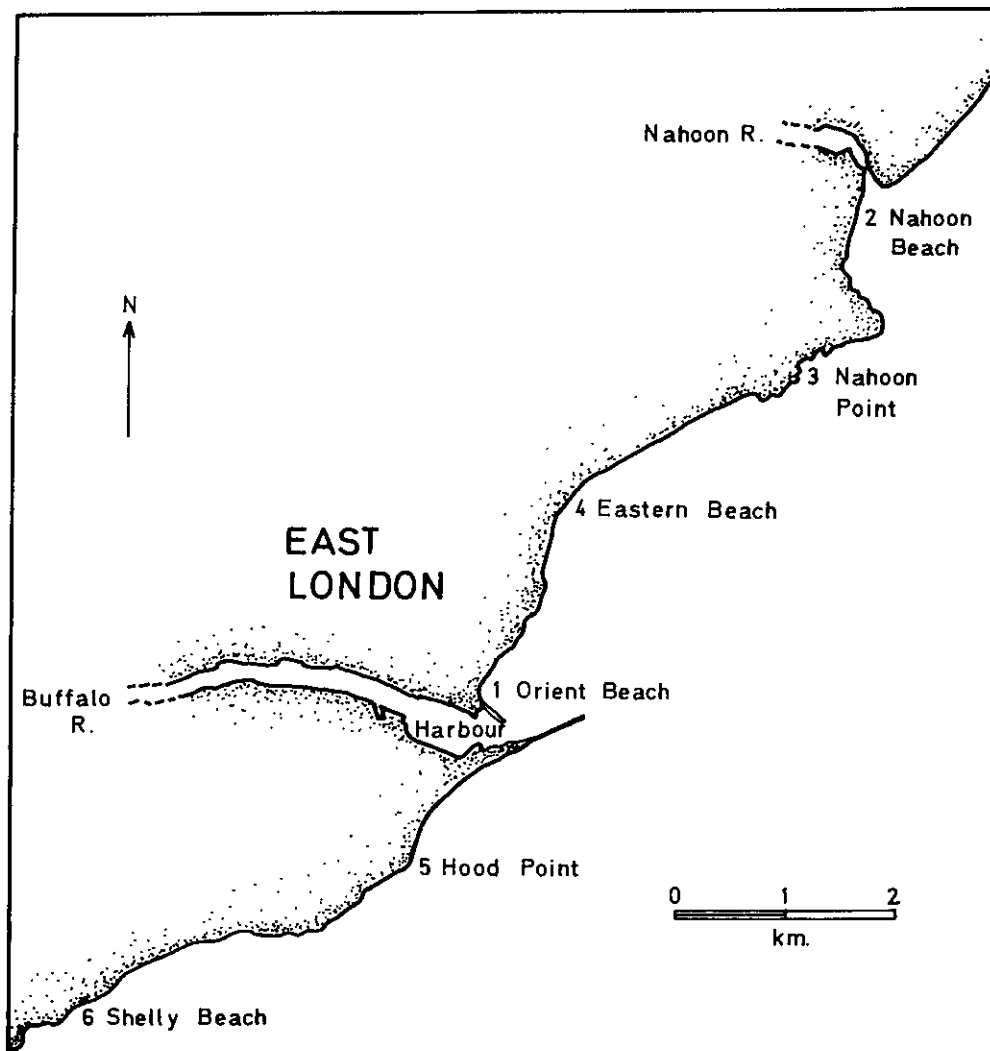


Figure 1. Location of East London sampling points.

The interstitial beach fauna was diverse and abundant at all stations. However, the faunal density was appreciably higher at station 3 indicating moderate organic enrichment from the sewage discharge ($1,35 \times 10^6 \text{m}^3 \text{a}^{-1}$) at Nahoon Point. The surf water samples were analysed for mercury, copper, cadmium, lead, zinc, iron and cobalt, whereas the beach sediments were analysed for the same elements plus chromium, nickel and manganese. The results were generally low and gave no evidence of trace metal pollution. Analysis of mussels (*Perna perna*), oysters (*Crassostrea margaritacea*), "crayfish" (*Panulirus homarus*), limpets (*Patella granularis*) and sand whelks (*Bullia* sp.) yielded generally low concentrations of mercury, copper, cadmium, lead, zinc, iron, chromium, cobalt and nickel. However, the two specimens of "crayfish" taken near the harbour wall at Orient Beach contained marginally increased concentrations of mercury (1,5 and 1,9 $\mu\text{g Hg g}^{-1}$ dry mass). Pesticide residues were low or below detection limits in all cases.

The bacteriological survey revealed generally satisfactory conditions over most of the study area. However, heavy sewage contamination was evident approximately one kilometre north of station 5 (Hood Point) and a relatively high *E. coli* I/100 ml count, indicative of moderate sewage contamination, was recorded at Nahoon Beach. These results can be attributed to a northward drift of effluents from the Hood Point and Nahoon Point sewage outfalls. The northward drift of effluent appears to be typical of west wind conditions. Under east wind conditions it is probable that bacterially contaminated water will proceed southwards, toward Orient beach.

Algoa Bay

Algoa Bay is bordered by the industrialised city of Port Elizabeth and is potentially a major impact area. During December 1975⁸² a brief survey was made at ten beach stations extending from Summerstrand to approximately 10 km east of the Swartkops estuary, and at eight offshore stations (Figure 2). Three aspects were of particular concern. Firstly, the contamination of beaches by sewage. Secondly, the potential impact of a proposed iron ore loading facility on the marine life surrounding St Croix island. Thirdly, the accumulation of pesticides and trace metals in the nearshore environment.

Oxygen absorbed values for the beach sediments and surfwater indicated moderate organic pollution between Summerstrand and the Swartkops estuary. This can be attributed to the discharge of sewage (estimated $16 \times 10^6 \text{m}^3 \text{a}^{-1}$) in the region of station S5 and to urban drainage. There was no evidence of organic pollution at the stations east of the Swartkops estuary. In comparison with Natal, the macrofauna and meiofauna of the beaches were surprisingly poor in both population density and diversity. This appears to be unrelated to pollution and is attributable rather to the fine sediments predominating in the region.

All of the offshore stations were found to support healthy benthic populations. There was evidence in both the chemical and faunal analyses of appreciable organic enrichment (OA $0,54 \text{ mg O}_2 \text{ g}^{-1}$) in the sediments around St Croix island (stations 4 to 8). This appears to be due to faecal pollution from the large seabird population inhabiting the island.

Destruction of the island as a habitat for seabirds could reduce the richness and diversity of the surrounding marine life.

A variety of marine organisms were collected in the vicinity of the beach stations and around St Croix island for pesticide residue analysis. None of the beach organisms, which consisted of gastropods (*Bullia rhodostoma* and *Burnupena cineta*) and mussels (*Perna perna*) contained DDT or similar chlorinated pesticide residues. However, a polychlorinated biphenyl (PCB) similar to Arochlor 1260 was universally present, the range being 35-75 $\mu\text{g kg}^{-1}$ wet mass. On St Croix island, mussels (*perna perna*), limpets (*Patella cochlear*) and three species of fish (*Chirodactylis grandis*, *Lithognathus mormyrus* and *Mugil* sp.) were collected for analysis. The same PCB was again present in all of the animals at concentrations up to 400 $\mu\text{g kg}^{-1}$ wet mass. In addition two eggs of the black-backed gull (*Larus dominicanus*) and Jackass penguin (*Spheniscus demersus*) were taken for analysis. PCB (4600 $\mu\text{g kg}^{-1}$), DDE (1900 $\mu\text{g kg}^{-1}$) and Dieldrin (190 $\mu\text{g kg}^{-1}$) were found in the gull eggs while only DDE (790 $\mu\text{g kg}^{-1}$) and Dieldrin (80 $\mu\text{g kg}^{-1}$) were found in the penguin eggs. The absence of PCB in the penguin eggs may be related to the fact that they feed in the Agulhas current some distance from Algoa Bay.

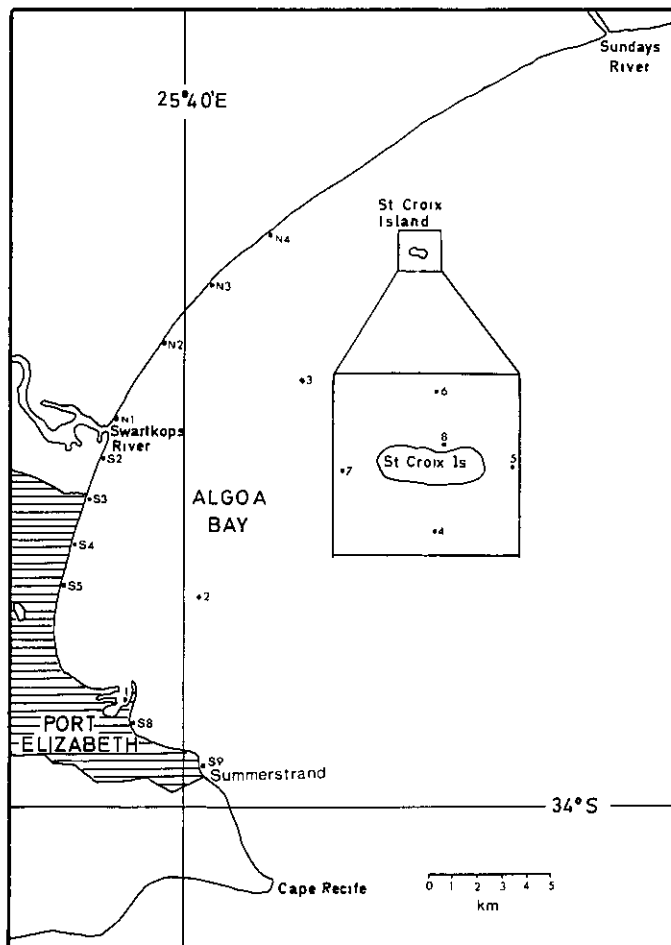


Figure 2. Map of Algoa Bay showing stations.

Sediments from the beach and offshore stations were analysed for mercury, copper, cadmium, lead, zinc, iron and chromium. The concentrations were remarkably uniform in the beach sediments, the results being low and generally compatible with those found on the Natal coast. This uniformity extended offshore to stations 2, 3 and 6. However, marginally increased concentrations were found at stations 4, 5, 7 and 8 near St Croix island.^{8,2} This was probably related to the fallout of faecal matter from the resident bird life. Within the harbour, at station 1, the sediment contained slightly increased concentrations of copper, lead, zinc, iron and chromium, as would be expected from the ore loading activity nearby. Biological tissues, collected near many of the stations, were analysed for the same suite of trace metals. Mussels (*Perna perna* and *Choromytilus meridionalis*) and gastropods (*Bullia rhodostoma* and *Burnupena cincta*) collected near the beach stations yielded generally low and consistent results. The only exception was a mercury concentration of 19,7 $\mu\text{g g}^{-1}$ dry mass in *Choromytilus meridionalis* from station S3. The samples from St Croix island, which included mussels (*Perna perna*), limpets (*Patella cochlear*) and a fish (*Oplegnathus conwayi*) also yielded generally low results.

Hartenbos, Little Brak & Great Brak Rivers, Mossel Bay

Mossel Bay

The largest concentration of population and industry along the south coast between Port Elizabeth and Cape Town is centred at Mossel Bay. The town has a population of approximately 23 000 and supports a considerable industry, notably in the Voorbaai area, where factory effluent ($100 \times 10^3 \text{m}^3 \text{a}^{-1}$) enters the sea via an open canal. Raw macerated sewage ($1 \times 10^6 \text{m}^3 \text{a}^{-1}$) is also discharged into the sea near the harbour (station 38, Figure 3). For these reasons, Mossel Bay represents a potential pollution impact area, especially since considerable development is planned for the future. Three rivers, the Great Brak, Little Brak and Hartenbos, enter the sea in the bay area. There is a small settlement near the mouth of each of the rivers and the whole area is popular as a tourist resort. The town of Great Brak River supports a tannery and a shoe factory.

The basement of the area is formed by the George Granite and associated metamorphics. This Series consists of well jointed medium-grained granites which are usually weathered to a depth of 10 metres.^{9,3} Because it is the hardest and most resistant Series, it forms the high ground to the north of the area. A considerable period of weathering took place after the formation of the granite and before the Cretaceous marine transgression caused deposits to be laid down unconformably on top of it.

After the Cretaceous period, one of isostatic readjustment occurred during the Tertiary and Quaternary periods. This resulted in the elevation of these deposits to as much as 70 m above sea level. The Tertiary and Quaternary deposits are represented essentially by coastal dunes which in some cases have been stabilized by the formation of calcrete. In some areas these dunes rise to 60 m above sea level and are composed of both eolian and marine sands. In the area of the Great Brak River they are

also backed by dune ridges running inland, signifying that the frontal dunes are essentially stable.

All three rivers have developed extensive flood plains composed of sand and clay and covered by vegetation.

Samples of sediment and water were taken from 34 stations in the vicinity of Mossel Bay during July 1978. These include 9 stations in the Great Brak River, 4 in the Little Brak River, 5 in the Hartenbos River, 4 in the Mossel Bay harbour, 8 along the beach around the factory outfall at Voorbaai and 4 from apparently clean beaches (stations 30, 34, 35 and 36) for reference purposes (Figure 3).

On the day of sampling, the current in the bay was observed to be moving in a clockwise direction. The survey was conducted during a period of prolonged drought when the rivers were flowing very weakly and the mouths of both the Great Brak and Hartenbos Rivers were closed. These two rivers were thus not subject to the influence of tides. The salinity of the Great Brak River was approximately 23‰ for most of the lower reaches up to the town of Great Brak River, where the salinity started to decrease. The Little Brak River was much more strongly influenced by the sea, with the salinity decreasing from that of normal sea water to 31‰ at the station farthest upstream. Although the Hartenbos River was also closed, the salinity reached a value of over 33‰ near the mouth, probably as a result of evaporation.³³

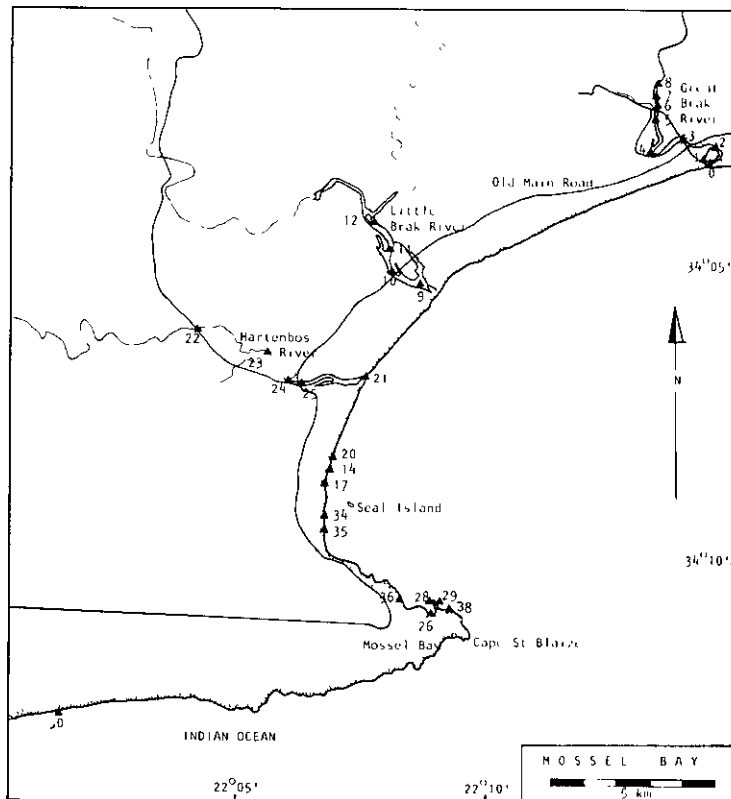


Figure 3. Mossel Bay sampling stations.

The total phosphorus concentrations in the three rivers ranged from 0,12 to 3,39 $\mu\text{moles l}^{-1}$. No particular trend could be observed. Nutrient concentrations near the factory outfall at Voorbaai were high but these levels diminished rapidly with distance from the discharge. Concentrations at other stations were all within the normal range expected for unpolluted areas.⁷⁰ As is normally the case, nutrient levels in interstitial water in the beach were higher than in the corresponding surface water. The levels were however, of the same order as those observed in samples from Jeffreys Bay and Keurboomstrand, two reference beaches along the south coast.

The OA values (450 mg l^{-1} maximum) for the factory effluent samples were extremely high, being approximately a hundred times higher than those of normal sea water. On the day of sampling, the discharge consisted of a foul-smelling, soupy liquid containing a considerable quantity of bean husks. The temperature was 10° higher than that of the sea. However, it appears that this effluent was rapidly diluted by the sea water as the OA values of samples taken 10 m away on either side of the outfall were normal. The OA values of some of the river samples³³ were also high, but this was to be expected since these samples were taken in reed beds and contained large amounts of organic detritus.

Except for the factory effluent, which had a pH of over 10, all samples had pH values in the normal range.

The sediment collected in the Little Brak River directly under the main road bridge consisted of a mixture of oil and sediment particles. This oil was residual material from the "Venpet-Venoil" spill which occurred in December 1977, some 8 months previous to the survey. Although a certain amount of oil still existed in depressions in this area, as indicated by an oily sheen which appeared in the water whenever the sediment was disturbed, most of the rest of the river appeared to be clean and seemed to have recovered well from the oil spill.

Meiofaunal samples were collected from Voorbaai beach and three other reference stations. The communities were made up predominantly of nematodes and harpacticoid copepods, with smaller numbers of flatworms, polychaetes, oligochaetes, archiannelids, mystacocarids and others. It was apparent from their distribution that the animals feed on the factory effluent although they tend to keep out of the effluent itself, large numbers of animals being found on both sides of the discharge while there were very few in the outfall. Numbers of individuals appeared to decrease towards background levels (indicated by the reference stations)³³ with increasing distance from the discharge.

The substantial differences between the numbers of animals at one of the reference stations (35) and those nearer the outfall (17 and 18) cannot be explained in terms of differences in the sediment characteristics, nor can they be accounted for by different sampling heights along the beach since all samples were taken from the half-tide mark. Furthermore, while the reference stations all had the greatest numbers of animals in the top 100 mm of sediment and the least in the deepest sample, the inverse was observed at station 18, 10 m north of the outfall. This station received

the full impact of the pollution and it is only probably at 200 mm below the surface that the pollutant reaches a dilution acceptable to the meiofauna. The distribution of animals was again normal 200 m north of the discharge.

Distribution of metals in surface water of the estuaries

Eighteen water samples were collected from the three rivers during July 1978 and sample sites are shown in Figure 3.

Trace element levels were generally low in the Hartenbos River although iron, manganese, zinc, copper, cadmium and nickel were somewhat elevated at station 24, near the road causeway and at station 21, near a farm track. Cadmium and copper levels were higher in the Little Brak River than in either of the other rivers, although nowhere did they attain significance. Water samples from the Great Brak River had trace element levels which were approximately average for rivers in the south-eastern Cape. Iron attained some significance downstream of Great Brak River town, but the highest concentrations of this element were upstream of the town and therefore do not indicate any pollutant source. Mercury levels in the three rivers attained levels above background ($0,025 \mu\text{g Hg l}^{-1}$ for rivers in the eastern Cape, but they were nowhere as high as the $0,400 \mu\text{g Hg l}^{-1}$ found in Knysna Lagoon which was considered to be indicative of urban contamination.⁹²

Distribution of metals in surface sediments of the estuaries

Eighteen surface sediment samples were collected from the rivers, sample sites coinciding with those for surface waters, figure 3.

The metal concentrations found in the surface sediments of the Hartenbos, Little Brak and Great Brak Estuaries are listed in Table 1.

Metal levels in the surface sediment of all three estuaries may be considered as average for rivers of the south-eastern Cape. The only exceptions were those at Site 23 (Hartenbos River) where lead, cobalt, nickel, chromium and mercury levels were considerably elevated above background; Sites 11 and 12 (Little Brak River), where cobalt, nickel and chromium were elevated and Site 4 (Great Brak River) where cobalt, nickel and chromium were also elevated. In addition, chromium was elevated between Sites 3 and 6 on the Great Brak River and in view of the extremely high chromium levels at depth, this river must be considered to be extensively polluted by this metal.

Mercury concentrations in surface sediments from the Little Brak and Great Brak Rivers were at background levels for the eastern Cape. In the Hartenbos River, however, there was evidence of mercury build-up, especially at station 23 near the farm track. Sediments from this location also had the highest levels of copper, lead, zinc, cobalt, nickel and chromium in the area.

TABLE 1. METAL DISTRIBUTION IN SURFACE SEDIMENTS

SAMPLE SITE	Concentration ($\mu\text{g g}^{-1}$)													Hg (ng g^{-1})			
	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Na	K	Ca	Mg	Sr		Al	Cr	
Great Brak R.	0	0,9	1,9	2,4	1690	7	0,1	0,6	0,016	1490	256	70100	2040	28	990	2,4	0,003
	1	1,2	4,2	6,5	4050	25	0,5	1,1	0,023	1500	345	95500	2670	830	1610	6,1	0,002
	2	1,5	8,8	6,2	4250	25	0,5	1,1	0,035	1580	434	85500	2580	560	2180	6,6	0,003
	3	1,5	4,5	6,6	3360	22	0,8	1,3	0,020	2920	600	58200	1940	514	334	12,0	0,017
	4	6,0	9,4	14,0	11900	103	3,7	6,0	0,019	7210	2100	1820	2010	21	1850	19,2	0,006
	5	5,9	8,6	13,1	10400	58	2,2	4,6	0,013	8860	1660	1350	280	21	1480	14,8	0,034
	6	6,3	9,4	17,1	10900	64	2,6	4,3	0,020	9400	1890	1400	250	20	1540	16,2	0,010
	7	1,7	4,2	6,5	13600	240	1,2	2,4	0,012	10600	2100	1350	270	20	1650	8,4	0,007
	8	1,8	2,1	4,6	15400	360	0,6	0,9	0,008	15400	2400	960	170	3	2140	5,9	0,006
Little Brak R.	9	1,8	10,0	2,9	1350	18	0,3	0,7	0,020	1960	400	89200	240	31	1240	2,6	0,001
	10	1,9	6,8	9,3	5580	33	1,3	2,8	0,072	2870	1050	5320	1080	2	4730	3,7	0,005
	11	7,1	16,5	22,5	13100	150	5,0	9,4	0,026	6200	2250	10900	2910	50	16000	20,3	0,009
	12	5,2	9,4	14,7	9190	180	3,5	3,7	0,035	5330	2030	9790	2790	91	15300	15,6	0,006
Hartenbos R.	21	1,9	10,3	6,0	1400	33	0,8	1,6	0,032	2140	881	81200	2260	27	2410	1,6	0,010
	22	1,8	3,2	7,3	16500	300	2,1	4,6	0,015	4130	1960	1790	250	3	15900	2,4	0,037
	23	8,5	37,5	22,6	16100	304	7,0	11,4	0,068	2660	353	4050	2690	3	20200	23,4	0,161
	24	4,1	10,2	11,7	698	52	1,5	4,9	0,011	1380	1920	1780	2130	1	12700	6,0	0,046
	25	5,1	12,6	15,3	2500	186	0,9	3,2	0,025	2000	750	75200	2150	32	2400	1,5	0,009

Distribution of metals in depth

Thirteen sediment cores were collected in these three rivers and analysed for those elements already determined in the surface sediments. Sample locations are coincident with those of the water and surface sediment samples and are shown in Figure 3. Sediment cores were taken on the side of the nearest available mud or sand bank.

All three rivers exhibited indications of unnatural build-up of toxic metals.⁹³

The main area of contamination in the Hartenbos River was at station 23 where levels of copper, lead, zinc, cobalt, nickel, cadmium and chromium were significantly elevated above the geometric means for elements in the study area (Table 2). Cobalt and nickel reached levels higher than in the other rivers.

Stations 10 and 11 in the Little Brak River also exhibited elevated metal concentrations, although these were not as significant as in the other two rivers and may simply represent contamination from the road and railway.

Perhaps the most interesting river in the study area is the Great Brak River. Here, especially associated with stations 3, 4 and 5, levels of copper, lead, zinc, cobalt, nickel and cadmium were elevated and their presence is probably indicative of industrial contamination. At station 4 chromium levels reached the highest found in sediments anywhere in the eastern Cape, one sample containing 1,13% chromium. This represents gross contamination by man and the source of this metal will be located during a future survey of the estuary.

Metal levels in the area are generally low and do not pose a pollution threat. The obvious exception is the chromium in the Great Brak River, which, were it to be remobilized during for example a period of flooding, could possibly reach toxic levels for fauna in the area.

AECI, Somerset West

A survey was conducted around the AECI outfall near Somerset West. This outfall discharges waste and sewage from the AECI factory complex and Triomf Fertilizers (Total maximum 1500 m³day⁻¹). All nutrients measured showed a prominent increase in and around the outfall, rising to between 2 and 40 times higher than background levels. These high concentrations fell off rapidly to the east, but less markedly to the west, the direction in which the plume was being carried on the day of sampling. The return to background was generally less rapid in interstitial than surface water. Dissolved oxygen concentrations and pH were both low (5,7 mg l⁻¹ and 5,3 respectively) in the outfall. Apart from some evidence of copper contamination (maximum 3,2 mg g⁻¹), trace metals in sediments were generally near normal (Eagle,²⁹1976).

Of the four dominant meiofaunal types, which include nematodes, turbellarians, polychaetes and harpacticoid copepods, only the first two

TABLE 2. GEOMETRIC MEANS ($\mu\text{g g}^{-1}$) OF METAL CONCENTRATIONS IN CORES FROM THE HARTENBOS, LITTLE BRAK & GREAT BRAK R.

CORE NO	Concentration ($\mu\text{g g}^{-1}$)														
	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Na	K	Ca	Mg	Sr	Al	Cr
0	1	2	3	2057	11	0,3	0,8	0,013	1862	259	77180	2393	40	1263	3
1	1	2	6	3933	23	0,5	1,1	0,021	1904	392	89820	2603	702	1895	6
2	1	3	6	3706	22	0,5	1,0	0,028	2144	445	80690	2446	524	2227	6
3	3	7	15	7897	61	1,8	3,4	0,034	5479	1262	45350	2550	407	6423	21
4	11	17	36	15366	107	3,1	5,9	0,061	7149	2320	1670	2818	25	1943	801
5	6	10	16	11661	100	2,4	4,6	0,017	5997	1964	1126	2252	14	1701	34
9	2	9	3	1415	22	0,2	0,7	0,030	1951	380	89717	2507	100	1079	3
10	3	11	12	7326	50	1,9	4,7	0,026	2772	1436	3921	1904	1	7719	10
11	3	10	11	7520	78	2,2	4,1	0,024	2810	1212	28643	1880	18	7691	11
12	3	6	9	6709	85	2,0	3,0	0,019	3009	1207	15940	1870	124	7960	11
21	2	9	6	1845	32	0,7	1,5	0,030	1984	702	81709	2100	26	2079	3
23	7	21	20	11399	187	5,1	11,4	0,028	1808	3564	1307	2629	45	22005	19
24	3	9	11	9933	52	1,7	4,2	0,006	3638	2121	3077	2269	3	11517	8
TOTAL	3	7	9	5288	47	1,3	2,6	0,024	2851	971	51933	2334	155	4307	44 (12)

occurred in significant numbers. There was, however, a dramatic decrease in the numbers of all animals close to the outfall.²⁹ The almost total absence of harpacticoid copepods is indicative of stress caused by low oxygen levels. This is particularly noteworthy when compared with results obtained at nearby Swartklip beach, where particularly high numbers of meiofauna were encountered.

Green Point

Approximately 30 megalitres of raw sewage is discharged daily via a pipeline into the sea off Green Point, Cape Town. The prevailing currents tend to carry the plume in an easterly direction parallel to the coastline. With onshore winds, however, the plume is driven towards the coast. In addition, the pipeline leaks on occasions and releases effluent close to the shore. The proximity of the discharge to a metropolitan area makes it a potential pollution hazard.

A detailed study of the area, carried out from June 1967 to June 1970 by Atkins², included measurements of currents, winds, tidal effects, waves, water temperature, salinity, bacteria and dilution factors. No other chemical or biological observations were made, therefore a survey was made to determine the present state of the outfall and its immediate surroundings.⁷¹

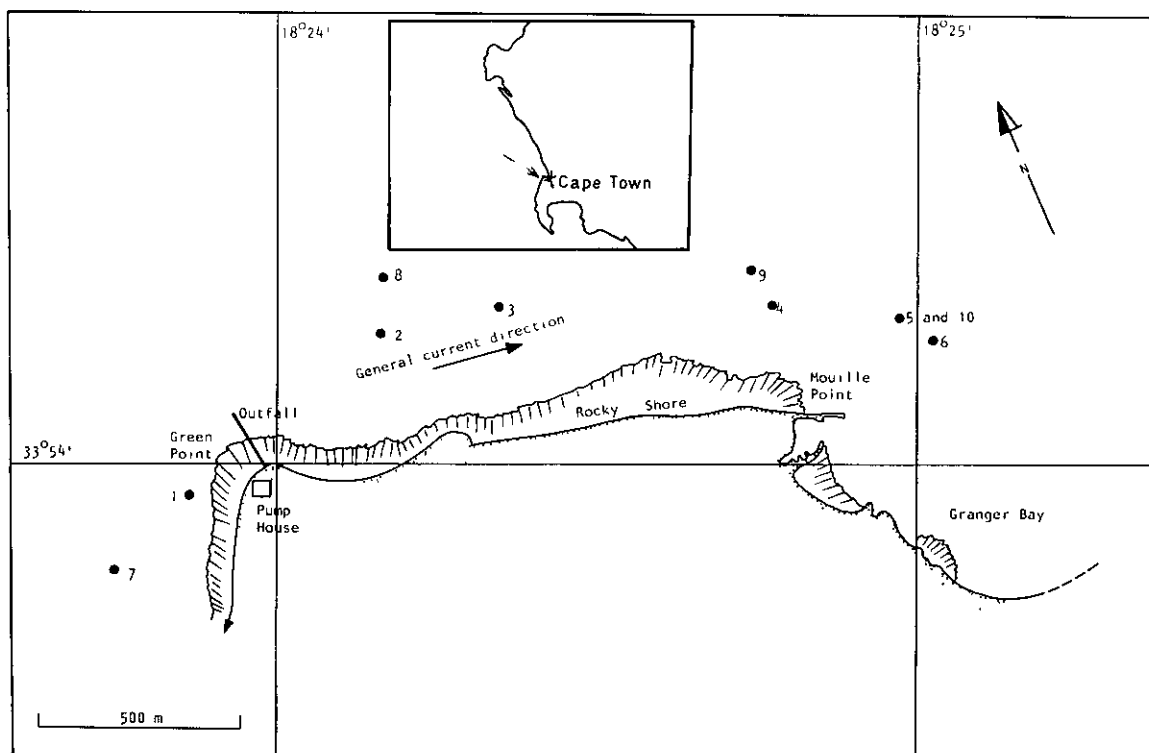


Figure 4. Sampling stations.

The survey was carried out during autumn from the research vessel "Thomas B. Davie". Conditions were almost windless and the sea was calm. Samples were taken from 10 stations both upstream and downstream of the outfall (figure 4). Water samples from just below the surface (at a depth of approximately 1 m) and near the bottom (at approximately 12 m) were obtained by means of non-metallic sampling bottles, and sediment and biological samples were collected by scuba divers using dry-suits and full face-masks to minimize the risk of infection. Complete depth cores could not be taken owing to the rocky underlay in the area and at some stations only the finely divided sludge which had settled in rock hollows could be sampled. Sediment samples were obtained from stations 1-6 and where sufficient sediment existed for a small core to be taken; this was divided into two sections, labelled 'top' and 'bottom'. At most stations sediment samples were taken in duplicate.

The OA values are a measure of the easily oxidisable content of the sediments and hence give some indication of the extent of the sewage pollution. OA values of 0,35-16 mg g⁻¹ at Green Point illustrate the organic enrichment of the area compared to Camps Bay where values of 0,03 and 0,20 mg g⁻¹ were obtained.³¹ One sample from station 6 at Green Point, had a particularly high value (16,0 mg g⁻¹), and that of another from station 5 was also relatively high (8,6 mg g⁻¹).

High concentrations of cadmium, copper, lead, nickel and zinc were found in the sediments. It is interesting to note that the concentrations of all metals were particularly high in those samples from stations 5 and 6 with high OA values.

The most striking feature of the results is the close correlation between the concentrations of all the metals examined (except cadmium) and the OA levels of the sediments. The correlation matrix is given in Table 3.

TABLE 3. CORRELATION MATRIX FOR TRACE METAL CONCENTRATIONS AND OA VALUES
(Results for sample 6a(top) omitted).

	Cd	Cu	Fe	Mn	Ni	Pb	Zn	OA
Cd	1,00							
Cu	0,80	1,00						
Fe	0,53	0,48	1,00					
Mn	0,35	0,47	0,87	1,00				
Ni	0,81	0,82	0,84	0,69	1,00			
Pb	0,60	0,81	0,51	0,38	0,77	1,00		
Zn	0,69	0,80	0,86	0,73	0,96	0,82	1,00	
OA	0,64	0,68	0,86	0,67	0,92	0,75	0,95	1,00

Number of observations - 13

In the calculation of this matrix, the results from sample 6a(top) were omitted, since one particularly high value, even though it may be correct, can give the correlation coefficients a false bias. For $n = 13$, the critical value for the correlation coefficient at the 0,95 significance level was 0,48. From this it can be seen that the concentrations of a large number of metals were closely correlated with each other. High values of r for the metal-OA correlations are to be noted. (With the results for sample 6a(top) included, these values, except that for cadmium, were all $<0,89$). This is strong evidence for the association of the trace metals with organic material in the sediments.

The reasons for the high concentrations of both the metals and organic material at stations 5 and 6 are uncertain. These samples were collected farthest from the outfall and were expected to show reduced pollution effects. However, Atkins² has shown that the currents in this area have significant onshore components, particularly during winter. With the general current direction being from west to east, the topography of the shoreline in this vicinity could lead to the formation of an eddy which would result in the deposition of suspended material. The definite accumulation of sludge in the area, as shown by the high metal and organic concentrations, is evidence for this.

Although the salinities were generally fairly uniform (mean salinity $34,57 \pm 0,117_{\infty}$), the mean bottom salinity was slightly higher than that at the surface. Nutrient concentrations were on the whole fairly similar to those at the nearby unpolluted Camps Bay beach used as a reference; total phosphorus was slightly higher, silicate levels were approximately twice those at Camps Bay, whereas nitrite and nitrate concentrations were similar at the two sites. The highest nutrient concentrations were obtained at station 8, (figure 4) close to the area where the discharge plume became visible. There was a definite decrease in dissolved oxygen concentrations near the outfall, where levels fell to just over 3 mg l^{-1} . OA values were high in the surface water downstream of the discharge.

Biological samples were collected at stations 1-6 both upstream and downstream of the sewage outlet. It was clear that nematode worms dominated the meiofauna, though there appeared to be no consistent trend in numbers of animals in relation to distance from the outlet pipe. Station 2, which was closest to the outfall, supported the highest concentration of nematode worms. In contrast with the large numbers of nematodes present, all other groups were represented by extremely small numbers. An interesting feature of the analysis is that, although the numbers of nematodes were extremely high, the diversity of species was small close to the outfall. Total numbers decreased with distance from the outfall, but this was apparently accompanied by an increase in the species diversity.

Harpacticoid copepods, being sensitive to low oxygen stress, are normally excluded from areas where anoxic conditions prevail. At Green Point they were present in only very small numbers and at some stations were completely absent. It is particularly significant that no harpacticoid copepods were found in those sediments with OA values greater than $0,7 \text{ mg g}^{-1}$, whereas they were present in all samples whose OA values were

less than $0,7 \text{ mg g}^{-1}$. While the figure of $0,7 \text{ mg g}^{-1}$ may not in itself be significant, it nevertheless indicates the effect of anoxic conditions on this group of animals.

The other meiofaunal groups, which include archiannelids, polychaete worms, flatworms and oligochaetes, have not been considered in any detail since an analysis of the whole spectrum of taxa was not practical within this programme. However, the presence or absence of these animals is considered to be important in the overall analysis.

The community composition of the macrofauna varied markedly in terms of the dominant species present. Upstream of the outfall the principal species were *Aulacomya magellanica* (ribbed mussel), *Parechinus angulosus* (common sea urchin) and *Bunodactis* (sea anemone). These were present in large numbers in a seemingly unspoiled environment. However, downstream of the outfall, at station 2, *Aulacomya* had completely disappeared and was replaced by *Pentacta doliolum* (sea cucumber). The numbers of *Parechinus* had also increased. The rocky surfaces and hollows were covered by a pulpy brown, very finely divided detritus, obviously caused by sludge settlement from the outfall. The exclusion of *Aulacomya* and the appearance of *Pentacta* at the station downstream of the outlet were probably due to differences in their modes of feeding. *Aulacomya* could not be supported because the suspended matter on which it feeds was too fine close to the outfall, which would have caused its gills to become clogged. Its absence is therefore a qualitative measure of the turbidity in the area.

Dido Valley Beach

A meiofaunal examination was carried out on the beach around the Marine Oil Refineries in Simon's Bay. Results of a chemical survey have already been reported.¹⁰ The beach was sampled on two occasions. The most notable features of the results obtained were the almost complete absence of harpacticoid copepods, again indicative of stress from low oxygen content and the generally low numbers of nematodes on the beach, particularly near the outfall.

Hout Bay

Hout Bay is a large U-shaped indentation along the west coast of the Cape Peninsula. It is about 2,5 km long and nearly 2 km wide. A sandy beach lies along the northern shore and steep, rocky cliffs form the eastern boundary. A commercial fishing harbour with its associated industry, is situated on the western side of the bay and sewage is discharged nearby ($<500 \times 10^3 \text{ m}^3 \text{ a}^{-1}$) (Figure 5). The magnificent scenic beauty of the area has unfortunately been marred by the development which has taken place around the harbour. The beach, a popular recreational area, is bisected by the Hout Bay River, a small stream which flows weakly, especially during the summer months. Owing to the presence of the fish processing factories and sewage outfall, the beach may be regarded as a potential pollution impact area and has been surveyed to ascertain the extent of possible chemical and biological degradation.

The survey was carried out in summer, and on the day of sampling an extremely strong south-easterly wind was blowing. These conditions normally result in pronounced upwelling along this stretch of coast. Samples were taken at five stations along the beach and two inside the harbour. One beach station (3) was in the mouth of the Hout Bay River, which contained very little water and tended to meander across a fairly wide section of beach.

Three particularly significant observations were made: the organic enrichment of the beach, indicated by high OA values, the extremely low values of dissolved oxygen in the interstitial water and low numbers of meiofauna in the sediments. The OA values of the surface water increased significantly towards the harbour end of the beach, where values of over $0,2 \text{ mg g}^{-1}$ were recorded. This represents a four- to fivefold increase over 'normal' values, which are usually in the region of $0,004 \text{ mg g}^{-1}$. Although the levels of dissolved oxygen in the surface water were normal, the interstitial water was almost anoxic and, in some cases smelled strongly of hydrogen sulphide. The low oxygen values are probably due to organic enrichment of the beach sand.

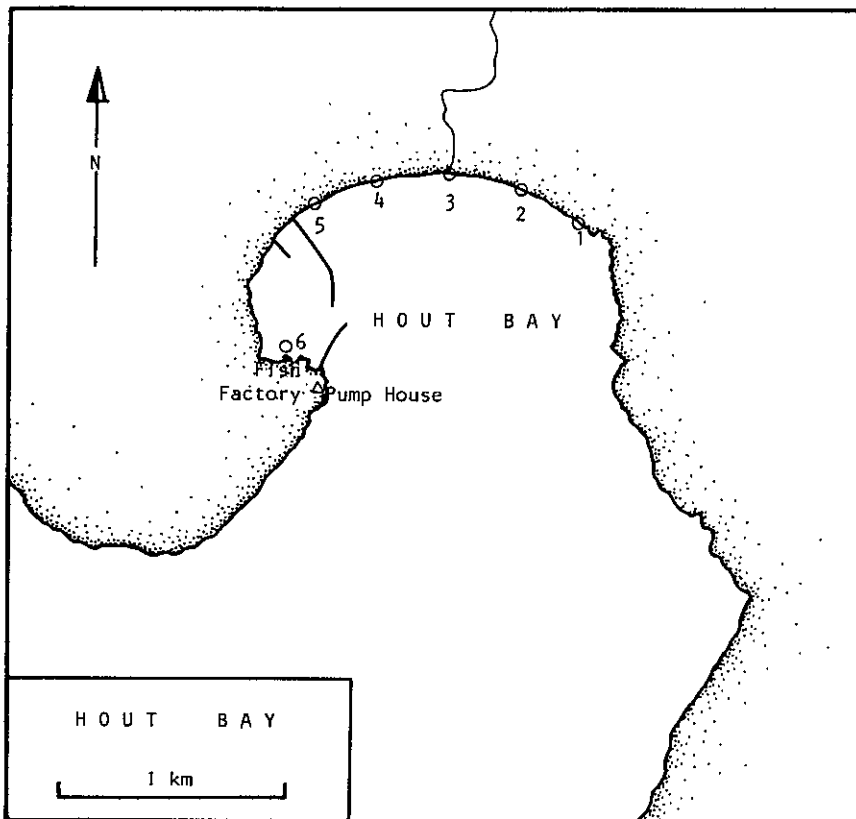


Figure 5. Sampling stations - Hout Bay

Meiofaunal analyses of the sediments³⁷ indicated that the low oxygen concentrations were accompanied by extremely small numbers of animals. Populations were generally less than 10% of those at nearby Camps Bay

beach, indicating conditions of stress. Harpacticoid copepods were virtually absent, suggesting an oxygen stress.

The acid-soluble metal content of the sediments was determined by atomic absorption spectrometry. The metals examined were cadmium, cobalt, copper, iron, manganese, nickel, lead and zinc. Concentrations in all cases were very low and no trends could be observed.

The temperature of the water in Hout Bay River was 10°C warmer than that of the sea but, because of its modest flow, this did not have any adverse effect on the bay. The river water was high in silicate but low in nitrate relative to the bay. The water from the harbour contained high nitrate levels³⁷ but was otherwise similar in composition to the bay water as a whole. The fish factories were not in operation during sampling and, since these discharge effluent directly into the harbour, the results of the present study probably reflect the least pollution. It is assumed that when the factories are in operation, concentrations of nutrients and organic matter in the harbour will rise. The extremely rough sea on the day of the investigation prevented samples from being taken near the sewage outfall. However, because of the generally strong mixing action in the region, any adverse effects of this outfall are probably confined to a small area.

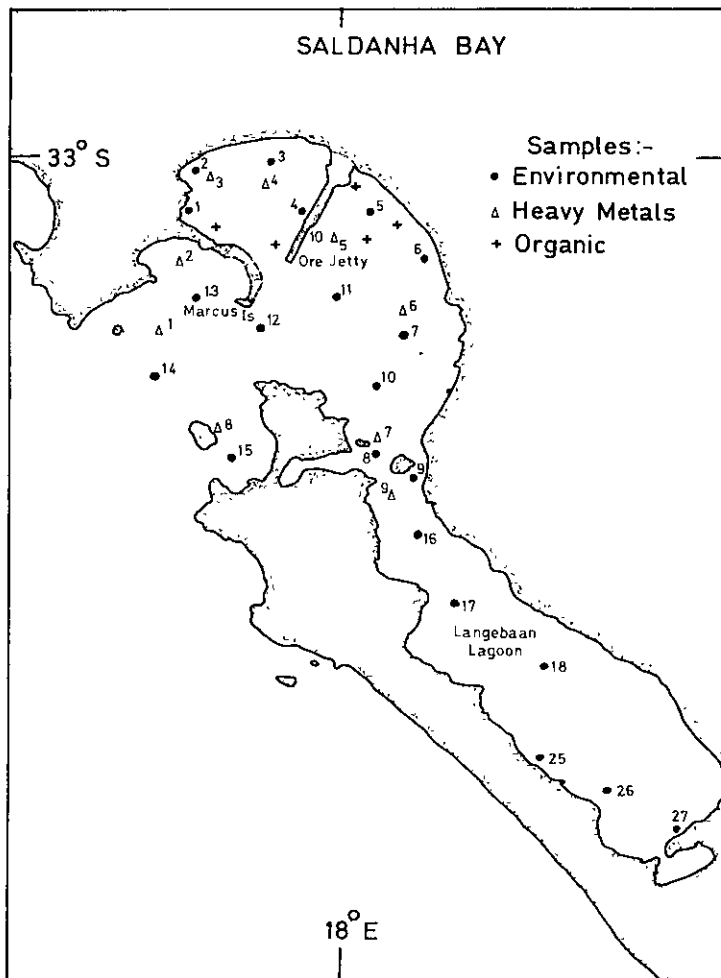


Figure 6. Saldanha Bay station positions.

Saldanha Bay

Research in this area has continued during this period following the same general pattern as was reported by Cloete and Oliff¹⁰. Quarterly surveys have been made at selected stations as shown in Figure 6. These were taken, where possible, during the same months of the year, and included sampling the water for temperature, salinity, heavy metal content, dissolved oxygen, nitrate/nitrite, ammonia, phosphate, silicate, pH, chlorophyll, chemical oxygen demand and oxygen absorbed from permanganate. This long-term data series is currently being prepared for publication, although the analysis of chemical oxygen demand has recently been abandoned because of the effect of chloride on the measurement.⁶

Previous studies in the region showed that the Bay and Lagoon were relatively unpolluted despite the presence of a fishing harbour at Saldanha. In September 1976, however, the ore jetty was completed and this has had a noticeable effect on the local environment.

The most obvious change in water quality has been in the area enclosed by the ore jetty, the causeway connecting Marcus Island to the mainland, and the coast to the north-west. Shannon and Stander⁷⁷ have described the current circulation pattern prior to the jetty becoming operable. They found that surface currents in the north-west down to 5 m depth tended to run at about 5-10 cm sec⁻¹ and to be highly wind dependent, with higher velocities in the mouth of the Bay and a maximum velocity of about 1 m sec⁻¹ at the mouth of Langebaan Lagoon (see Figure 7a). Since 1976, however, the currents in the north-west corner have decreased to less than 5 cm sec⁻¹ (Figure 7b) and this has resulted in concomitant changes in the chemistry of the area. As a result, the three systems - Bay, Benguela and Lagoon - classified by Shannon and Stander⁷⁷ can now be considered as four systems, with the Bay system being split into the Harbour system (inside the boundaries delineated above) and a new Bay system (to the South and East of the jetty).

Such a change in the current regime has naturally caused some changes in the water chemistry, and has particularly affected the distribution of the organic pollution from the fish factories in the area. The Harbour area has been found to have particularly strong thermoclines, with gradients of greater than 0,5°C m⁻¹ being a regular feature. A maximum gradient of 1,2°C m⁻¹ has been reported between 5 and 10 m in this area. Thus little vertical mixing takes place during the summer months.

Despite this, oxygen levels have tended to remain well above saturation point because of the high phytoplankton productivity⁵¹ with one exception in March 1978, when a fish kill was observed and oxygen levels declined to less than 2,0 mg l⁻¹. This was caused by the discharge of a large volume of fishery waste on a hot calm day with little water movement.

Although this lack of acute pollution is encouraging, there is little doubt that the chronic long-term pollution of the area is increasing. Values of oxygen absorbed have been increasing markedly since 1977 (Table 4) and the area affected extends over virtually the whole of the Harbour system and along the coastline of the Bay system⁵.

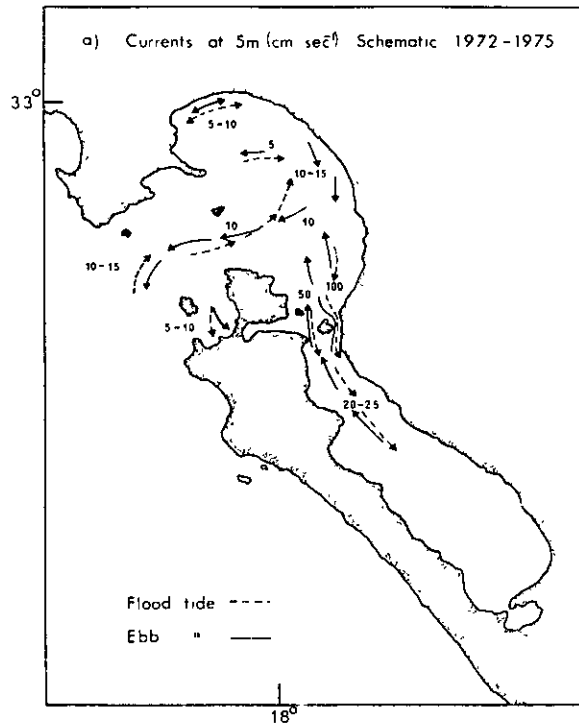


Figure 7a. Currents at 5m (cm sec^{-1}) Schematic 1972-1975.

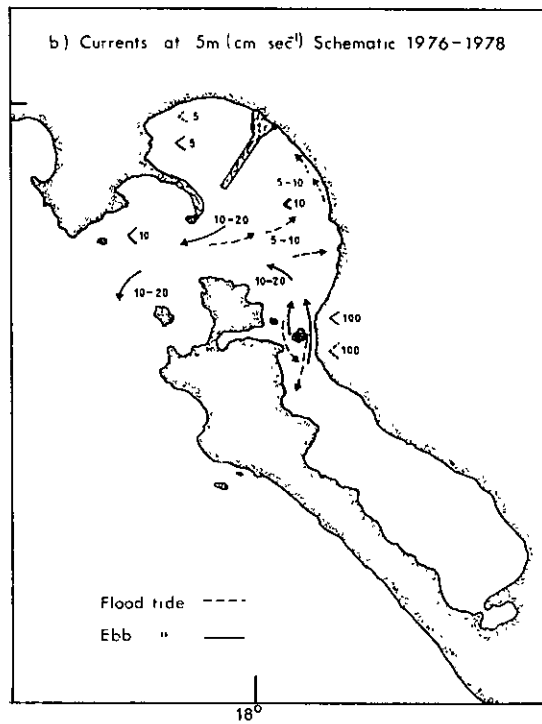


Figure 7b. Currents at 5m (cm sec^{-1}) Schematic 1976-1978.

During the summer months, the pollution is at its height, and changes in pollution levels with depth are very obvious. This results partly from the thermal stratification and also because of the oily nature of much of the waste. Both these factors combine to keep the pollution at the surface of the water column.

Of the other common parameters measured, phosphate⁵ is the only one that has shown any change from values accepted as "normal" in South African west coast waters. During times of excessive discharge of fish factory waste, for example during the fish mortality referred to above, levels of this nutrient have been found to increase by an order of magnitude above normal conditions. It must be emphasized, however, that this phenomenon is usually very short-lived and occurs only close to the outfall pipes.

Metal distributions have been monitored at the same stations as used by Fourie.³⁵ No significant increase in the content of any metals in the water has been noticed during this time. Metal concentrations in biological organisms collected in the area have similarly shown little change, with the exception of iron in the black mussel *Choromytilus meridionalis* which has increased by about a factor of three. This increase has occurred throughout the area and may be due to either fine particles of iron ore dust being deposited around the Bay, or to the redistribution of sand following dredging operations near the jetty. This latter explanation seems more likely since Willis (U C T Geochemistry Dept., pers comm.) has detected no change in iron ore concentrations in the sediments of the Saldanha Bay/Langebaan Lagoon complex. When compared, however, to levels of iron in *Choromytilus* from an unpolluted site at Melkbosstrand⁸³ there appears little reason to suspect that these increased iron concentrations are causing an environmental hazard.

The cultivation of oysters (*Crassostrea gigas* and *C. margaritacea*) for use as indicators of concentrations in the environment has not been fully successful due to the very rapid fouling of the oyster cages. In many instances this caused the oyster shells to cement together, which frequently proved fatal. The use of a different form of container for the oysters is presently under investigation.

Despite the still apparently healthy state of the area as regards metal pollution, there is a need for caution. As the new mines in the north-west Cape come into production after 1980/81, it is virtually certain that exports of copper and zinc concentrates will be made through Saldanha Bay, and lead and arsenic may also be shipped. Thus it will be necessary to continue monitoring studies in this area for some considerable time.

More significant changes have been caused by dredging in the Bay to keep the main shipping channel clear. The construction of the harbour wall and the excavation of the navigation channels near the ore jetty from January 1972 to August 1976 necessitated the removal of some 25 million cubic metres of sediment to deepen the channel from 17 m to 23,3 m. Investigations in 1975 showed that considerable changes in the distribution and abundance of benthic organisms had occurred since 1960.⁶⁶ Even in the limited period from 1974, the redistribution of sediment in the area was enough to cause extensive changes in the classification analysis of the stations sampled due primarily to the re-settlement of fine particles over the whole Saldanha Bay area, with a corresponding

tendency for the communities to become more similar. A further survey conducted in 1979 has tended to confirm this hypothesis.

TABLE 4. MEANS AND STANDARD DEVIATIONS OF OA VALUES FOR ALL SAMPLES TAKEN THROUGHOUT THE YEAR. Numbers of observations in parentheses.

All values in mg l⁻¹.

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 (62)	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)

As a result, changes in faunal abundance have become apparent. Of the 122 species (excluding amphipods) collected from the 10 sites during the three surveys, only 22 occurred in all three investigations. 27 species collected before dredging started were not found later, and 29 new species have been observed since the 1975 survey. It is expected that these distributions, when analysed fully, will show the change from mixed substrate biotypes to those indicative of fine sandy sediments.

In one area, however, the benthic diversity has increased. This is in the harbour area, where the reduction in pollution due to the fish factories changing from "wet" to "dry" offloading has resulted in an increasingly more diverse biota.⁹ Monitoring of the benthic communities in these areas will be continued as harbour development proceeds.

With the advent of the use of Saldanha as an oil storage and trans-shipment depot, the Institute has initiated an investigation into the oil levels in water and biota. Results of this are not expected to be finalised before 1981.

South and West Coasts of the Cape Province

Reference beach surveys

Ten beaches were selected to obtain criteria whereby the extent of natural variations could be assessed and compared to beaches which had a

pollution impact. All were apparently unpolluted and were some distance from any known pollution source or other discharge. Some of the beaches were sampled during both summer and winter to give an indication of seasonal variation. The beaches were Jeffreys Bay, Keurboomstrand, Witsand, Arniston and Betty's Bay (south coast), Swartklip (False Bay) and Sandy Bay, Camps Bay and Silwerstroomstrand (west coast) (Figure 8). After an initial survey, the beaches at Witsand and Swartklip were, however, found to be unsuitable as reference beaches. The influence of the Breede River, 6 km to the west of Witsand, resulted in reduced salinity at this site, while exceptionally high meiofaunal numbers at Swartklip were attributed to organic enrichment of the beach.

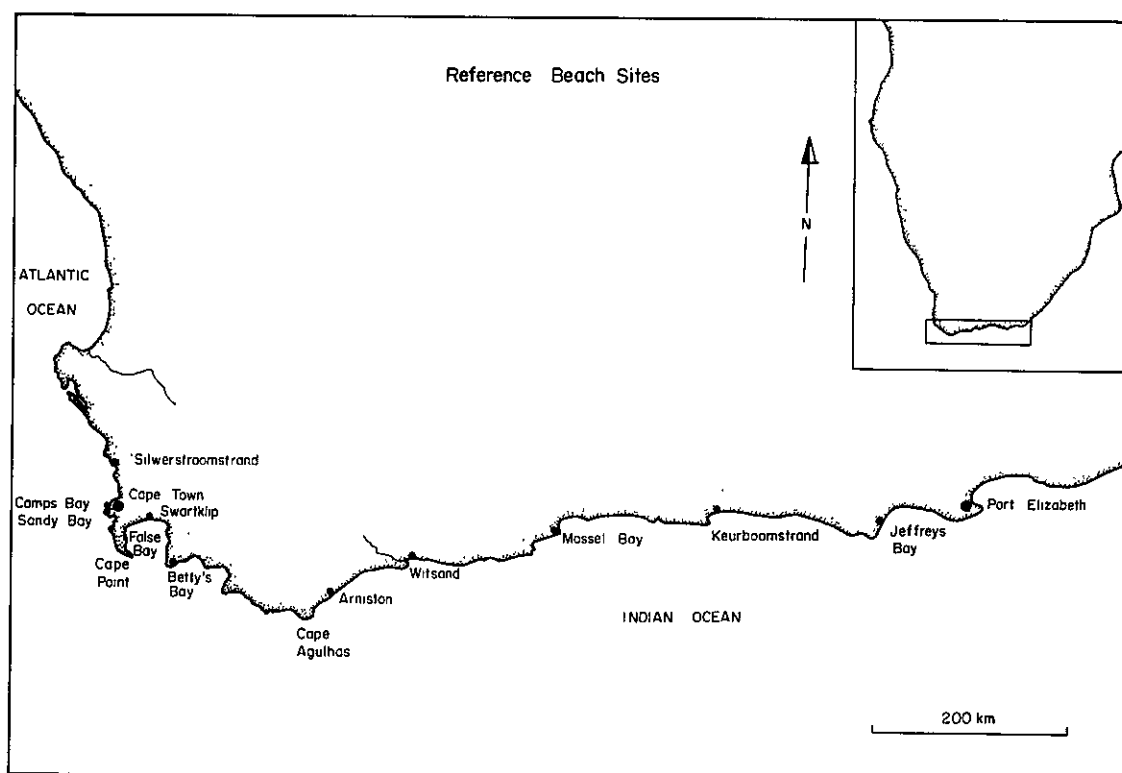


Figure 8. Reference Beach Sites.

With few exceptions, the concentration of the chemical parameters measured showed only slight variations between stations along each beach. Consequently, mean values give a good indication of the average concentrations of the various study parameters around the coast. It was originally hoped that some relationship would be found between the levels of the chemical and biological components of the system. Duplicate samples were therefore collected simultaneously from all stations. However, apart from correlations of silicate and nitrate concentrations with animal numbers, attempts to relate populations to the measured chemical parameters have met with little success. This may be due to

the fact that the response of a biological community to a chemical change is relatively slow, or that the organisms monitored have a wide tolerance range to the parameters measured. For example, at the time of sampling, Witsand had a low mean salinity due to the contribution of freshwater from the Breede River, yet the concentration and composition of the meiofauna showed no difference from those at other reference beaches. A summary of the mean values of the chemical parameters measured is shown in Table 5.

Salinity

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

Temperature

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

Dissolved oxygen

The mean concentration of dissolved oxygen in the surface water was slightly low at Betty's Bay (4,8 mg l⁻¹), but varied between 6,3 and 9,0 mg l⁻¹) at other localities. This indicates a high degree of oxygenation at all beaches. The dissolved oxygen concentration in the interstitial water varied between 1,4 and 7,1 mg l⁻¹. At each site there was a tendency for those samples with the coarser sediment particles to have higher dissolved oxygen concentrations although this had no direct correlation between sites. Better irrigation would be expected through coarser sediments, and this should lead to higher dissolved oxygen concentrations.

Oxygen absorbed

Results from oxygen absorbed (OA) measurements (Table 5) indicate the

relative amounts of easily oxidisable organic material in the sample, which is of obvious importance in a pollution context. The amount of oxygen absorbed from alkaline permanganate by the surface water varied randomly between 0,003 and 0,009 mg g⁻¹ (highest at Silwerstroomstrand), while interstitial water gave results between 0,002 and 0,009 mg g⁻¹ (highest at Arniston). OA values of sediment samples ranged between 0,04 and 0,18 mg g⁻¹ (surface) and 0,04 and 0,14 mg g⁻¹ (subsurface). Again, variations were random with no particular trends apparent.

Nutrients

Concentrations of nutrients in the surface waters were generally lower than those in the interstitial waters. Levels in the interstitial waters at Jeffreys Bay (during both summer and winter) were much higher than those in other south coast beaches, and the same was true for Silwerstroomstrand on the west coast. The reason for these anomalous results is not known, although the number of holiday houses at Jeffreys Bay with soakpit sewage systems could account for the high nutrient concentrations obtained there. These high values were apparently coupled with low levels of dissolved oxygen. In general, the nutrient concentrations in the surface water along the west coast were approximately twice those on the south coast.⁷⁰ Camps Bay had higher nutrient concentrations in summer as a result of upwelling.

The nutrient concentrations at most stations seemed to follow a definite trend, particularly in the surface water samples, where there was a strong correlation between total phosphorus, silicate and nitrate and an inverse correlation of all three with nitrite. These correlations were less evident in interstitial samples. This is to be expected as there is limited mixing within the sediment. At some sites, particularly in Sandy Bay, there was an inexplicable range of concentrations for certain nutrients. For example, two interstitial samples contained very high levels of nitrite and nitrate (greater than 6 and 20 $\mu\text{mol l}^{-1}$ respectively). It is thought that the high concentrations were not due to contamination but rather to some natural variation. Because of this, the calculation of mean nutrient values for this beach was not possible.

Size of sediment particles

The mean size of the sediment particles varied between 196 and 337 μm , with near symmetrical skewness. The one exception was the sediment from Arniston, with a mean particle size of 661 μm . This sediment was also only moderately well sorted. There were some variations between sediment sizes at stations along individual beaches, and pronounced stratification was also observed.

Trace metals

The concentrations obtained in water from the surf zone fit into ranges similar to those given by Phillips⁷³ in a summary of results obtained by other workers, mostly in Britain and the United States. Results obtained by Chester and Stoner⁷ for samples collected off the South African coast were also of the same magnitude. The concentrations found for lead and

cadmium were higher than those obtained in oceanic water.⁴ This was probably not due to contamination or experimental procedure, as samples collected up to 100 km offshore had very low lead and cadmium concentrations (unpublished results). It appears therefore that concentrations of trace metal in inshore waters are higher than those further offshore.

TABLE 5. MEAN VALUES OF MEASURED CHEMICAL PARAMETERS

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

The mean concentrations and ranges of metals measured⁷⁰ in the acid leach of sediments were, in general, extremely low when compared with those obtained by other workers using the same technique.^{44,77,89} The reason for these low values is not certain although it may be a result of the low organic content of the sediments, indicated by low OA values, since it is known that trace metals can be associated with organic material in sediments.^{71,73} However, as with most environmental parameters, the relative concentrations are most important because of the large variations which occur with different locations. Levels measured here cannot be regarded as universally applicable, but rather as guidelines for possible concentrations in sandy beaches.

Meiofauna

One of the characteristics of meiofaunal communities found to date is the recurrence of certain species assemblages with particular substrates. The communities generally consisted of a number of groups, of which nematodes and harpacticoid copepods were by far the most dominant, and there was a strong correlation between these two groups (Figure 9).

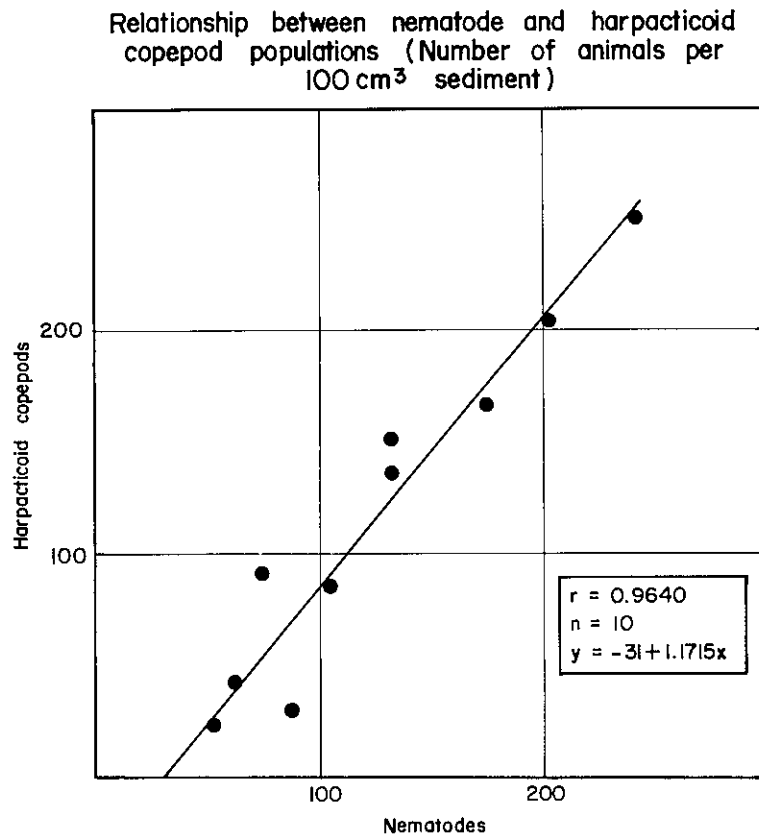


Figure 9. Relationship between nematode and harpacticoid copepod populations (Number of animals per 100 cm³ sediment).

This study has shown that the optimum sand particle diameter was 284 μm for the interstitial meiofauna in the sandy beaches studied. The numbers of animals decreased in a normal type distribution on either side of the optimum. Hence a linear correlation at 95% confidence limits was found between the animal numbers and the absolute mode of the deviation of grain size from this optimum.³⁸ Significant correlations were also found between animal numbers and the concentrations of silicates and nitrates. The actual numbers of animals obtained varied considerably from place to place, illustrating the patchiness with which they occur. Harpacticoids apparently have an even more patchy distribution than nematodes. Regression analysis indicated that in general the harpacticoids were slightly less numerous than the nematodes (Figure 9). No real difference between the populations of the south and west coast beaches could be observed. The better correlation of harpacticoid numbers to silicate and nitrate concentrations may indicate that they are more sensitive to chemical changes. Other work at impact areas^{37,71} has shown that the absence of harpacticoid copepods is a good indicator of low oxygen. On reference beaches there was also a reasonable correlation between the dissolved oxygen content of the interstitial water and the number of animals, despite the fact that the interstitial water was collected from a depth of 1 m while the biological samples were collected between 200 and 300 mm. Smaller numbers of other taxa, e.g. flatworms, acarines, juvenile crustacea, polychaetes, oligochaetes, mystacocarids and archiannelids, were found on most beaches but a more detailed analysis of faunal relationships will have to await solution of taxonomic problems.

Unusually high nematode densities were found at Swartklip in False Bay, where samples of the top 10 cm of sediment contained 690-3770 animals per 100 cm^3 of the sediment. Numbers decreased with depth but were elevated throughout the sequence. The top layer of sediment consisted of fine-grained sand with a mean particle diameter of 167 μm .

The northern shore of False Bay is a bayhead beach but it does not have the conventional half moon shape usually associated with such shorelines. The refracted long period swell approaches the Swartklip section of this bayhead obliquely⁷⁸ suggesting that seasonal longshore drift of fine-grained sediment at Swartklip is probably a transient feature related to the availability of this material and wave regime (J G K Glass, personal communication). Offshore reefs of Malmesbury slates and shales provide a suitable substrate for macrophytes. These latter are abraded by the transported sediments and the resulting detritus is trapped in the fine sands along the beach thereby providing the first step in a food chain which supports the nematodes. This could explain the high numbers of nematodes in the beach, and for this reason the beach at Swartklip cannot be regarded as a reference beach.

General

From the measurements made, it is apparent that the extensive upwelling which occurs along the west coast in summer gives rise to greater seasonal differences, higher nutrient concentrations and lower salinities than along the south coast. As grain size appears to be the main cause of variations in the population density of meiofauna in unpolluted beaches, standards can be set to cover the observed particle size range from

196-337 μm . The ratio of nematodes to harpacticoids should remain constant.

However, the variability of the biological results demonstrates that considerable differences exist between apparently unpolluted beaches, both temporally and with location. Thus it is the relative differences in measurements which are important and which can be used to identify impact sites.³³ No fixed values can be put forward as being universally applicable, although many measurements fall between certain limits. The mean values of all chemical measurements made in this study are given in Table 5 and can be used as guidelines for conditions applicable to unpolluted sandy beaches along the south and west coasts of South Africa.

ESTUARIES

Kosi Bay

The Kosi system was dealt with in the previous report,¹⁰ but the lakes were revisited in August 1976. The earlier report¹⁰ adequately described the area. Sampling points are shown in Figure 10.

Just prior to the 1976 visit, heavy rains had fallen on the Zululand plains. This resulted in the salinity of Lake Hlange having a salinity level of only 0,8‰, compared with 5‰ reported by Hemens *et al*,^{4,7} and 3-5‰ found by Bolt and Allanson³ for the period 1965 to 1969. Similarly Lake Sifungwe, with a normal range of 13-17‰ salinity was found to be 2,5‰ during the present survey.

In addition to low salinities Kjeldahl nitrogen levels had dropped markedly in the lakes compared with the 1971 survey. Near the mouth the levels were markedly similar (15 $\mu\text{mol l}^{-1}$), but in Lakes Sifungwe and Hlange the range was found to be 5-11 $\mu\text{mol l}^{-1}$ in the present survey compared with 21-47 $\mu\text{mol l}^{-1}$ in 1971. Oxygen levels were also noticeably higher. All these data probably reflect the flushing effect of the rains. A small anaerobic zone at 18 m depth was still present in Lake Sifungwe, but was estimated to be only 10-15 m in radius.

Sediment analyses yielded results for OA and nitrogen essentially similar to those of the 1971 survey. Apart from the middle lakes, the overall picture is one of low nitrogen, low carbon sediments.

A bacteriological survey demonstrated a marked absence of any significant faecal contamination. The total coliform picture was typical of a clean river.

Meiofauna and macrofauna samples showed the central lakes (Sifungwe and Mpungwini) to be sparsely populated in deeper waters, but in Hlange and the shallower areas numbers were surprisingly high. However, the fauna was dominated by small organisms and the biomass values, though not measured, were estimated to be low.

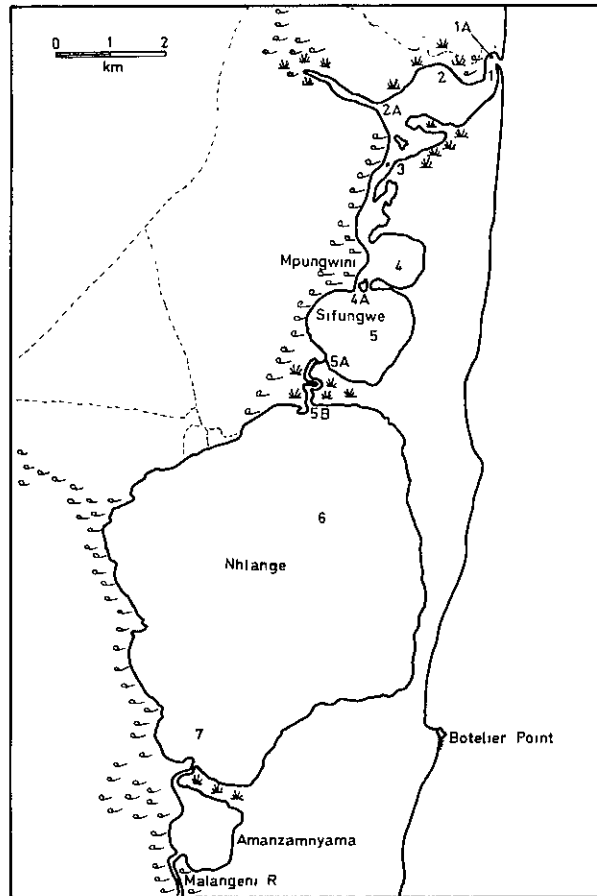


Figure 10. Kosi Estuary and lakes.

The zooplankton survey showed all the major components of estuarine zooplankton present, but in low numbers. As is usually the case a higher species diversity was encountered near the mouth of the estuary, while in the main lakes the low salinity water yielded a fair number of freshwater Cladocera.

The low biomass of zooplankton was probably due partly to the low overall productivity of the system and also to the fact that a stable benthic population acts as a biological trap of much of the available nutrient. In addition the nitrogen levels were low during the winter of 1976, as mentioned earlier and in many estuaries zooplankton biomass drops considerably in winter. Both copepods *Pseudodiaptomus stuhlmanni* and *P. hesseli* were collected in samples, extending the known northward distribution of the latter species.¹¹

Sediments and fauna from the lakes were analysed for pesticides and for the first time in the marine pollution survey, detectable levels of DDT were found in sediments. A high proportion of DDT and TDE as opposed to the more stable DDE indicated that the pesticide was of local origin.

Levels in fish were higher than recorded anywhere else on the east coast of South Africa. An interesting feature is that while mean DDE levels in the livers of Durban harbour and Kosi Bay fishes were very similar at 146 and 137 $\mu\text{g kg}^{-1}$ respectively, levels of DDT and TDE were many times higher at Kosi, averaging 464 $\mu\text{g kg}^{-1}$ compared with 72 $\mu\text{g kg}^{-1}$. This again indicates that essentially very local origin of the DDT and its derivatives detected in the Kosi system. Since malaria spraying continues and indeed has possibly increased due to a breakdown of malaria control in neighbouring Mozambique recently, there is clearly a need for continuous monitoring of DDT levels in this area.

Low levels of all metals measured were found throughout the estuary. Mercury concentrations increased up the estuary to a maximum in Mpungwini (0,118 $\mu\text{g l}^{-1}$), then decreased again towards Hlange. Although all mercury levels within the system were higher than those measured in the adjoining surf water (0,02 $\mu\text{g l}^{-1}$) all were well within the normal range expected for clean estuaries. Concentrations of all other elements were among the lowest yet measured in an estuary and are considered low even for clean open-ocean seawater.¹⁸

St Lucia Estuary

The topography of the St Lucia system was described by Day *et al.*²⁷ At that time the Umfolosi River opened into the mouth of the St Lucia system, but since then has been diverted so that it now opens separately into the sea, at a point about 2 km south of the St Lucia estuary mouth (Figure 11). In addition extensive dredging above and below the road bridge across the estuary between stations 5 and 6, has resulted in improved tidal exchange. At the time of the study, dredging was also in progress above station 1 (Figure 11), cutting a new channel between "The Forks" and the main lake.

A survey was conducted by the marine pollution study group during April 1978,²³ but the study area was confined to the narrows and mouth of the system, since it was felt that any serious pollutant entering the lakes would be detected at this point. Prior to the study the lakes had been well flushed by good rains, and in fact had, for some time, been almost totally fresh. By April 1978 this had changed slightly, with most of the main lake at 4-6‰ salinity, and levels up to 30‰ in the narrows.

Oxygen levels in the estuary were good, as might be expected in a shallow, turbulent (wind induced) system. The Kjeldahl nitrogen (170 $\mu\text{mol g}^{-1}$ maximum) and OA (34,9 $\mu\text{g O}_2 \text{g}^{-1}$ maximum) values indicated the presence of high levels of nitrogenous and easily oxidisable organic material in the sediments throughout the survey area except the actual mouth (station 7) where the clean well-washed sands of marine origin contained little such material.

Meiofauna was surprisingly poorly developed, apparently due to a fine silt layer and, at least at station 1, an anaerobic zone on the bottom. At this station the meiofauna was restricted to relatively few nematodes. The large number of big prawns *Penaeus indicus* in the narrows might also have had a depressing effect on the meiofauna at the time of sampling.

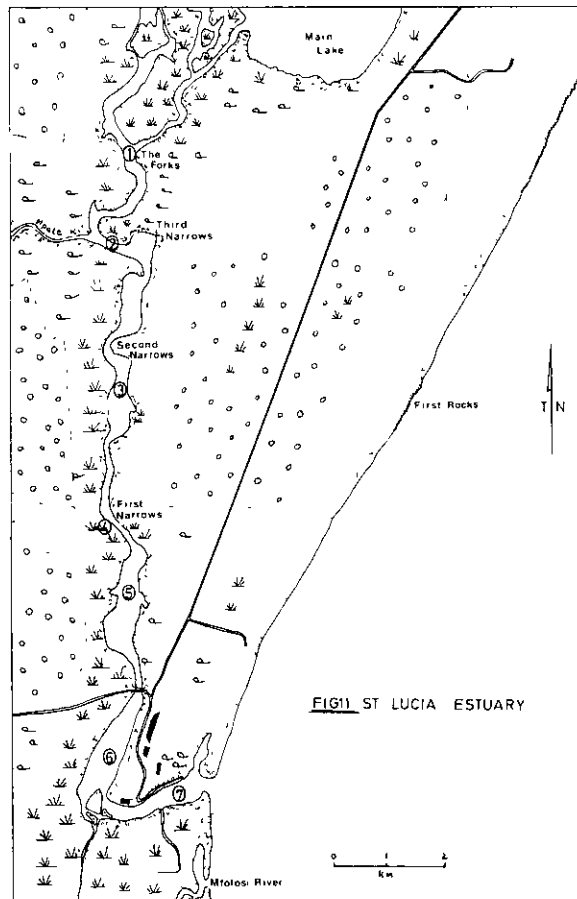


Figure 11. St Lucia Estuary.

The zooplankton was dominated throughout the narrows by crab zoeae. The calanoid copepod *Pseudodiaptomus stuhlmanni* was encountered only in small numbers, but was probably more common than the samples suggested, since they were collected in good light to avoid having to navigate past hippo herds in the dark. The settled volume of the samples was consistently below 5 cc, indicating a relatively low zooplankton biomass.

Samples of sediment, *Penaeus* prawns and fishes were analysed for pesticides. None was detected in sediments, but some DDT and its derivatives TDE and DDE were found in the fishes at about an order of magnitude lower than levels detected at Kosi Bay. However, the residues were dominated by DDT over DDE, again suggesting that the origin of the pesticide is local.

Some bird eggs from St Lucia estuary have also been analysed for pesticides. Neither the grey-headed gull nor the spoonbill eggs showed DDT levels as high as those in black-backed gull eggs from St Croix island in Algoa Bay, but whereas the mean level of $1008 \mu\text{g kg}^{-1}$ in the black-backed gull eggs was all DDE, about 45% of the pesticide was in the form of DDT in the grey-headed gull of St Lucia, again suggesting local origin. In the latter

species and in the spoonbill, total DDT was about $100 \mu\text{g kg}^{-1}$. Dieldrin levels were low in the grey-headed gull eggs, but the spoonbill eggs ranged from 70 to $80 \mu\text{g kg}^{-1}$, similar to levels found in seabird eggs from St Croix island.

Trace metal levels in sediments revealed little of any consequence apart from high levels of iron. These were even higher, on average, than found in the sediments of Durban Bay. The origin is presumed to be geological and may be aggravated by dredging operations. Nickel was also relatively high with as much as $83 \mu\text{g g}^{-1}$ recorded for station 1. The highest recorded level in Durban Bay sediments was only $25 \mu\text{g g}^{-1}$.

In water samples iron was again high, but the remainder of the results were typical of unpolluted estuaries. Nickel was unfortunately not analysed in the water samples. Analysis of fish and prawn tissues, however, showed no buildup of iron or nickel in the fauna of the system.

Richards Bay Harbour

By late 1976 Richards Bay harbour had developed to the point where two quays were in use for ocean-going shipping, namely the coal-loading facility near station 8 of Figure 12, and a "clean cargo" quay. The sampling stations used during a marine pollution survey study during November 1976¹² are shown in Figure 12.

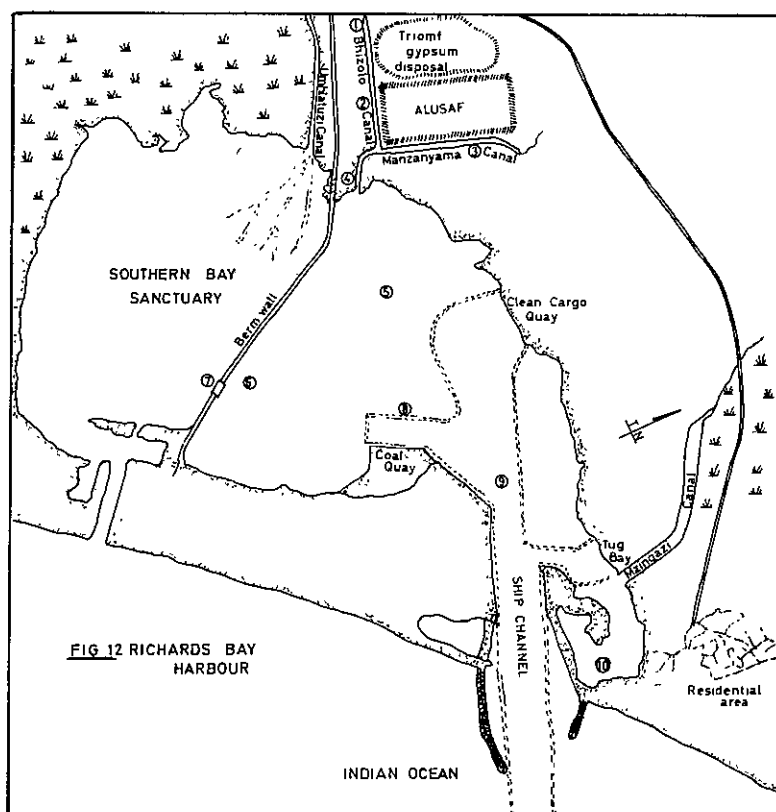


Figure 12. Richards Bay Harbour and Sanctuary.

With the diversion of the Umhlatuzi river into the southern bay sanctuary, freshwater input into the harbour area has become reduced to the small contributions of the Mzingazi lake and Manzanyama river. The harbour area is as a result virtually a marine bay and salinities are high throughout (23,8-34,27_∞).

The benthic faunal analyses showed a very limited meiofauna, possibly due to the fine silty nature of the sediments. Macrofauna, on the other hand, was fairly diverse and abundant.¹² Some changes were apparent compared ^{45,46} with previous studies. The formerly common crab *Tylodiplax blephariskios* was virtually absent, as was the gastropod *Nassa kraussiana*. These were replaced by a considerable variety of polychaete worms, ostracods and cumaceans. This suggested that the benthos was undergoing modification in response to the new circumstances in the bay. Large areas of *Upogebia* burrows were also noted on mudflats exposed at low tide.

Comparison of zooplankton in the less disturbed areas of the harbour with similar samples collected in the southern sanctuary area prior to dredging of the new mouth²⁵ revealed marked similarities. The most striking feature was the total dominance of these samples by the calanoid copepod *Acrocalanus similis*.

Total DDT pesticide levels were found to be lower in the fishes of Richards Bay harbour than at Kosi Bay and Durban Bay. However, the higher levels in Durban Bay fishes were made up mostly of the more resistant derivative DDE (mean of 146 $\mu\text{g kg}^{-1}$ in the liver and 40 $\mu\text{g kg}^{-1}$ in flesh compared with DDT of 72 $\mu\text{g kg}^{-1}$ in liver and 32 $\mu\text{g kg}^{-1}$ in flesh) whereas in Richards Bay harbour mean levels in livers of fishes sampled were 25 $\mu\text{g kg}^{-1}$ DDE and 87 $\mu\text{g kg}^{-1}$ DDT. The dominance of DDT over DDE in fishes of Richards Bay harbour suggests a local source of DDT in that area, presumably from mosquito control activities.

Heavy metal levels in the bay waters were generally high, and the mercury levels in particular, give cause for concern. The measured range for mercury was 0,23 - 1,92 $\mu\text{g l}^{-1}$ whereas the normal level for Natal estuaries is probably less than 0,3 $\mu\text{g l}^{-1}$. The highest levels were obtained in the Manzanyama canal.

Increased levels of copper (4,01 $\mu\text{g l}^{-1}$), lead (4,2 $\mu\text{g l}^{-1}$), zinc (3,8 $\mu\text{g l}^{-1}$) and nickel (13,4 $\mu\text{g l}^{-1}$) were also obtained in water from station 2 (Figure 12), below the Alusaf outfall and Triomf gypsum disposal dam. Elsewhere in the harbour area levels of those metals measured in this survey were comparable with levels found elsewhere in Natal.

Increased levels of copper, cadmium, lead, zinc, chromium, nickel and cobalt were also obtained in sediment from stations 2, 3, 4, 5, and to some extent 6, as the following data shows (data in $\mu\text{g gm}^{-1}$ dry weight).

<u>Station</u>	<u>Cu</u>	<u>Cd</u>	<u>Pb</u>	<u>Zn</u>	<u>Cr</u>	<u>Ni</u>	<u>Co</u>
2	40,0	1,6	33,2	179,4	120,1	73,5	23,2
3	35,7	1,4	5,5	149,1	139,6	46,1	22,0
4	40,3	1,2	10,5	121,4	121,4	38,9	23,1
5	38,3	0,9	23,4	157,1	98,2	41,0	23,5
6	33,4	1,1	20,0	75,9	118,4	41,7	22,9

These stations are all within the area of influence of the gypsum disposal dam and Alusaf outfall area.

The Southern Bay conservation area of Richards Bay

A report dealing with the conditions in the southern portion of Richards Bay before the new mouth had been dredged open, was summarised by Cloete and Oliff.¹⁰ In the first half of 1975, the new mouth was cut through to the sea as shown in Figure 12 thus again allowing tidal exchange of water in the southern bay.

The bay was sampled for benthic fauna and zooplankton in October 1975 in a limited follow-up survey on the effects of the new mouth on these faunae. Benthic fauna was found to be essentially similar to the 1974 survey.²⁵ The only notable differences were the ingression of an apparently marine polychaete *Ancistrosyllis parva* into much of the bay, and considerable numbers of a freshwater oligochaete in samples from stations in the vicinity of the Mhlatuzi river mouth. This latter occurrence was thought to be due to the diversion of the Mhlatuzi and the newly deposited river sediments. The small crab *Tylodiplax blephariskios* was still abundant in certain areas of the bay during this study, amounting to an estimated standing biomass of 80 000 kg.

Zooplankton samples taken in October 1975 showed an increase in species diversity but a decrease in biomass, both resulting from a relatively high tide exchange, calculated at 33-50% during a spring tide cycle. This rate of exchange was apparently making it difficult for estuarine forms to maintain their numbers in the bay. Consequently the previously common *Aerocalanus similis* (mean of 37 790 per sample in November 1974) had dropped to a mean of only 2 540 per sample in October 1975. Despite this *A. similis* was still the most common species in October 1975.

It was hoped that the mouth would assume more realistic proportions as the bay settled down to its new configuration, and that the reduced rate of tidal exchange would allow a higher standing crop of zooplankton to become established. However, in March 1976 severe floods in the recently diverted Mhlatuzi river brought huge quantities of silt into the southern bay, silt which had previously been trapped by the vast reed and papyrus swamps in the broad Mhlatuzi valley. The consequent shallowing of the northern section of the bay aggravated the already high tidal exchange rate by reducing the volume of water. On the spring tide, exchange had reached as high as 80% of total water volume per tide cycle.⁴⁸

When sampled in June 1976¹⁷ the benthos showed a drastic reduction in the crab *T. blephariskios*, and the zooplankton numbers had dropped to about half (mean of 3 250 animals per sample) those collected in October 1975. This may have been a seasonal effect, but certainly showed no improvement in the plight of the southern bay.

Durban Bay

Durban Bay is in many respects the most atypical estuarine system on the east coast. The Buffalo estuary in East London is associated with harbour development, but remains in its own right, a typical estuary upstream of the harbour. In the case of Durban Bay, only two small rivers, the Umhlatuzana and the Umbilo, enter the top end of the bay (Figure 13). In addition the Amanzanyama contributes a small amount of fresh water, and

several stormwater drains feed into the bay during rain. Neither the Umhlatuzana/Umbilo nor the Amanzanyama has an estuary as such, since both are canalised and discharge directly into fairly deep bay water. Generally freshwater inflow into the bay is limited, and the salinity of the water is at most times that of seawater throughout the bay, except in the region of Station 1. The only other system with similar features is the newly created Richards Bay harbour.

With the recent closing of Fynmlands outfall, and the construction of offshore sewage effluent pipelines, the two major sources of faecal pollution to Durban are the Umlaas and Umhlatuzana canals. Recent surveys of the Durban Bay show the Umhlatuzana as the only major source of *E. coli* in the bay itself,²⁴ but the source of this pollution, as in the case of the Umlaas canal, is outside the Durban municipal area.

The deeper shipping channels of the bay were found to have sediments rich in nitrogenous ($36 \mu\text{mol g}^{-1}$ at station 6) and easily oxidisable organic materials ($\text{OA } 10,7 \text{ mg O}_2\text{g}^{-1}$ at station 1). The shallow central sandbank at station 4 consists of coarse sand and shell fragments and is thus less rich. Meiofauna was found to be rich and abundant at all stations except station 1 where only a small number of nematodes were located, and there was evidence of anaerobic conditions.

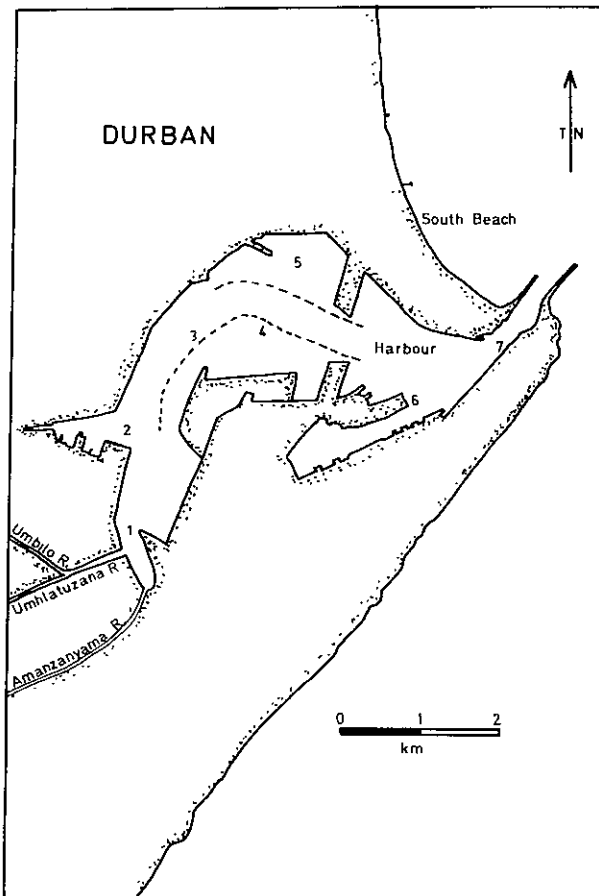


Figure 13. Durban Bay.

Zooplankton samples reflect strongly the neritic marine nature of the bay, mixed with the larvae of many caridian shrimps in the central portion of the bay. Nowhere was the zooplankton found to be rich, with settled volumes consistently low at about 1 ml compared with 10-20 mls in the Umgababa¹³ and over 100 mls in parts of the Bashee estuary, using the same sized plankton net, over the same length of sampling haul.

Chlorinated pesticide (DDT) residues in fish tissue were relatively high compared with remote estuaries, including St Lucia, but were not as high as at Kosi Bay. The dominant DDT residue was DDE, but strangely, the reverse was true of mullet from the Umgeni river, where some TDE and unaltered DDT suggested a local source of contamination. Mean concentrations ($\mu\text{g kg}^{-1}$) were

		n	DDT + TDE	DDE	Dieldrin
Durban Bay	flesh	8	32	40	118
	liver	7	72	146	95
Umgeni river	whole animal	12	147	60	41

Dieldrin levels in fishes from the Umgeni river and Durban bay were the highest recorded. In every other area studied, levels have been less than $10 \mu\text{g kg}^{-1}$, but in Durban Bay they were an order of magnitude higher.

Trace metal levels in sediments and water, measured in samples collected in 1974 and 1978, showed essentially similar levels except for chromium in the sediments which had dropped from a mean of $284 \mu\text{g g}^{-1}$ in 1974 to $53 \mu\text{g g}^{-1}$ in 1978. One anomaly in 1978 was station 5, with elevated levels of Hg (0,871), Cu (77,2), Pb (117,0) and Zn (247,0 $\mu\text{g g}^{-1}$) in the muds. In the water samples, highest levels were recorded in the less saline surface waters of the upper reaches of the bay, particularly at station 1. Levels of Cu, Pb, Cd, Zn and Co were all elevated, but not seriously so. Mercury levels, at $100-300 \mu\text{g l}^{-1}$ were lower than found in the Umgababa estuary, but are a little high compared with the $20-50 \mu\text{g l}^{-1}$ levels usually measured in more isolated estuaries.

The Umgababa Lagoon

The Umgababa river is a small system about 35 km south of Durban on the Natal south coast. The river rises about 13 km from the coast, and is dammed about 4 km from the mouth of the lagoon (Figure 14). The reservoir was originally built to supply water to the titanium mine which operated between the Umgababa and Umzimbazi rivers (Karridene) during the late 1950s and early 1960s. The river has a small catchment, the area being about 35 km^2 , and consequently the lagoon is blind, opening only during periods of heavy rains in the catchment. The system is productive, with mud prawn beds (*Upogebia*) near the mouth, and when the mouth is open, provides good light tackle angling.

The lagoon was visited during June 1976 and February and June 1977. During the June 1976 visit the lagoon was very full, and several days after benthic fauna, sediment and water samples had been collected, the lagoon broke open to the sea. This provided the opportunity to more easily collect fish, mud prawns and oysters, for pesticide and heavy metal analysis.

In February 1977 the lagoon was visited to collect zooplankton, meiofauna, water and sediments, and a similar set of samples was collected in June 1977.

During the first visit¹³ the lagoon was found to be well stratified, with surface water salinity of 1,87‰, and 12,67‰ at the bottom at station 1, where depth was only 1,5 m. At station 5, surface salinity was 11,47‰, and on the bottom 31,67‰, in 2,6 m of water. Kjeldahl nitrogen levels were quite high at between 45 and 71 $\mu\text{mol l}^{-1}$ in water samples, but this was derived from the river, since levels of 57 (surface) to 86 $\mu\text{mol l}^{-1}$ (bottom) had been measured in the dam at the wall during the same period. During June 1977 bottom waters were consistently above 70 $\mu\text{mol l}^{-1}$ Kjeldahl nitrogen. Nitrate and ammonia levels were consistently low.¹⁹

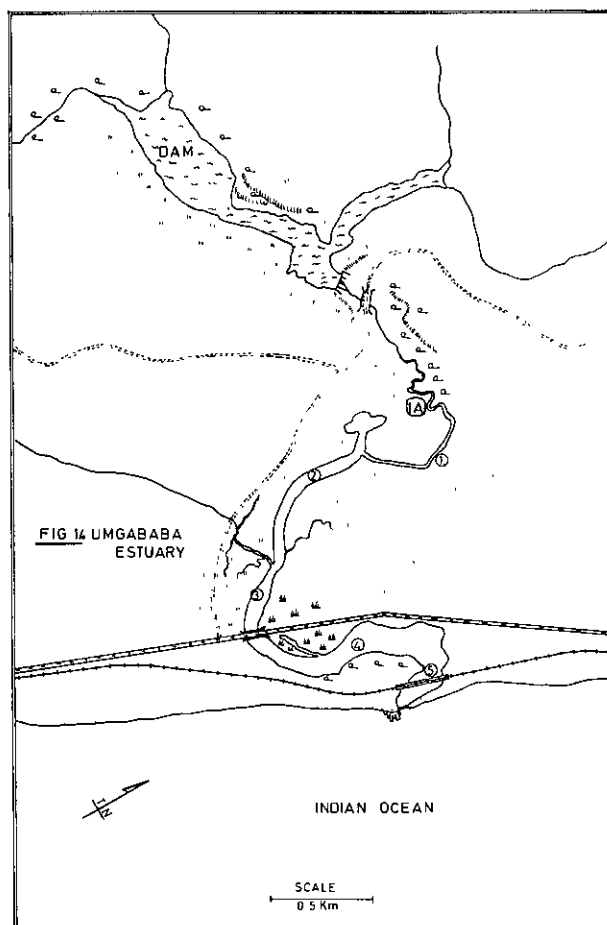


Figure 14. Umgababa Estuary.

Benthic fauna and meiofauna were found to be diverse and abundant, the former sampled in June 1976 and the latter in February and June 1977. Meiofauna was considerably more abundant in June than in February, presumably due to the longer period of stable conditions preceding the June 1977 visit. A similar effect was noted in the biomass of zooplankton collected, with a 3-5 fold increase in the June samples despite the colder water conditions prevailing at that time of year.¹⁹

Levels of pesticide contamination in the fauna were found to be low, as were the levels of trace metals, except for mercury. This applied both to fauna from the lagoon and some crayfish (*P. homarus*) from a reef at the mouth of the lagoon. Similar levels have been encountered in fishes from Umzimkulu and Bashee estuaries, suggesting a geological origin.

In sediments, trace metals were all low except for mercury, throughout the estuary, and lead and zinc at station 5, these latter two probably resulting from highway runoff. The mercury levels in sediments were missed in the June 1976 run, but the February 1977 samples yielded levels higher than normally found elsewhere. The June 1976 water samples were damaged in transit, but February 1977 samples were consistently above $0,6 \mu\text{g } \ell^{-1}$ with a maximum of $1,01 \mu\text{g } \ell^{-1}$, compared with levels rarely above $0,3 \mu\text{g } \ell^{-1}$ elsewhere. Cobalt levels were also relatively high at up to $12,0 \mu\text{g } \ell^{-1}$, also presumably of geological origin. A snap survey of water and sediment samples in January 1979 confirmed the relatively high mercury levels in the water, but showed low levels in the muds, such as were found in the summer of 1977.

The Umzimvubu Estuary

The Umzimvubu river is one of the largest draining the eastern slopes of South Africa. It rises in the Drakensberg south of Giants Castle, draining slopes which, on their western side, drain into the Orange river in Lesotho. The catchment area of the river is about 19 925 sq km.

Both biologically and chemically, the estuary and river are poorly known. Samples were collected from the estuary during the University of Cape Town's estuary research programme of the 1950s, but no report was published.

The river enters the sea at the resort village of Port St Johns (Figure 15) passing between the famous landmark "The Gates", with Mount Theisiger (370 m) on the south bank and Mount Sullivan (340 m) on the north bank. During the survey in mid August 1977 the estuary was navigable to small craft, for about 9 km at low tide.²⁰

The estuary, formerly a port for small sea-going vessels, has in the past several decades become progressively more silted and is presently, apart from short periods after major floods, a relatively shallow system with a narrow mouth. The mouth tends to meander along the beach with the shifting of the sandbanks, particularly during the winter months when freshwater flow into the estuary is reduced.

No signs of organic pollution were detected in water and mud samples collected, but the consistency and layering of sediments encountered during meiofauna sampling using scuba apparatus, suggested that the sediments were being continuously eroded and redeposited. In view of this it was not surprising that relatively sparse benthic fauna populations were encountered.

Zooplankton sampling, by contrast, revealed a remarkably rich population, with settled volumes for samples from the middle reaches of the

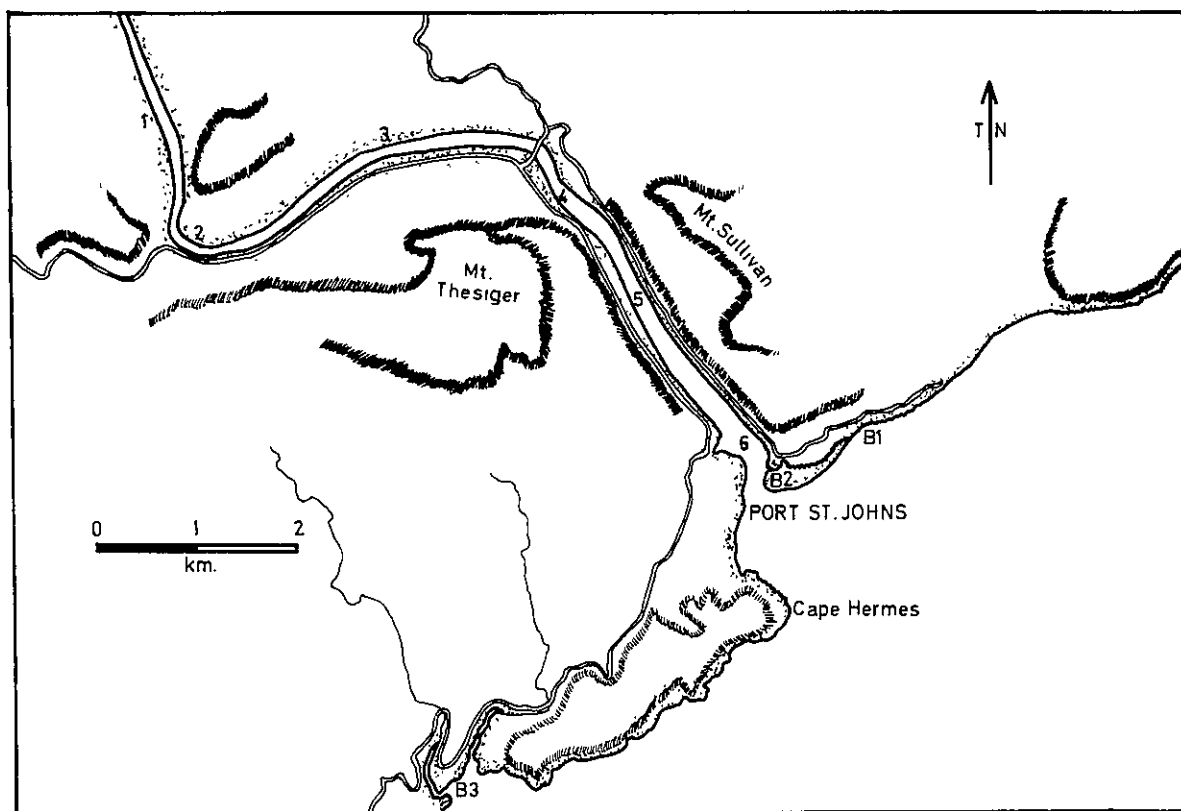


Figure 15. Umzimvubu Estuary.

estuary (stations 2-5) of 138, 71, 60 and 31 ml respectively. Such high values have only previously been encountered in the Bashee estuary.^{14,15} Two other interesting parallels could be drawn between these two estuaries, as have been mentioned above, namely the unstable oozy mud bottoms and the remarkably sparse benthic communities. In most estuaries studied, by far the largest biomass of animals has been in the benthos, usually as vast communities of the burrowing prawn, or in Richards Bay the crab *Tylodiplax*. In the Bashee *Upogebia* is confined to a few small areas, while very few *Upogebia* burrows were seen anywhere in the Umzimvubu estuary. It would appear that the lack of a suitable benthos in a potentially rich estuary leads to the zooplankton maintaining a dominant biomass. In the Bashee this biomass was seen to be maintained summer and winter.^{14,15}

Pesticide levels in fish were fairly high but the results were elevated by the concentration of 321 $\mu\text{g kg}^{-1}$ DDE found in a large grunter (*Pomadasys commersoni*). The kob (*Argyrosomus hololepidotus*) showed increased levels with increase in size. Mean levels were lower than in Richards Bay harbour and the Buffalo estuary, but higher than areas such as the Swartkops, Bashee and St Lucia estuaries. No PCB was detected in the area.

Trace metals in water were all low, as might be expected of a rural area. Slightly elevated levels of copper (12-13 $\mu\text{g g}^{-1}$), zinc (34-64 $\mu\text{g g}^{-1}$) and chromium (50-87 $\mu\text{g g}^{-1}$) in muds suggest some geological contamination.²⁰

The Mngazana Estuary

The Mngazana estuary is in several ways unique among Transkei estuaries. Instead of the usual deeply incised valley which is typical of estuaries on the Transkei coast, the Mngazana meanders over a fairly flat coastal plain. As a result, areas of typical mangrove swamps have developed, including red, white and black mangroves, and extending over an area of about 40 ha.²¹

During the team's visit in August 1977, the estuary was navigable to small craft, for about 6,5 km at high tide (station 1A, Figure 16). The two creeks opposite stations 4 and 6 were also navigable even at low tide, where the narrow channel is hemmed in on both sides by a wall of mangrove trees, on muddy banks teeming with crabs, particularly *Sesarma catenata*.

The catchment area of the Mngazana is small; an area of roughly 350 sq km. This is probably the major reason why the estuary has remained relatively unchanged and silt free while many of the larger catchment rivers have badly silted estuaries. In addition the peculiar promontory of rock in the sea just south of the mouth probably assists in keeping the mouth open and relatively free of sand. The river rises a mere 20 km from the estuary and agriculture in the catchment is not intensive.

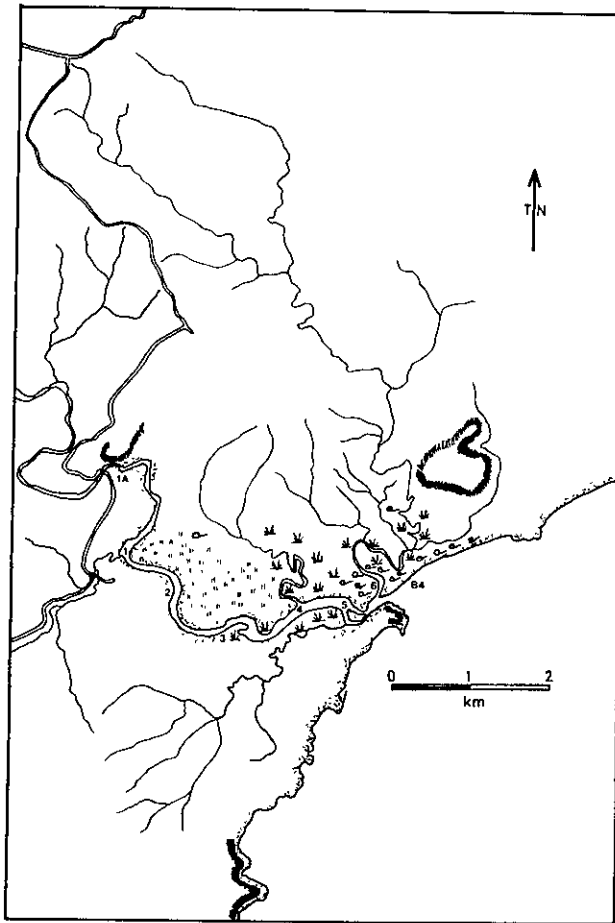


Figure 16. Mngazana Estuary.

Sediments were seen to change from clean medium to fine grained sand at the estuary mouth to progressively finer and muddier sand up the estuary. The detritus content on the other hand, was seen to increase toward the mouth, probably due to the contribution of the fringing mangrove swamps. The benthic macrofauna was found, likewise, to increase in both diversity and abundance, seawards, perhaps capitalising on the detritus as a food source. There was no clear trend in the distribution of meiofauna apart from an increase in diversity and abundance at station 6.²¹

Zooplankton densities were not impressive compared with the Umzimvubu sampled two days before,²⁰ but compared favourably with estuaries such as the Buffalo and Swartkops. Biomass was relatively low, but in summer this might be expected to increase considerably, as has been reported by Wooldridge.⁹⁶ The main contributors to the summer increase were the Mysidacea, which featured very poorly in the present samples. The copepod *Pseudodiaptomus stuhlmanni* was collected in this estuary, extending its known southern distribution.

Due to its remoteness and short catchment, the Mngazana was used as a background area for the trace metal survey. However, at station 2 an astonishing level of $10 \mu\text{g l}^{-1}$ of mercury was recorded in surface water, and station 5 surface water was also relatively high at $0,8 \mu\text{g l}^{-1}$. Station 2 is opposite the launching site for small boats, where several boathouses are situated. It seems probable that some mercury-containing compound had been used or spilled in this area. Sediment analyses confirmed the contamination, with muds from stations 2 and 3 above average ($0,11-0,25 \mu\text{g g}^{-1}$ dry mass). A remarkably constant increase in sediment levels of zinc, iron, chromium, copper, cobalt and nickel were noted toward the top of the estuary, and at the upper stations these values could be considered fairly high ($70,7, 4993, 126, 14,8, 3,8$ and $34,6 \mu\text{g g}^{-1}$ dry mass respectively).

Pesticide levels detected were confined to small quantities of DDE in one *Elops machnata* (springer) (liver $60 \mu\text{g kg}^{-1}$). In all other fish analysed, and in sediments, none was detected.

The Bashee Estuary

The Bashee river is fairly typical of the larger east coast estuaries entering the sea between Port Elizabeth and Durban. The river rises in the foothills of the Drakensberg, to the northwest of Elliot, at an altitude of about 2000 m and flows south-east to enter the sea about 150 km away near The Haven on the Transkei coast. The catchment area of the Bashee river system is approximately 6000 km².

The river is poorly known in all its aspects, and we have thus been unable to locate any published data on the chemical and biological aspects of the incoming waters and the estuary itself. Although samples were collected from the Bashee during the University of Cape Town estuary research programme of the 1950s, no report was published. However, taxonomic papers such as Tattersall⁸¹ make mention of these samples from the Bashee.

The estuary was visited in June 1975,¹⁴ and again briefly in December 1975.¹⁵ It was again visited in April 1977 while returning from the

Buffalo estuary. The river was navigable to station 1 (Figure 17) at high spring tide but was generally fairly shallow, with no depth over 2,15 m being recorded at low tide.

Water and sediment analyses showed nutrient levels similar to the Swartkops estuary, but with PO_4 levels much lower ($0,1 \mu\text{mol P l}^{-1}$), and without a tendency to increase upstream as in the Swartkops, suggesting a low input from the river. This was confirmed in the December 1975 visit when river waters were sampled for nutrient and algal growth potential (AGP) analysis.¹⁵ AGP results were low, despite some relatively high NO_3-N levels, probably due to the low PO_4 level.

A moderate amount of faecal pollution was indicated by *E. coli* I counts¹⁴ for water from the upper reaches of the estuary, probably from the inhabitants living along the banks of the river further upstream. Reduction in these numbers at stations 5 and 6 suggested no further contamination within the estuarine region.

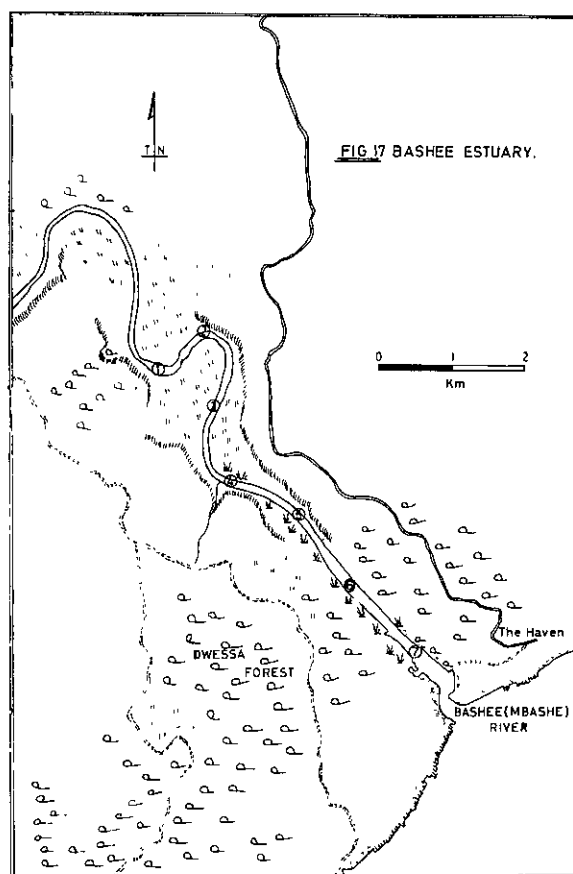


Figure 17. Bashee Estuary.

Benthic fauna (macrobenthos) was surprisingly poor, with only station 6, near the mouth showing a relatively diverse and abundant fauna. The cause of this was thought to be the smothering effect of the loosely compacted sediments. While diving it was found difficult to sample the interface

between mud and water because it was so poorly defined.

The loose sediments also led to difficulties sampling the zooplankton with a sled-net, but the standard length hauls yielded enormous volumes of zooplankton, dominated by high numbers of mysids. Settled volumes in the middle reaches of the estuary varied from 35,0 - 157,0 cm³. The mean of 54,0 cm³ for this set of *winter* samples contrasts strongly with most other estuaries which are usually below 10 cm³ settled volume for the sled-mounted plankton net used in these studies. In view of the poor benthic fauna, it is possible that release to the plankton of nutrients which would normally be tied up in a rich benthic fauna, might be a major factor contributing to the large zooplankton biomass encountered. The high biomass was confirmed by the samples collected in December 1975.¹⁵

Three sets of fish and other fauna, one from each visit, have been analysed for pesticides, and all have shown very low levels of DDE, together with on one occasion some DDT in big mullet and *Elops* (springer). This data serves to highlight the fact that pesticide contamination is of local origin in southern Africa, and not global.

Trace metal levels were predictably low, and uniformly distributed in the muds, but with a tendency toward higher levels in the headwaters of the estuary. This was a natural consequence of the higher silt load in the headwaters. The ranges were as follows:-

Hg 0,0012 - 0,0145;	Cu 2,7 - 17,1;	Cd 0,23 - 0,7;
Pb 5,3 - 22,9;	Zn 8,4 - 26,2;	Fe 4778 - 19 758;
Cr 5,0 - 13,8.	(all units $\mu\text{g g}^{-1}$ dry mass)	

The Buffalo Estuary, East London.

The Buffalo river is not a large system, with its headwaters about 75 km from the coast, 25 km to the north and north-west of King William's Town. Its importance lies in the fact that it enters the sea through the Buffalo harbour at East London. The catchment area is about 1320 km².

The estuary was visited in April 1977,²² and found to be navigable for only about 5 km (station 1 of Figure 18). Water depth was only 1-2 m, increasing only within the range of harbour dredging activities, near the Buffalo Bridge (station 5).

Kjeldahl nitrogen levels at station 4 indicated a nutrient input in that area, and a sample of water from Second Creek (Figure 18) contained 640 $\mu\text{mol l}^{-1}$ available for algal growth. This sample also contained 16 $\mu\text{mol l}^{-1}$ orthophosphate, but an algal growth potential (AGP) assay yielded less growth than expected, suggesting some toxicity.

The nutrient rich water from Second Creek was not considered harmful to the estuary, but the bacteriology of this water, as reflected in the survey of the estuary, was far from acceptable (Table 6). The indicators for station 4A show very clearly that this stream was receiving considerable quantities of untreated sewage. The high levels at station 3 suggest a further source upriver as the tide was well out when the samples were collected. The elevated counts for station 6A, together

with the presence of a parasitic worm ovum, indicate a nearby source of raw sewage. The data presented in Table 6 would be reason for considerable concern in any estuary, let alone one which is a popular site for power-boating, rowing, yachting and fishing.

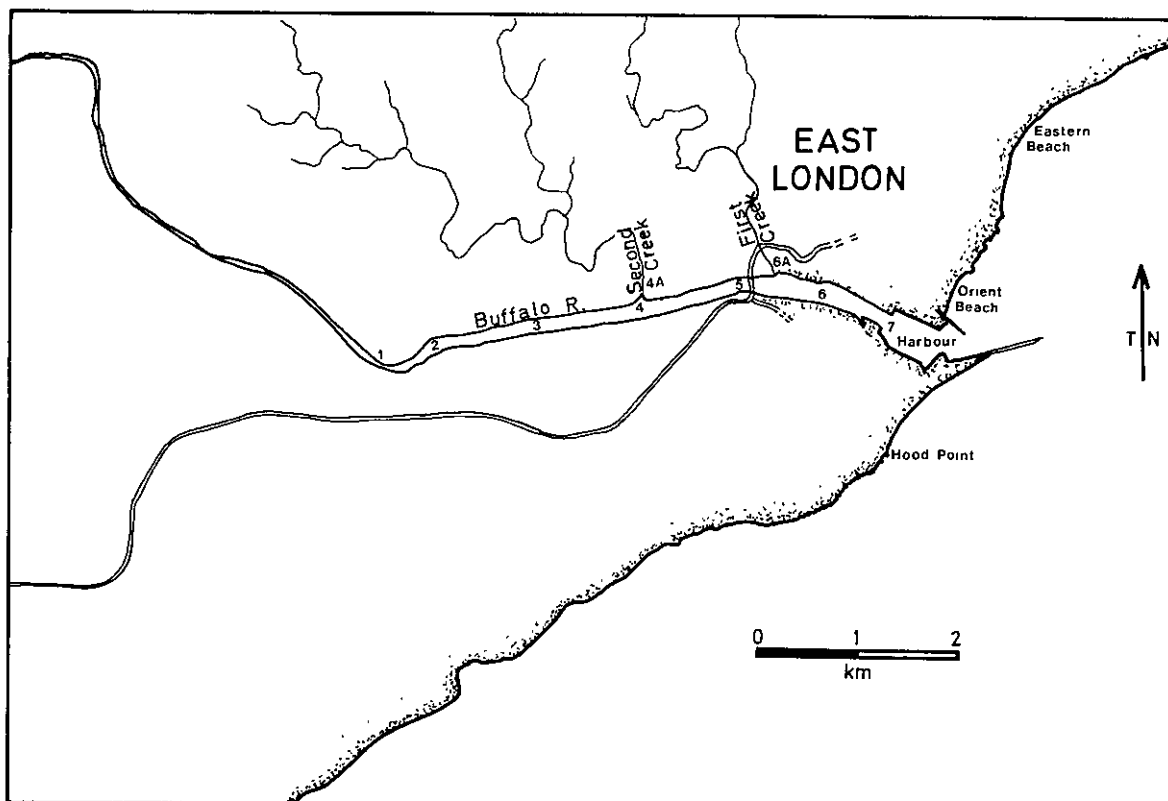


Figure 18. Buffalo Estuary.

The meiofauna was found to be diverse and abundant at all stations. High densities were attributed to the organically rich sediments, and the high diversity indicated the absence of adverse conditions such as low dissolved oxygen. The zooplankton samples were unusual in that they were dominated by two species of *Acartia*, with *A. (Paracartia) longipatella* more common than *Acartia natalensis*. Biomass was moderately low for a nutrient rich system. Settled volumes ranged from 3-5 cm³, for a standard 50 m D.net haul.²²

No chlorinated pesticides were detected in the sediments, and no PCBs were detected in any of the samples. Average levels for all fish analysed were: DDT 16 µg kg⁻¹ in flesh and 108 µg kg⁻¹ in liver, and DDE 8 µg kg⁻¹ in flesh and 129 µg kg⁻¹ in liver. These levels are approaching those found in the Durban area and suggest moderate local contamination.

Trace metal analyses of water samples yielded no unusual levels, despite the input of sewage from Second Creek. There was a general trend of increasing levels of several metals, including mercury (0,485 µg g⁻¹ at station 6), copper (69 µg g⁻¹ at station 7), cadmium (0,253 µg g⁻¹ at station 6), Lead (65 µg g⁻¹ at station 6) and zinc (155 µg g⁻¹ at station 5). The copper, lead and zinc levels are fairly high suggesting

contamination from the harbour.²² Some moderately elevated mercury levels were found in the tissues of some fish species, and one outstanding concentration of copper (394,6 $\mu\text{g g}^{-1}$ dry mass) was found in the liver of a spotted grunter.

TABLE 6. BACTERIOLOGY OF THE BUFFALO ESTUARY AND WATERS ENTERING VIA FIRST AND SECOND CREEK. Stations as in Figure 18. Samples collected 30.1.78 at 11h30-12h30. High tide 0h12.

Station number	3	4	4A	5	6	6A	7
Coliform organisms M.p.n./100 ml	180 000+	35 000	540 000	17 000	16 000	54 000	3 500
<i>F. coli</i> I M.p.n./100 ml	180 000+	4 000	180 000	16 000	390	2 600	1 100
<i>Salmonella + Shigella</i> organisms/125 ml	-ve	-ve	-ve	-ve	-ve	-ve	-ve
Parasitic worm ova/250 ml	-ve	-ve	-ve	-ve	-ve	1	-ve
Chlorides as Cl (% mass/vol)	0,51	0,82	0,015	1,39	1,72	0,015	1,77
NH ₃ M mg l^{-1}	0,36	0,27	0,7	0,11	0,15	1,1	0,11

4A is water from Second Creek, hence the low chlorides
6A is water from First Creek, hence the low chlorides

The Swartkops Estuary

The Swartkops estuary has been well described in a paper by Macnae,⁵⁹ and appears to have changed little since then, except for the more extensive development of pans for the commercial recovery of salt. Macnae commented (*loc. cit.* page 116) that the mouth of the river was permanently open to the sea, with conditions similar to those recorded by Methven in 1905, and he concluded that this was due to the fact that the catchment area had not proved suitable for agriculture.

The Swartkops River (entrenched mainly in Table Mountain Sandstone) is joined by the Eland River (entrenched in Bokkeveld Shales) soon after entering the coastal plain (Figure 19). After entering the coastal plain the Swartkops River is entrenched in the marine clays and marls of the Cretaceous Uitenhage Series. In the upper reaches of the coastal plain the Uitenhage Series forms banks and the bed is composed of fine silt, while in the lower reaches, the banks disappear and gravel is replaced by sand and mud as the river enters the sea. The banks may attain heights of up to four metres, but below the town of Redhouse, these are replaced by a broad flood plain with associated levées. These levées are eroded almost entirely below Swartkops town, where salt marshes predominate until the river enters the sea through eolian sand dunes approximately 10 km north east of Port Elizabeth.

On the subject of pollution of the estuary, Macnae stated that there was very little of concern in the rural catchment area and within the region under the jurisdiction of the Port Elizabeth Divisional Council. On the other hand, he noted considerable industrial and sewage pollution in the vicinity of Uitenhage. Of particular note were the wastes of tanneries and wool-pulling concerns, both of which produced very foul effluents.

He stated that these effluents, although at times causing extensive fish kills in the river between Uitenhage and Perseverance, rarely reached the estuarine waters. The sources of these pollutants were stated to be about 16 km above the tidal limit. During the present survey Redhouse Yacht Club members remarked on the foul-smelling waters encountered at times in the upper reaches of the estuary above Redhouse (Figure 19).

The estuary was visited in February 1975¹⁶ again in December 1975¹⁵ and again in April 1977. During the first survey the estuary was navigable as far as station 1, about 10 km from the mouth. Between station 1 and the mouth the river was navigable at low spring tide in all areas except where the river widened below the brickworks and shallowed to 30-40 cm. At stations 2 and 12 depths in excess of 3 m were recorded at low tide.

The flat nature of the estuary basin, coupled with a generous tidal exchange and a relatively deep stretch of water between stations 1 and 5, resulted in fairly high salinities being present fairly far up the estuary, even at low tide. While lower salinity surface waters drained downstream on the outgoing tide, high salinity waters remained trapped in the deeper basins.¹⁶

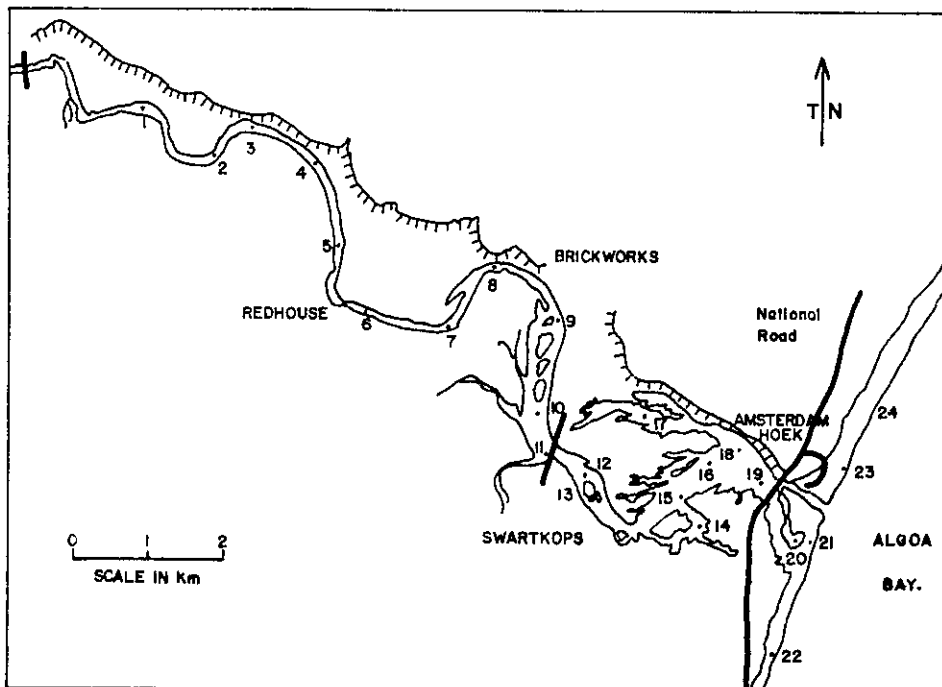


Figure 19. Map of the Swartkops River showing sample sites.

In both water and sediments nutrient and OA levels increased steadily toward the top of the estuary, indicating nutrient-rich waters entering the estuary above station 1. From the salinity of the samples analyzed the values recorded at station 1 indicate about $20 \mu\text{mol l}^{-1} \text{PO}_4$ and $90 \mu\text{mol l}^{-1} \text{NO}_3$ in the incoming freshwater of the Swartkops river.

Bacteriologically the estuary showed signs of moderate levels of sewage pollution, but only in the region of Redhouse and above, indicating that the contamination was from above Redhouse and probably coming into the estuary with the freshwater input.¹⁶

The macrobenthos was found to be rich and diverse in the upper reaches of the estuary, but became progressively more sparse toward the mouth.^{16,15} The most noticeable cutoff point was between stations 5 and 8 where the drop in numbers was from 2259 to 181 in the sample. Above this point the benthos appears to benefit from the high nutrient input, but from station 8 to the mouth tidal flushing action appears to have made the sediments of the main river channel unsuitable for most benthic organisms.

Zooplankton samples confirmed that there is a large area in the estuary which, due to intense tidal exchange, does not support a rich estuarine zooplankton. Thus as distance from the mouth increases, numbers of species decreases, but the number of individuals in the samples increases dramatically. With a spring tide high in the river, the area up to station 8 was thus found to have a poor biomass of zooplankton.¹⁶ Above this station the zooplankton was abundant and fairly diverse, with mysids well represented. Settled volumes of 2,4 - 4,4 cm³ were, however, not particularly high for a nutrient rich estuary. During the December 1975 study, biomass was improved, with settled volumes of up to 10 cm³ and as high as 28 cm³ in a sample collected at night.¹⁵ The Swartkops supports dense beds of the burrowing prawns *Upogebia* and *Callinassa*, and is thus an example of an estuary which would be expected to show a marked difference between summer and winter zooplankton biomass (see comments under section on Bashee river).

A reduction in biomass and increase in species diversity is a common occurrence near the mouth of an estuary, the former mainly due to the unsettled nature of the situation, the latter due to mingling of estuarine and marine species. However, despite the fact that the Swartkops had a wide, open mouth at the time of sampling, and samples were collected on the full spring tide, marine species were not well represented in the samples. For example, only four species of marine calanoid copepod were represented in the samples from stations 8-15 of the Swartkops, compared with 28 at stations 5 and 6 of the Bashee in June 1975,¹⁴ and 20 in the Richards Bay Southern Sanctuary in June 1976.¹⁷ This poorly represented marine fauna, which was again evident in December 1975¹⁵ suggests that there might be an inhibiting influence affecting the intrusion of neritic marine zooplankton into the mouth of the estuary.

Chlorinated hydrocarbon levels in the Swartkops were low at a mean of 5,7 µg kg⁻¹ DDE and 12,5 µg kg⁻¹ DDT for all the fish analysed. In addition a mean level of 8,5 µg kg⁻¹ Dieldrin was detected. Since the fish collected were all small, only flesh analyses were done. The levels are lower than have been detected in populated areas, probably as a result of the Swartkops not being influenced unduly by the harbour and city of Port Elizabeth.

Trace metal analyses on water showed the estuary to be relatively uncontaminated except at station 7, where levels of copper, cadmium, lead and zinc were an order of magnitude higher than elsewhere. Sediment

analyses showed that there was a source of elevated levels of some metals at station 12, with mercury (0,149), copper (15,3), lead (18,8), zinc (48,5), iron (11860) and chromium (101,9 $\mu\text{g g}^{-1}$) showing elevated levels. Levels in sediments from below this station (nearer the sea) were not comparable with those above as the sediment was much more sandy and less likely to contain metals.

An obvious pattern in the distribution of a number of the parameters measured, was discernible in the estuary. Both the benthic fauna and zooplankton communities became abundant only above station 8, while bacteriological counts and nutrient (N + P) concentrations were much higher in the upper half of the estuary, dropping dramatically downstream of station 8. It is evident from the structure of the sediment and zooplankton communities, that spring tide water exchange results in an unstable habitat from the mouth to roughly as far as station 8 in the estuary with retention time becoming increasingly longer for water upstream of this point, thus allowing a more stable habitat to develop. This does not, however, explain the dearth of neritic marine forms in the plankton samples collected downstream of this point, nor does it explain the relatively high trace metal levels detected in the region of station 12. These latter are consistent with sewage effluent yields, but Department of Water Affairs officials (Mr Pretorius, personal communication) report that no sewage effluent is discharged into the estuary. Suggestions that the low numbers of the neritic marine plankton may be due to high chlorine levels in the power station effluent entering at station 12 were also rejected by Mr Pretorius, who reported that regular tests of this effluent had failed to detect chlorine. Perhaps unusual conditions in the neritic marine zone were responsible for low zooplankton entering the estuary from this source.

Distribution of trace metals in water

Eighteen samples of water were collected in April 1977 and analysed for copper, lead, zinc, iron, manganese, cobalt, nickel, cadmium and mercury.⁹¹

The distribution of sodium, potassium, calcium and magnesium agreed well with the previous impact survey¹⁶ and indicated that there was a significant marine influence on the river as high as station 1. The sea water contribution became progressively greater towards the mouth with the tidal lag being only 70 min at Swartkops. Samples were collected at low tide, starting at the mouth and working towards station 1, always staying ahead of the tide.

The distribution of copper and lead was somewhat erratic, although there was a general trend towards lower values nearer the sea; anomalies occur at Redhouse, Swartkops and the north-east side of the main Fishwater Flats Sewer Outfall.

There was a general increase in zinc and iron values in the middle region of the river, associated with two very high values near Redhouse. Zinc values were also high in Tippers Creek (station 17) near Amsterdamhoek and at the Fishwater Flats Outfall. Concentrations at Swartkops village, however, were not significantly elevated.

The Fishwater Flats sample had an elevated iron concentration of $155 \mu\text{g l}^{-1}$. The reduction in iron values below Redhouse are associated with a sharp increase in sodium concentrations, reflecting the increased sea-water contribution to the river.

Manganese, cobalt and nickel concentrations fell gradually towards the sea. There appeared to be no significant input of manganese along the whole river. A slight increase was experienced in the Fishwater Flats sample.

Cadmium values remained uniform along the length of the river and no sites of cadmium input into the river could be found.

Mercury values remained below the analytical limit of 5 ng l^{-1} , which indicates that the area was uncontaminated with respect to this element.

As water is a transient medium, few definite conclusions can be drawn from its metal content. However, there are indications that the three villages of Redhouse, Swartkops and Amsterdamhoek, together with an area adjacent to the Fishwater Flats sample, make a significant contribution to the trace metal load.

Sample 10 was collected in the channel carrying the power station cooling water effluent to the river. It was concluded from the results of a previous survey¹⁶ that there was a significant trace metal input at this site. During this previous survey, however, no sample was collected in the effluent channel and conclusions were drawn from the trace metal contents of adjacent samples. The results obtained in the present survey differed from the initial findings as the metal concentrations in the water appeared to be normal. This indicated either considerable variability in metal content or an improvement in quality.

Distribution of trace metals in surface sediments

Eighteen surface sediment samples were collected in the Swartkops estuary at the sampling sites shown in Figure 19.

Samples were collected using an aluminium drag which was towed on the end of a nylon rope behind a boat. Three towing traverses were made at each site and a composite sample mixed from the three bulk samples. Approximately 500 g of the composite sample was transferred to a polythene bag.

The levels of copper in the surface sediments appeared to decrease towards the sea. However, after an initial decrease above Redhouse, copper levels increased to reach a maximum ($27 \mu\text{g g}^{-1}$) in the sediment immediately opposite the town. Below the brickworks, the main channel samples appeared to have background concentrations ($<4 \mu\text{g g}^{-1}$), with the exception of the sample taken in the power station effluent channel ($9,6 \mu\text{g g}^{-1}$). This may represent copper accumulation in the sediment associated with the effluent.

The higher levels in the upper regions of the river may represent input from the towns of Perseverance and Uitenhage, both of which discharge

effluent into the Swartkops River.

The pattern for the distribution of lead in the surface sediments was almost identical to that for copper. The value of $53,2 \mu\text{g g}^{-1}$ for the lead concentration at Redhouse indicated a local source, probably directly connected with the large numbers of petrol driven craft in the area. Enhanced levels also occurred at the site of the power station effluent (16,6), Modderspruit (24,0) and Tippers Creek ($11,0 \mu\text{g g}^{-1}$).

Zinc displayed a similar distribution to that of copper and lead with the exception of one anomalous value at Amsterdamhoek ($38,2 \mu\text{g g}^{-1}$). Although this value was not as high as those associated with Redhouse ($84,6 \mu\text{g g}^{-1}$), it was nevertheless significantly elevated with respect to the adjacent samples ($<10 \mu\text{g g}^{-1}$) and probably represented local input.

The distribution of iron in the surface sediment in the upper reaches, may be the result of precipitation from the water column with increasing salinity. Local elevations in the lower reaches may therefore be directly related to local sources of input. Sample 2 was again anomalous, as it had been for all elements discussed thus far. This fact is difficult to explain as the sample area is well removed from habitation and there are no apparent local input sources. The aluminium concentration was also locally elevated and it may be that this area is one of clay flocculation and precipitation. Consequently, this could be a site of adsorbed-metal deposition. High concentrations were again observed at the power station effluent site, which is to be expected as the effluent pipes are composed of steel. There are, however, no sites where iron may be said to be a pollution hazard.

Manganese had a more complicated distribution pattern than iron. Four anomalous areas were apparent, including Redhouse and Tippers Creek ($500 \mu\text{g g}^{-1}$). Although nearby samples contained background levels ($<100 \mu\text{g g}^{-1}$). In general, manganese concentrations were at levels to be expected for rivers draining sandstone and marl sequences.

The distribution of cobalt, nickel, chromium and mercury in the surface sediments appeared to be very similar to that of zinc, with anomalously high concentrations at Amsterdamhoek ($0,8 \mu\text{g g}^{-1}\text{Co}$) and Tippers Creek ($5 \mu\text{g g}^{-1}\text{Ni}$). The broad increase in levels around Redhouse was again apparent (eg $1,2 \mu\text{g g}^{-1}\text{Co}$), together with relatively increased levels at the power station effluent site upstream of Swartkops.

The distribution of calcium and strontium was dependent upon the presence of shell debris. The upper reaches of the river above the brickworks were particularly poor in shell debris while downstream near Swartkops shell debris became increasingly common. In the mouth area and along the adjacent beaches, shells may compose up to 50% of the sediment.

The distribution of magnesium in the surface sediments of the Swartkops River was unrelated to the presence or absence of shell debris. It was in fact more closely related to the distribution of sodium, aluminium and potassium, which are indicative of the presence of clay minerals and organic material in the sediment. The main source of magnesium in the upper reaches of the river was probably the marine Cretaceous Uitenhage marls, which form high banks in the area.

TABLE 8. GEOMETRIC MEANS ($\mu\text{g g}^{-1}$) IN CORES FROM THE SWARTKOPS ESTUARY COMPARED WITH A GEOMETRIC MEAN FOR ALL CORES FROM THIS AREA;

Sample Number	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Na	K	Ca	Mg	Sr	Al	Cr
1	2,7	4,4	6,9	3768	210	1,2	2,7	0,006	1753	685	139	685	12	2377	3,9
2	1,9	4,4	7,5	3799	156	1,0	2,2	0,006	1778	620	140	678	4	2459	4,2
3	2,5	5,6	10,7	6007	46	1,1	2,1	0,02	2840	933	239	1004	5	3139	7,5
4	2,7	4,2	10,5	5702	27	0,9	2,1	0,017	2448	880	597	1132	6	3165	9,8
5	3,9	6,8	17,6	13003	33	1,3	3,5	0,04	2922	1719	1038	2159	5	5749	16,5
6	2,1	5,1	9,0	2762	77	0,9	1,7	0,007	2107	779	2284	855	8	2996	6,2
7	3,0	6,9	11,0	3330	15	0,8	1,9	0,03	2298	1026	3058	903	15	4341	10,5
8	6,3	12,4	30,2	8333	57	2,1	5,2	0,03	3816	2504	2519	2892	15	12205	25,6
9	5,7	13,4	25,2	5632	41	1,2	3,1	0,05	3516	1798	51349	5131	411	8395	19,9
10	3,0	10,6	12,8	2600	19	0,5	1,4	0,05	3134	909	81703	3579	648	4383	8,2
12	3,7	12,0	22,9	3699	26	0,8	2,7	0,06	3404	1817	53889	3094	440	7611	14,1
15	1,6	4,2	6,0	1170	11	0,1	0,4	0,04	2921	593	90031	2804	737	2240	4,9
18	3,6	8,5	21,9	6506	31	0,6	2,1	0,11	4225	1655	86865	3963	740	5554	17,8
19	1,2	2,9	4,6	741	12	0,1	0,2	0,03	2869	426	102152	2859	883	867	3,3
20	1,7	2,6	4,0	617	29	0,1	0,4	0,02	2980	589	109758	2391	1187	1110	4,9
21	1,8	2,5	3,6	584	29	0,1	0,3	0,02	2382	535	125515	2516	1902	1077	4,6
22	1,7	3,4	2,8	680	13	0,2	0,3	0,01	2851	308	111485	2144	1099	681	2,8
23	1,2	3,8	2,3	754	17	0,2	0,2	0,01	2597	290	72654	2158	1363	708	3,8
X	3,1	7,3	14,1	4719	53	0,9	2,2	0,04	2878	1167	35264	2297	293	4687	10,9

TABLE 9. SWARTKOPS RIVER CORE 12

Sample	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Na	K	Ca	Mg	Sr	Al	Cr
873	4,0	15,3	27,0	3430	30	0,9	2,8	0,060	2720	1890	56400	3050	423	7670	14,4
872	4,2	16,2	25,0	4030	27	0,9	2,8	0,064	3510	1820	59900	3040	482	7710	17,4
871	4,6	19,5	23,8	4010	40	0,9	3,4	0,056	4470	2060	52400	3570	391	8270	20,0
870	4,7	17,7	20,8	4560	40	1,1	3,3	0,064	4330	2130	57500	3500	429	4170	21,5
869	5,1	13,7	33,8	4310	41	1,0	4,5	0,068	4400	2210	48800	3670	389	4070	21,0
868	4,5	17,1	29,3	4160	28	0,9	3,1	0,059	4050	2050	54400	3440	421	8650	17,9
867	4,1	18,5	29,3	3570	23	0,7	2,6	0,058	3460	1720	52500	3010	420	7410	15,0
866	4,3	14,9	27,4	3470	23	0,8	2,9	0,067	3640	1850	53300	3140	475	8040	17,6
865	3,8	12,3	23,6	3280	26	0,7	2,5	0,061	3090	1510	50000	2720	389	7020	14,5
864	4,3	20,9	34,4	3770	32	0,9	3,2	0,075	3770	2230	52300	3570	392	8320	17,9
863	4,5	18,8	30,1	3830	33	0,9	3,2	0,064	3760	2040	49800	3380	416	8590	17,4
862	4,0	11,2	27,5	4060	33	0,9	3,0	0,060	3430	1760	48900	3070	373	8150	19,3
861	4,1	11,7	28,7	3790	29	1,0	3,2	0,068	3250	1640	51700	3060	413	7160	12,3
860	3,4	11,4	25,1	3190	26	0,7	2,6	0,055	3190	1870	47800	3080	398	8030	15,9
859	5,0	12,2	30,6	4350	32	1,0	3,3	0,075	3550	2130	47400	3250	383	9540	19,1
858	5,5	18,2	28,1	4030	26	1,0	3,1	0,067	3380	2030	50900	3140	400	8830	17,1
857	4,4	13,9	24,5	3970	31	0,9	2,8	0,061	2990	1450	44300	2730	336	7680	17,1
856	4,5	11,1	26,6	3870	25	0,8	2,9	0,066	3450	1930	49000	3140	408	8130	18,2
855	5,2	21,1	31,3	4370	33	1,0	3,5	0,073	4090	2470	53000	3720	451	9770	20,4
854	4,9	9,0	16,8	2470	11	0,7	1,4	0,049	2210	1080	43800	2070	364	4780	8,4
853	2,4	6,9	13,6	3450	22	0,6	2,1	0,063	3250	1700	58200	2950	411	6820	10,5
852	2,3	7,0	12,8	3690	13	0,7	2,0	0,058	3090	1560	61800	2480	515	6640	7,9
851	2,6	6,2	15,2	3600	21	0,8	2,4	0,056	3260	1800	61600	3170	521	7380	10,6
850	2,3	5,8	12,4	3020	21	0,5	1,9	0,047	2820	1590	54300	2740	460	6220	7,4
849	3,0	8,2	17,4	3380	26	0,8	2,6	0,057	2610	2020	65200	3480	535	7960	10,3
848	2,3	4	12,2	3650	16	0,7	2,1	0,050	3170	1700	58500	3010	500	6990	10,3
847	1,7	4,7	9,0	2420	11	0,4	1,5	0,041	2810	1200	54800	2440	479	5070	5,7
846	2,0	5,8	11,3	3250	16	0,4	1,9	0,055	3010	1540	58000	2840	542	6090	10,5
845	2,1	5,1	10,4	2790	16	0,4	1,7	0,052	2790	1400	59500	2820	526	5750	4,7

Lark grey medium to fine sand with some silt and broken shell debris

Dark grey medium sand with shell debris

There are six basic types of scatter plot which are worthy of note:

Figure 20(1) The first type can be exemplified by the zinc/nickel scatter plot. The sub-populations were spatially separated from each other; an excellent inter-element relationship existed between the two. Regression lines drawn for each population were close to being parallel.

Figure 20(2) The second type can be exemplified by the copper/zinc scatter plot. The sub-populations were spatially separated from each other with an excellent inter-element relationship for the lower population. Both sub-populations had the same regression line.

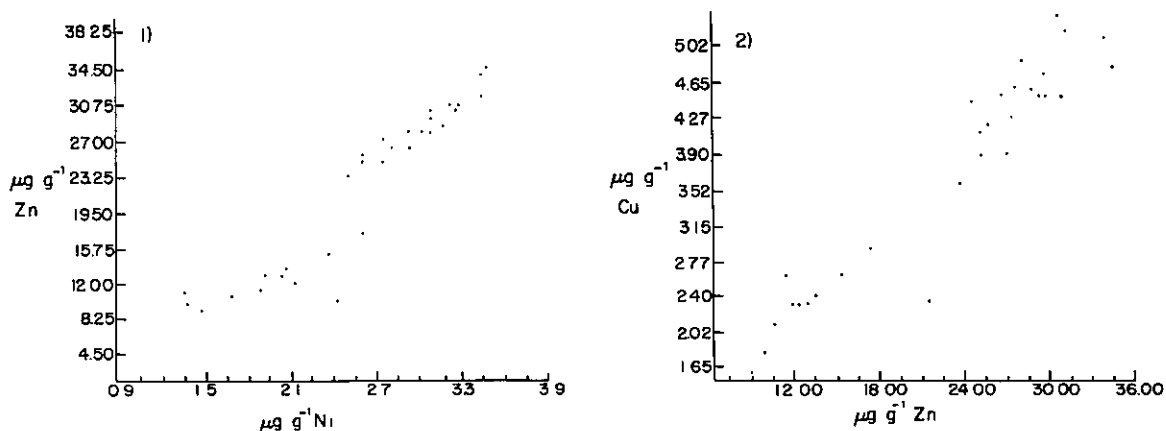


Figure 20. Scatter plots of the Zn/Ni and Cu/Zn relationships

Figure 21(1) The third type can be exemplified by the iron/aluminium scatter plot. There was no spatial separation of the two populations and there was an excellent inter-element relationship between both variables.

Figure 21(2) The fourth type can be exemplified by the lead/iron scatter plot. Here there was no significant spatial separation of the two sub-populations. However, the inter-element relationship in the low metal content population was excellent while that in the high metal population was very poor.

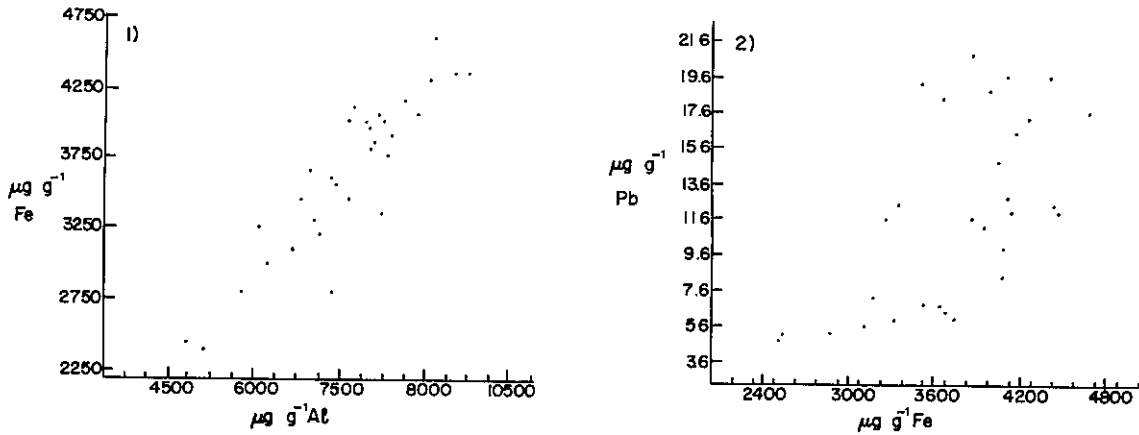


Figure 21. Scatter plots for the Fe/Al and Pb/Fe relationships.

Figure 22(1) The fifth type can be exemplified by the manganese/cadmium scatter plot. Here there was no spatial separation of the two sub-populations and no significant relationship between the two variables.

Figure 22(2) The sixth type can be exemplified by the nickel/strontium scatter plot. Here there was a spatial separation of the two sub-populations, but no significant relationship between the two variables.

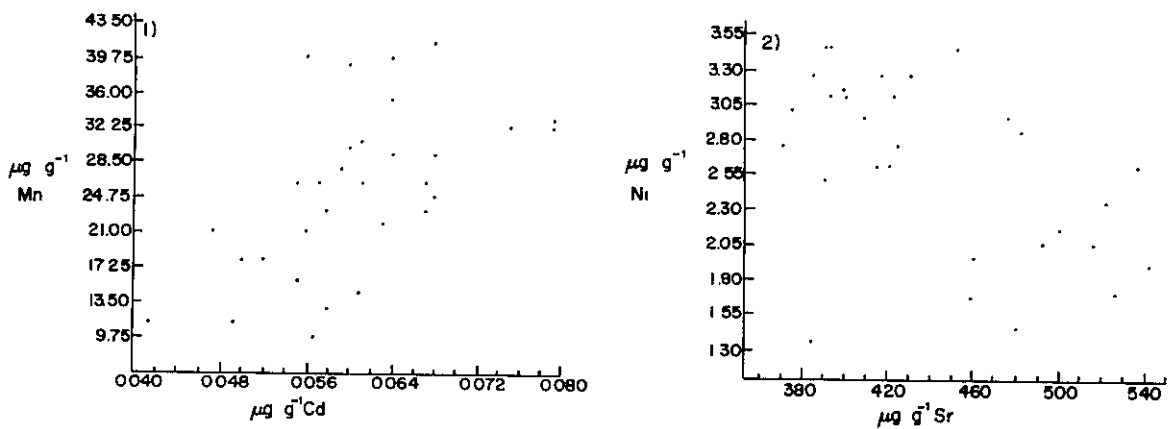


Figure 22. Scatter plots of the Mn/Cd and Ni/Sr relationships.

An attempt has been made in the above examples not to use the same elements to typify the types of scatter plot.

There is a definite indication that in the upper part of this core, above sample 854 (Table 9), there has been a swift increase of metal input into the area.

This metal input is not coincident with a major change of matrix components and consequently is not related to a change in the geological provenance of the sediment. This change in metal content is probably related to a period of growth of Swartkops Town and consequent increase in man's activities in the area. If this is the case, then the Swartkops core represents the most logical and identifiable instance of the effects of man on a sedimentary sequence so far encountered.

In general metal levels in the Swartkops River are not significantly elevated above background although four sites of local input, Redhouse, the brickworks, Swartkops and Amsterdamhoek have been identified. At present, the anomalies associated with these inputs are not extensive and there are no apparent adverse effects on the local biota.

Keurbooms and Bietou Rivers

Description of area

A map of the study area is shown in Figure 23. The Keurbooms River has its source in the Kammanasie mountains north of Plettenberg Bay while the Bietou River rises at Kafferskop. Both rivers combine and flow into a lagoon approximately 6 km long and 0,5 km wide, east of Plettenberg Bay. The lagoon is tidal and contains several large islands. The configuration of the mouth is continuously changing and is occasionally totally blocked leading to dramatic fluctuation of the water table within the lagoon.

The area along the river banks is used for residential, agricultural and recreational purposes. Part of the left bank of the Bietou River is owned by the Department of Forestry and is approachable only by boat. On the right bank of the Keurbooms River, north of the road bridge, the Cape Provincial Administration is developing a recreational resort.

Distribution of metals in surface water

Sampling locations are shown in Figure 24. Results are discussed in detail by Watling and Watling.⁹⁴

The concentrations of copper, zinc, iron, manganese, cobalt, nickel and mercury found in these surface water samples were considered to be average for Eastern Cape Rivers.^{89,90,91,92} Lead and cadmium values were elevated but showed no obvious trend which might allow a source to be identified. In fact, cadmium levels were, on average, ten times higher than those determined for any of the Eastern Cape Rivers studied so far. It is probable that the cadmium is of geochemical origin as there was

significant input from the upstream sections of the rivers, but no obvious man-made source of pollution was apparent in this area.

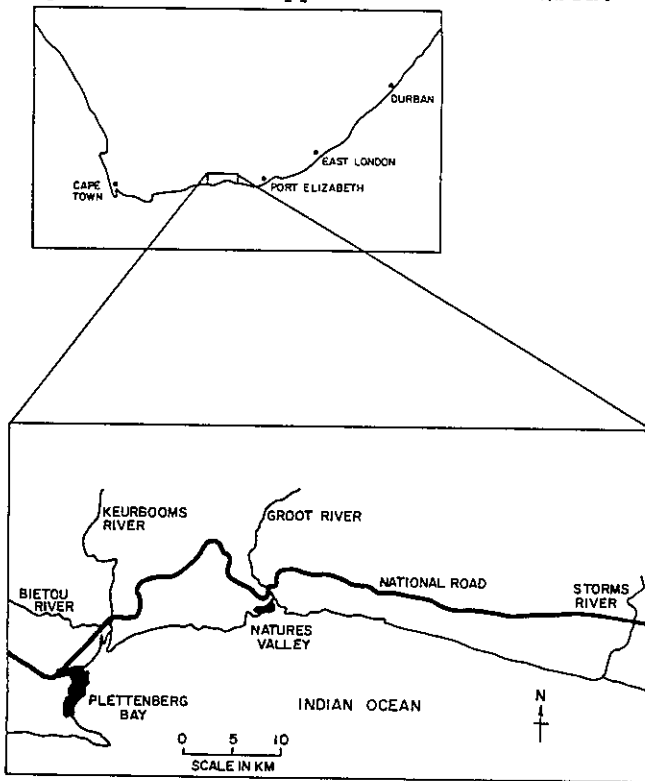


Figure 23. Map of the study area

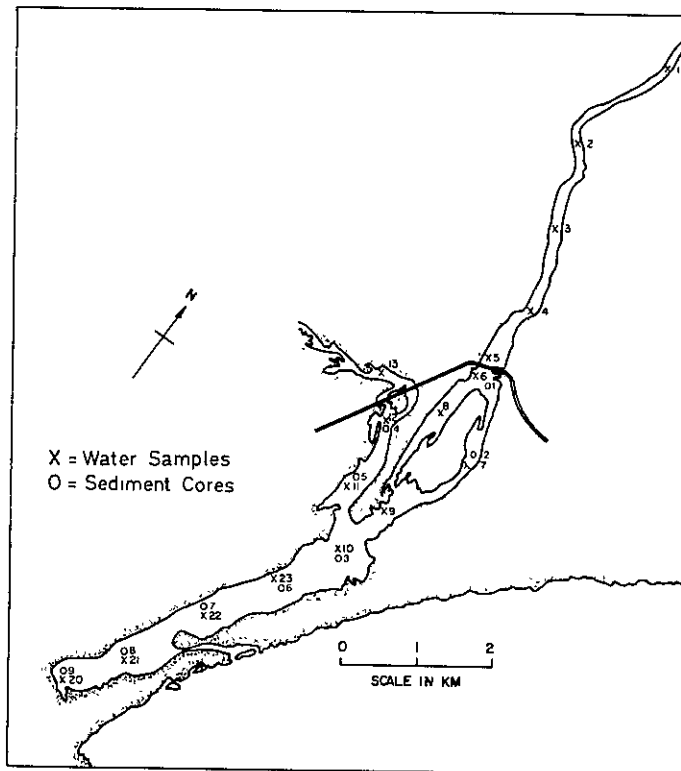


Figure 24. Keurbooms and Bietou River sampling sites
X Surface water samples
O Sediment cores

The trace metal chemistry of the water did not appear to have been significantly influenced by the local urban development. However, with the continuing development of Plettenberg Bay town, the waters of this biologically productive lagoon must be monitored on a regular basis.

Distribution of metals in surface sediments

Metal levels in surface sediments were average for rivers of the Eastern Cape, although the sediments in the Bietou River had elevated metal levels when compared with the concentrations found in sediments collected in the Keurbooms River at an equivalent position in the estuarine sequence.⁹⁴

Metal levels, particularly those of copper, lead and zinc, decreased along the Keurbooms River as the region of greater salinity was approached. Concentrations in Sample 6 were anomalously high, probably because the sample was collected in the area adjacent to the marina (Figure 24). The relatively elevated zinc, cobalt, nickel and iron concentrations in Sample 6 could be derived from this source.

The traverse from the Bietou River joins that of the Keurbooms River at Sample Site 10. Concentrations of copper, lead, zinc, iron, cobalt, nickel and chromium in samples from the Bietou River were elevated relative to their concentrations in samples from the Keurbooms River. This may be due to the presence of some mineralization in the Bietou River catchment.

Metal levels again rose sharply at the extreme south-western end of the traverse, in the estuarine area associated with the town of Plettenberg Bay. These elevated levels were most likely the result of urban contamination. Runoff from new developments in the area entered this region of the estuary directly but tidal exchange was minimal.

Distribution of metals in depth

A list of the element concentration means and standard deviations for all nine cores collected in these rivers are given in Table 10. The anomalous situation existing in the Bietou River (cores 4 and 5) is apparent. A correlation matrix for the total data is shown in Table 11. Here, many of the inter-element relationships were masked by superimposed trends as the area had two definite metal sub-populations. It is necessary, therefore, to consider the Bietou River as a separate entity from the Keurbooms River and estuary when interpreting the implications of their trace metals.

It is obvious from the surface sediment data and from the metal concentrations in the two cores collected from the Bietou River (Table 10) that this river has a mineralized catchment. Catchment leaching has increased the metal contents of the sediments probably as far as the confluence of the two rivers. The inter-relationship of the sediment geochemistry with iron and manganese in the correlation matrix web indicates that the catchment rocks are rich in iron.⁹⁴ Dissolved iron in

the river water precipitates when conditions of higher salinity are encountered, carrying other metals with it. The collection and analysis of core samples higher up the river should confirm the presence of this proposed mineralization.

The concentrations of metals in the cores collected from Keurbooms River and estuary were much lower than those found in the Bietou River. In addition, fewer significant inter-element correlations existed. The carbonate facies and clay facies were well developed but the cobalt, nickel and zinc matrix was not related to the clay facies. Consequently, adsorption of elements onto the clay minerals was not the main distributing factor for metals in this section of the estuary. There was slight evidence of urban contamination at the south-western end of the estuary but this was not significant when the estuary was considered as a whole.

Groot River

Description of the area

The Groot River has its origin in the foothills of the Tsitsikamma mountains and enters the sea about 40 km east of Nature's Valley. The left bank of the river is under the control of the National Parks Board. The river forms a lagoon at its mouth. The lagoon is approximately 2 km long and 0,5 km wide. The mouth is usually closed to the sea by a bar but occasional high tides inundate the area. The town of Nature's Valley is situated on the south-western bank of the river but small residences also line the river bank for a considerable distance upstream.

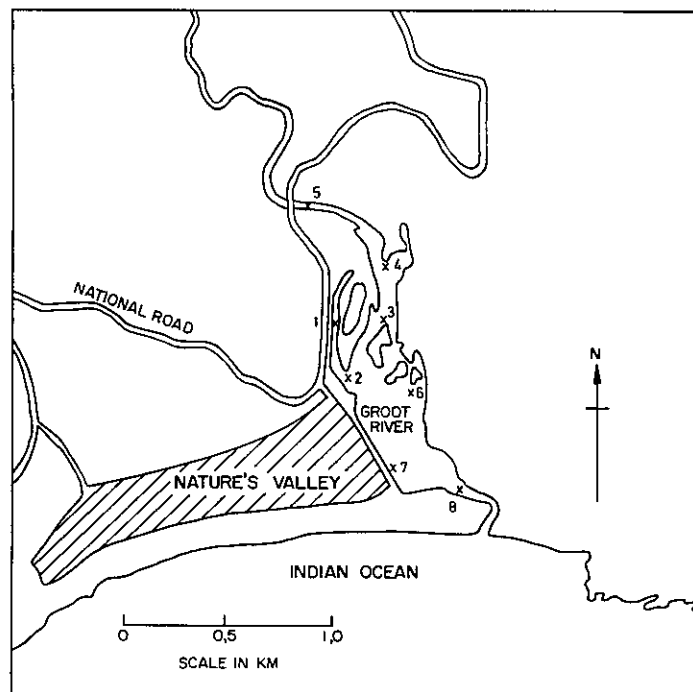


Figure 25. Map of the Groot River showing sampling sites

Distribution of metals in surface water

The sampling site locations are shown in Figure 25. In general metal concentrations were similar to those found in the Keurbooms and Bietou rivers, with the exception of copper and mercury concentrations which were elevated.⁹⁴ Cadmium values were again higher than might be expected and it is probable that there is a geochemical source of this element in the area. Minor element concentrations were low and there was considerable freshwater influence even at the mouth of the river. The holiday township of Nature's Valley cannot be said to have contributed in any way to the trace metal assemblage of Groot River water.

Distribution of metals in depth, in sediments

Cores were only taken at Sites 1 and 8.

The area around Core 1 was composed predominantly of reducing clays and sands and acted as a metal trap with levels of copper, lead, zinc, cobalt, nickel, cadmium and chromium elevated in the top 150 mm. Core 8, however, had metal levels which were average for sandy sediments.

Storms River

Description of area

The Storms River enters the sea through a massive gorge about 40 km east of Nature's Valley. There is no lagoon at the mouth of this fast flowing river which enters the sea directly. The whole area is within the Tsitsikamma Coastal Marine Park so that the biota of the area are protected totally.

Distribution of metals in surface water

Continued rough weather during the preliminary investigation of this river made it impossible to take a boat up Storms River. Consequently sampling was restricted to two water samples, one collected at the mouth (Site 1) and the second collected just upstream of a suspension bridge (Site 2). The results of trace metal analyses of these samples are given in Table 12.

TABLE 12. METAL CONCENTRATIONS IN SURFACE WATERS FROM STORMS RIVER

SITE	Metal concentration $\mu\text{g } \ell^{-1}$								
	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Hg
1	0,4	0,3	0,2	37	0,7	0,1	<0,1	0,1	0,037
2	0,6	0,3	1,3	78	1,7	0,2	<0,1	0,1	0,037

It is impossible to say anything constructive about Storms River on the basis of two water samples. However, when the results are compared with those of Keurbooms and Bietou River samples these levels are found to be average for rivers of the south-eastern Cape.

The analysis of sediment and water samples collected during the follow-up survey should show whether metals in this river are indeed at background levels.

Knysna Estuary

Description of the area

The Knysna river has its source in the Outeniqua Mountains of the Southern Cape. It is situated between the major centres of Mossel Bay and Port Elizabeth (Figure 26) being some 80 km from the former and 240 km from the latter. The river has a small drainage basin and is about 60 km long, being tidal for the last 20 km. The tidal region is the area generally known as Knysna Lagoon which is a broad valley between sandstone and conglomerate escarpments. Where the estuary joins the sea, two high sandstone cliffs constrict the valley; these are called the Knysna Heads.

Krige⁵⁶ considered the Knysna River to be a drowned valley which had largely been silted up, a tendency in most Cape rivers. He suggested that the maximum depth of the estuary was about 13 m whereas bedrock is often not encountered in boreholes of 30 m depth. The estuary reaches its major width of 3 km south-east of the railway bridge and in this region the two permanent islands, Thesens and Leisure, are situated. Thesens Island is occupied by Thesen and Co., a major wood distributor and marine timber treating organization, the Knysna Oyster Company and a regional office of the Fisheries Development Corporation of South Africa (FISCOR). Leisure Isle is the site of a high density "prestige housing" enclave. Both these islands are connected to the mainland by badly designed causeways which have done much to aggravate siltation problems in the area.

The first detailed account of the ecology of the Knysna Estuary was published in 1952 by Day *et al.*²⁸ On the basis of a comparison of this area and thirty others the authors were able to state that Knysna "has the richest fauna we have seen". They listed a total of 357 species of animals not including fish, birds or plankton. On the basis of physical parameters they recognized four faunistic divisions within the estuary; these were -

- a) Knysna Heads
- b) Main Lagoon, below but not including the Point
- c) The Westford Channel to the Old Drift
- d) Charlesford Rapids

By far the greatest species diversity was found between the Heads and Leisure Island where the fauna has both a marine and an estuarine component. Detailed faunal distributions are given for other areas within the lagoon but these are not quantitative. In 1967 Day²⁶

published a further paper on the biology of the Knysna estuary. In it he stated that the Knysna estuary had a wide variety of substratum types and consequently provided a varied bottom environment. In addition, because of the relatively large tidal range throughout the estuary, the water was well oxygenated and a considerable amount of organic detritus was transported within the estuary.

Genade⁴⁰ recorded that the first organized attempt at aquaculture took place in 1948 with the founding of the Knysna Oyster Company. Korringa⁵⁵ published an account of oyster culture in South Africa in 1956 and discussed the suitability of certain estuaries for the purpose. He concluded that the middle section of the Knysna estuary could be most suitable for this purpose as it had rich algal growth, warm water and a lack of silt in the water column. However, after initial trials using tiles to facilitate spat fall and on growing these spat near Belvedere, the Knysna Oyster Company experienced problems. In 1963 the Fisheries Development Corporation of South Africa (FISCOR) initiated a cooperative programme to promote oyster culture in the lagoon.

Salinity-temperature distribution within the estuary

Salinity-temperature profiles were taken from an anchored boat at nineteen sites within the Knysna estuary.⁹² Results were recorded using a temperature-salinity meter and measurements were made with the probe in place so that it was easy to establish the exact position of any halocline.

As would be expected, salinity decreased towards the National (new) Road Bridge, but as all measurements were taken only at high tide at this point, the influence of saline water was clearly seen. Temperature also increased in the same direction. This was a direct result of the shallowness of the lagoon, enabling the sandbanks to absorb heat at low tide and so heat the surrounding water. At Belvedere and above, although mixing had to some extent occurred, there was a marked increase in salinity with depth, suggesting a wedge of saline water underneath the lighter mixed waters coming down from the river. Salinity stratification appeared, however, to be absent in the main body of the lagoon.

Distribution of trace metals in waters

Twenty-five samples of water were collected in the Knysna River and estuary (Figure 26). The traverse line started at the Heads at turn of tide and worked towards Station 12 at Charlesford Rapids keeping ahead of the tide.⁹²

In general, metal levels were higher in the river, gradually decreasing towards the National Road Bridge after which relatively constant background levels were found. There were, however, two notable exceptions, cobalt and mercury. The cobalt levels in the river were low, $<0,3\mu\text{g l}^{-1}$, but immediately below the National Road Bridge levels increased sharply and remained, with the exception of localized low values, approximately 5-10 times higher than the river values. The most elevated levels occurred below the Railway Bridge in that area of the lagoon which may be said to be the most exploited commercially. It appeared that these relatively

elevated levels were indicative of an unnatural build-up of this metal, but as yet the source has not been identified.

Mercury concentrations varied considerably over the length of the river with values reaching as high as $600 \text{ ng } \ell^{-1}$. This particularly high level was at Site 7 which represented a consistent anomaly for many of the study elements. The area below the Railway Bridge again had high mercury levels, the highest being associated with Leisure Isle which could indicate sewage input from French drains and soak-aways. It is interesting to note that mercury levels in the Swartkops Estuary⁹¹ were consistently $<5 \text{ ng } \ell^{-1}$, while the mean of the values obtained for Knysna water was $136 \text{ ng } \ell^{-1}$. In the Knysna River, the most interesting site was 7 where the value of $10,1 \mu\text{g } \ell^{-1}$ cadmium is one of the highest encountered by the authors on the South East Cape Coast. The anomaly was still apparent on resampling, although there was no visible sign of a source of pollution in the area.

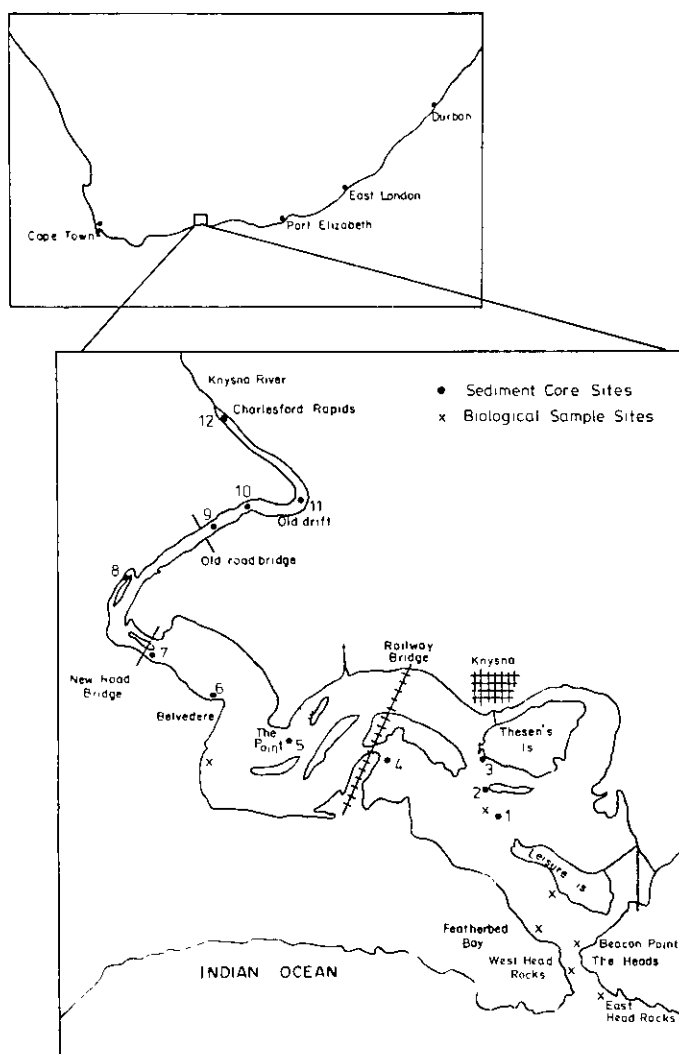


Figure 26. Knysna estuary.

In general, and with the exception of cobalt and mercury, metal levels in surface water associated with the urban area below the Railway Bridge were near background for this type of environment and showed no signs of pollution build-up.

Distribution of trace metals in surface sediments

An initial survey of the distribution of metals in the surface sediment of the Knysna estuary using 153 samples was undertaken in 1975.⁹⁰

From these data it was established that the estuary was relatively unpolluted with respect to trace elements. Isolated sites appeared to have anomalous element concentrations but in most cases these related to specific nearby sources of urban input and were not serious. One area worthy of interest, was that adjacent to Leisure Isle and bounded by the causeway. Here a salt marsh appeared to act as a metal trap. The area to seaward of Leisure Isle also had anomalous values, but this was thought to be of primary geochemical significance or related to French drains or soak-aways. The concentration of zinc was highest at sites associated with Knysna town. In general, copper levels were low with the exception of Knysna town drain and the sewage works, while cadmium was elevated in the Leisure Isle salt marsh and at the Heads.

One of the most interesting study elements was mercury, particularly at one area adjacent to the Point. In the initial survey the main anomaly, with values of 39,3 and 4,3 $\mu\text{g Hg g}^{-1}$, was upstream of the railway bridge and associated with the Point urban area. This area has a large boat mooring and utilization zone and it was felt that the whole anomalous zone could be caused by mercury antifouling paints being leached from these boats. Consequently, a follow-up survey,⁹² was undertaken with special reference to the channel between the Point and a local offshore island, which is used for bait collection. 131 samples of surface sediment were collected and analysed for zinc, cadmium, copper, lead, nickel and mercury. From these results it was impossible to isolate a coherent anomaly for any of the study elements. It was therefore apparent that the mercury anomaly found in 1975 was transitory in nature and its cause, although still not determined with any degree of certainty, does not represent a long term pollution threat.

Distribution of trace metals in depth

A distribution map of core sample sites is shown in Figure 26 and results are summarized in Table 13. Results have been published elsewhere.⁹² It is apparent from Table 13 that there were essentially three sites of metal build-up in the estuary. The National Road bridge (7), the railway bridge (4) and Thesens Island Jetty (3). Levels of copper, lead, zinc, cobalt, nickel and chromium were above the mean for the area and probably represented introduction of metals during construction of the structures and leisure activities such as shooting and fishing. Metal levels in depth were low and do not represent any long-term pollution threat to the estuary.

TABLE 13. MEAN METAL CONCENTRATIONS IN KNYSNA CORES (1978) ($\mu\text{g g}^{-1}$)

Core	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Na	K	Ca	Mg	Sr	Al	Cr
1	3,17	12,40	9,93	3965	38	0,56	2,24	0,17	4947	1539	128000	5670	570	5593	11,03
2	2,72	8,80	7,00	2544	22	0,45	1,68	0,09	3160	1066	78033	1945	2040	3721	6,78
3	4,99	9,91	11,86	5642	22	0,93	3,79	0,10	4694	1363	89	1563	7	7252	11,75
4	2,13	34,96	8,01	4060	24	0,59	1,85	0,01	2451	1001	7979	1297	88	2380	7,23
5	1,96	5,32	7,46	3815	19	0,71	2,25	0,06	3238	974	4890	1170	77	2922	9,07
6	1,95	4,98	8,46	2893	9	0,46	2,05	0,05	3239	907	3659	1088	40	3425	6,57
7	5,95	13,97	16,62	7158	18	1,00	5,97	0,12	2427	578	182	752	9	4120	11,18
8	1,36	3,51	5,81	2810	12	0,39	1,61	0,01	3817	912	372	1088	15	3231	5,16
9	1,41	4,52	4,67	2338	22	0,56	1,62	0,01	3495	820	437	1045	19	3518	4,70
10	2,35	5,56	9,48	3924	19	1,05	2,35	0,05	4938	1078	755	1592	32	5163	6,83
11	0,41	1,87	2,02	1074	29	0,31	0,50	0,01	1252	326	184	398	8	1039	1,38
12	0,65	1,69	2,39	1011	15	0,18	0,64	0,01	1561	369	155	448	8	1061	1,54
TOTAL	2,37	9,15	7,56	3291	21	0,58	2,11	0,05	3255	902	17891	1453	205	3636	6,54

Distribution of trace metals in the biota

The extent to which the three oyster species growing in Knysna estuary, *Crassostrea gigas*, *Crassostrea margaritacea* and *Ostrea edulis* have accumulated metals is minimal.⁸⁶ Samples of other molluscan species have also been collected from sites in the estuary and from the rocky shores near the Heads (Figure 26). Metal levels in *Perna perna* collected from a number of sites in Knysna estuary (Table 14) are low when compared with levels for this species growing at other sites on the South African coast.⁸⁷

TABLE 14. METAL CONCENTRATIONS IN PERNA PERNA

Sample location and date	n	Wet mass (g)	Dry mass (g)	$\mu\text{g metal g}^{-1}$ dry tissue										
				Zn	Cd	Cu	Pb	Fe	Mn	Ni	Co	Cr		
<u>West Head</u> November	1975	34	\bar{x}	4,00	73	6,0	7,0	0,7	570	5,7	7,6	0,5	8,1	
			S	1,69	23	2,9	2,1	0,6	158	1,8	3,8	0,3	3,8	
August	1978	40	\bar{x}	4,70	0,69	75	4,6	5,9	0,3	500	5,2	7,3	0,7	4,8
			S	1,54	0,24	16	1,2	2,0	0,1	123	1,9	3,2	0,2	1,3
<u>Featherbed</u> July	1976	30	\bar{x}	4,06	85	3,4	7,5	0,8	643	5,1	6,4	0,5	4,5	
			S		18	1,2	2,0	0,6	358	2,1	5,7	0,3	2,4	
<u>Beacon Point</u> July	1976	15	\bar{x}	5,54	44	2,0	2,8	1,0	234	2,6	1,9	0,1	2,1	
			S		16	1,0	1,0	0,8	84	1,2	1,2	0,1	2,1	
August	1978	11	\bar{x}	3,49	0,58	101	6,4	7,8	0,6	429	6,8	9,6	0,8	4,1
			S	0,92	0,16	20	1,5	1,6	0,2	71	2,4	3,2	0,1	1,4
<u>East Head</u> August	1978	30	\bar{x}	4,48	0,67	83	3,6	6,1	0,3	416	4,7	7,9	0,5	4,9
			S	0,91	0,09	13	1,0	1,5	0,1	123	1,5	3,7	0,2	1,0

A limited survey was made at Knysna Lagoon (Figure 27) in collaboration with the School of Environmental Studies, University of Cape Town, to determine the levels of organic and nutrient pollution caused by a sewage outfall into the Lagoon.³⁰ Analyses of the water samples showed high levels of nutrients and samples of sediment taken near Thesen's Causeway, which joins Thesen's Island to the mainland, had an extremely high organic content with values up to 20 mg g^{-1} . In comparison to this value, the highest OA value obtained for a sample taken adjacent to the Green Point (Cape Town) sewage outfall was 15 mg g^{-1} . While it is normal for estuarine sediments to be rich in organic matter, the high OA values observed in sediment samples from the lagoon indicate abnormal accumulation of organic material.

Although identification of the source of the organic material did not fall within the scope of the survey it was apparent that, by restricting circulation, the causeway was responsible for a considerable percentage of the pollution problem in the area. Significant differences were observed in the water quality on opposite sides of the causeway and water levels were also noticeably different.

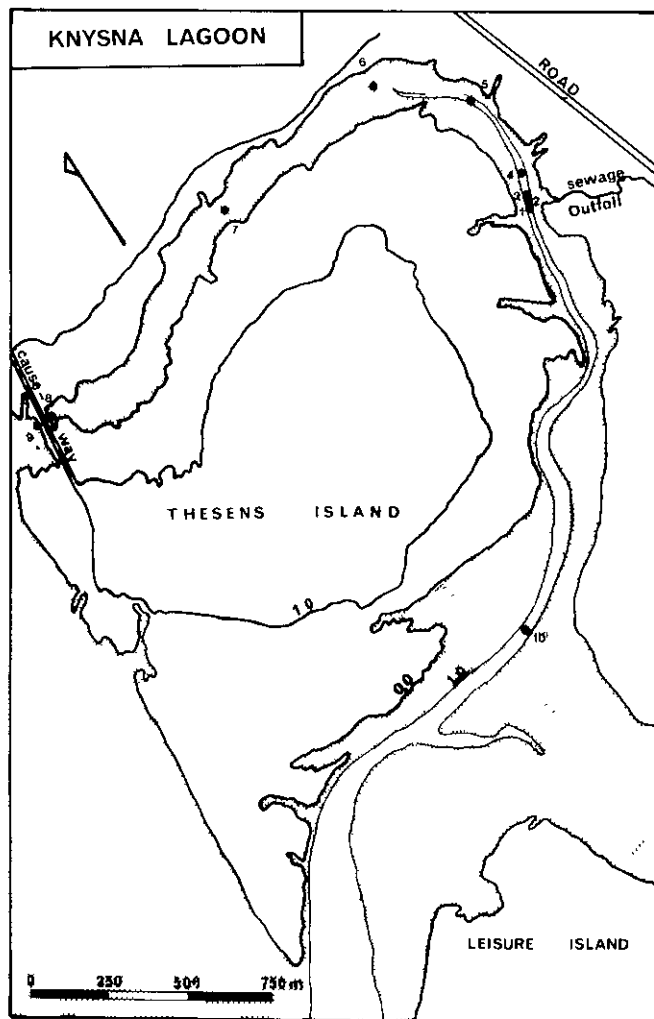


Figure 27. Knysna Lagoon.

Wilderness Lakes

Description of area

The Wilderness Lakes region is situated on the Southern Cape coast between the cities of Cape Town and Port Elizabeth (Figure 28). The lakes occupy east-west valleys approximately parallel to the coast and generally at right angles to the main drainage direction, being defined by parallel ridges of Pleistocene dune rock.^{53,61}

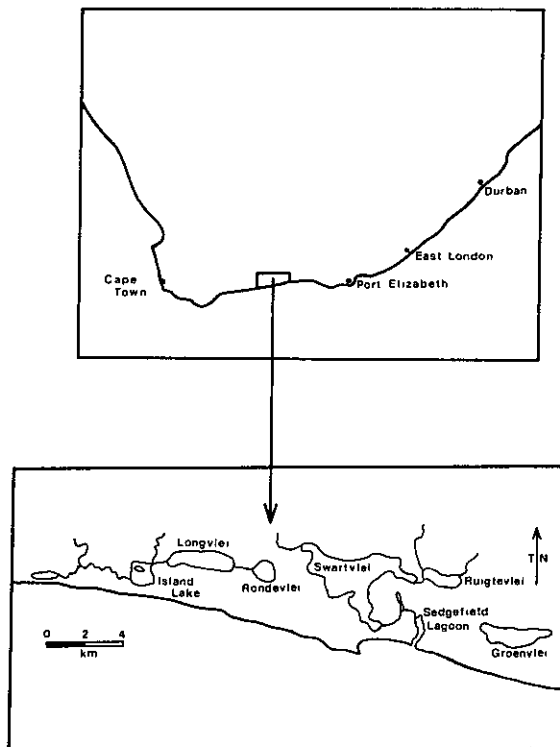


Figure 28. Location map of the Wilderness Lakes.

In general, the catchment areas of the individual lakes are small in relation to their surface area⁸⁹(Table 17) as might be expected in the case of their formation through coastline drowning. Swartvlei, however, does receive water from three reasonably large rivers, Diep, Hoogenkraal and Karatara and is also tidal, being separated from the sea by a bar. Bar formation is typical of many South African rivers and the Goukamma River is one local example. In the case of bars forming across the mouths of the Sedgefield Lagoon and Wilderness Lagoon the consequences can be serious and result in extensive flooding of low-lying areas surrounding the lakes.

The exception to this system is Groenvlei which is separated from the Swartvlei by a wide strip of alluvium and sand from Ruygtevlei, and from

the sea by dune formations rising to a maximum height of 180 m above sea level. At its eastern end it is separated from the Goukamma River by dune sand.

The geology of the area has been extensively studied by Schwartz⁷⁶ and Potgieter⁷⁴. The igneous and metamorphic Pre-Cape rocks in the west and Table Mountain Sandstone in the east form a peneplain, levelled during the Tertiary, into which rivers have cut deep meanders. Sea attack on this raised plain has produced an impressive cliffed coastline especially in the west towards Victoria Bay.

Distribution of trace metals in water - Wilderness Lakes

Water samples were taken and analysed for copper, lead, zinc, iron, manganese, cobalt, nickel and cadmium and twenty-nine for mercury. Results were reported in detail by Watling⁸⁹ and analytical techniques were described by Watling⁸⁸ and Watling and Watling⁸⁵. In general the levels of metals in the waters from the Wilderness Lakes were low. Average concentrations are given in Table 18.

TABLE 17. SURFACE AREA/CATCHMENT AREA RELATIONSHIPS IN THE WILDERNESS LAKES

Lake	Surface area Km ² (S)	Catchment area Km ² (C)	S/C	C/S
Swartvlei and Sedgefield Lagoon	10,73	397,6	0,027	37,04
Groenvlei	2,46	9,45	0,260	3,85
Langvlei	2,14	20,79	0,103	9,71
Island Lake	1,48	11,16	0,133	7,52
Rondevlei	1,41	4,76	0,296	3,38
Ruigtevlei	1,18	15,10	0,078	12,82

TABLE 18. AVERAGE METAL CONCENTRATIONS IN WATERS TAKEN FROM THE WILDERNESS LAKES (Results expressed as µg metal per litre water)

	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Hg
mean	0,64	1,12	1,28	199	70,3	0,1	0,1	0,54	0,234
Sd	0,60	0,75	0,69	261	176,8	0,1	0,2	0,63	0,252

Metal levels in waters from the Swartvlei-Ruigtevlei complex were generally higher than in the other lakes with manganese and iron reaching levels higher than anywhere else in the Eastern Cape.

In addition to the surface water survey a detailed survey of the Swartvlei halocline was also undertaken. Swartvlei is by far the largest and deepest of the Wilderness Lakes. It has a surface area of 10,7 km² and a maximum depth of 12,5 m, although this varies somewhat depending on the height of the bars at Wilderness and Sedgefield. Three sites were chosen (Figure 29) and at each site metal, salinity and temperature profiles were constructed. It was established that, although a thermocline was not present, there was a significant halocline at a depth of approximately 6 m (Figure 30). This implies that there was little circulation below 5 m and that the bottom was anoxic and reducing.

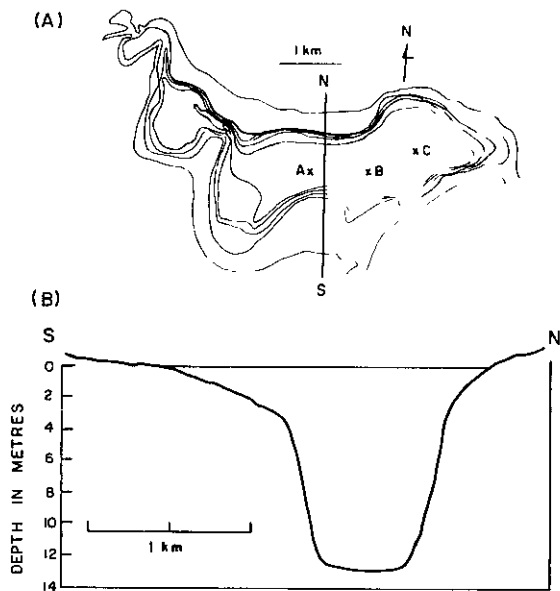


Figure 29 (A). Bathymetric map of Swartvlei with transect line and position of profile samples.
(B) Cross section along transect line.

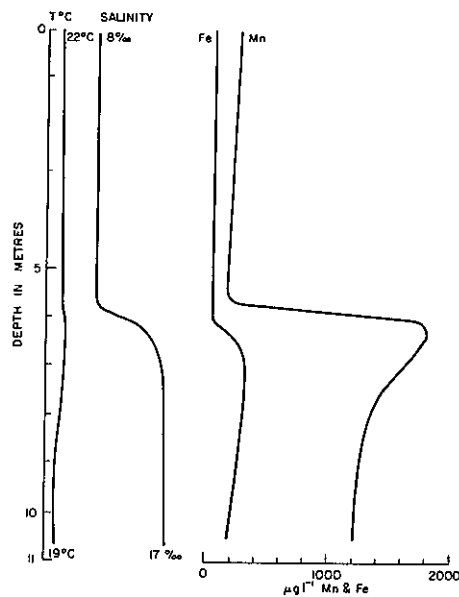


Figure 30. Profile in halocline section of Swartvlei.

With the exception of iron and manganese, all trace metals investigated showed little change across the halocline. The concentration of iron increased rapidly just below the halocline while that of manganese increased just above (Figure 30). Towards the bottom, concentrations appeared to decrease slightly but this was probably due to precipitation of iron and manganese sulphides.

Distribution of trace metals in sediments - Wilderness Lakes

A detailed description of analytical techniques, sampling procedures and results have been published.⁸⁹

Sediment samples were taken throughout the lakes. In general metal levels were extremely low although two general areas of elevated metal levels were present. The first of these was the area under the halocline in Swartvlei. These levels were often much higher than those directly attributable to pollution. However, they represented only the accumulation of precipitated sulphides from the water column. The anomalous area associated with Island Lake was related to other causes, as direct contamination from a yacht club and holiday resort were clearly in evidence. The effect at present is however minimal, but continued use of the area for recreational purposes could lead to considerably more elevated levels of metals being present in the sediments.

Distribution of trace metals in depth

Sixteen core samples up to 600 mm in length were taken in the area.⁸⁹ Cores varied from oxic coarse grained sands with broken shell debris to reducing anoxic muds. Copper, lead, zinc, iron, manganese, cobalt, nickel, cadmium, sodium, potassium, calcium, magnesium, strontium, aluminium and chromium were determined on samples taken every two centimetres along the length of the core. A matrix web was used to interpret inter-element relationships and to assess the effect of changing sedimentary facies on the trace element assemblage.

The core taken downstream of Sedgefield town was particularly interesting in that copper, lead, zinc, cobalt, nickel and chromium values increased markedly over the top 10cm. This obviously would be expected if the town was allowing contaminated effluent to enter the estuary. The cores taken near holiday camps on Swartvlei and Island Lake and adjacent to the yacht club in Island Lake also showed clear evidence of man-made contamination entering the area.

In general metal levels were low and do not present any significant environmental threat. This area is, however, in great demand by holiday makers and future developments, and increased utilization will undoubtedly lead to an increase of metal levels. The effect of this on the area remains to be seen and a close watch should be kept on all future developments.

Berg River (west coast)

A survey of the Berg River was undertaken in August 1976 when the river was in its winter spate. This was undertaken to augment an earlier survey carried out during summer conditions.¹⁰ The same stations were occupied as previously (Figure 31). In addition a further three offshore stations in a line directly opposite the river mouth were sampled. The estuarine and near-shore water was cloudy and brown because of the silt-laden freshwater discharge. Water samples were collected at high and low tides and sediment samples were collected from each station.

The strength of the flow during winter was illustrated by the salinity of less than 5‰ at the end of the breakwater (7‰ at the end of the lagoon side arm) at high tide. The concentrations of other chemical constituents (nitrate 10-25 $\mu\text{mol l}^{-1}$, phosphate 0,5-2,5 $\mu\text{mol l}^{-1}$) were within the expected ranges. Meiofaunal numbers in sediments were very low, as is usual for estuaries.

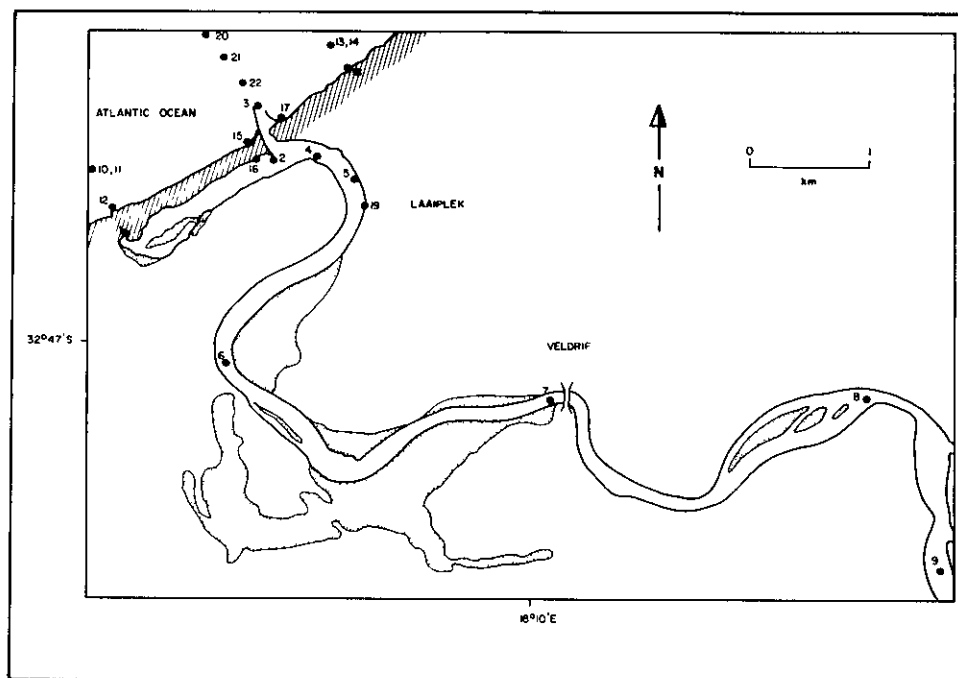


Figure 31. Berg River Estuary.

Olifants River (west coast)

Two sampling surveys of the Olifants River estuary were made in February 1976 and July 1977. This river enters the sea along South Africa's west coast at a position 31° 43'S, 18° 10'E approximately 400 km north of Cape Town. The catchment area of this river, 45 625 km² in extent,⁵² lies largely in the semi-arid region of the Western Cape Province. The mean annual runoff is 1217 x 10⁶ m³. Most of the area is subject to winter rainfall although some of the tributaries fall into a summer rainfall area. The rainfall in this region is, however, so low that it is thought not to influence the flow conditions to any great extent. The river flows across base saturated substrates including solonchalic, saline soils.

The flow in the lower reaches of the river, which is extensively used for irrigation, is governed by the Clanwilliam storage dam. Viticulture is practised extensively all along the valley. In this area there is a canal on each side of the river.

The estuary supports an extremely large and varied bird life and, although no estimates were made of fish stocks, it was apparent from various observations that the river also supports very large numbers of fish. Near the mouth is a large island which, in the dry season is joined to the southern bank by a spit. Just upstream from this, the sediment undergoes an abrupt change from coarse wind blown sand to extremely fine mud (Figure 32).

During summer high tides, saltwater penetration could be observed for about 14 km. Some stratification was also noted for the first 5 km although this was not marked as the estuary is somewhat shallow. An interesting feature of the river water was the relatively high salinity ($>27_{\infty}$) measured at stations where sea water could not have penetrated. This must therefore be due to land derived salts leached from the catchment.

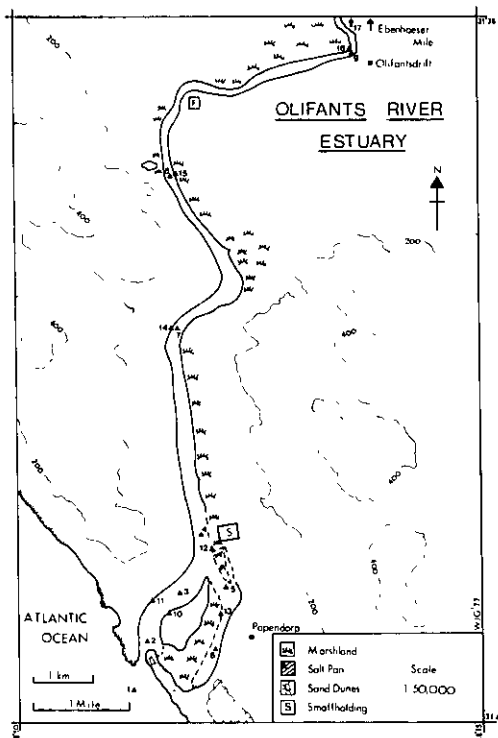


Figure 32. Olifants River Estuary.

All trace metals studied increased in concentration in the transition from coarse to fine sediments. This is a well documented phenomenon and will form the subject of a far more detailed study.

The river was in flood, during the winter survey, heavy rains having fallen in the catchment area in the preceding few days. SCUBA diving for samples was hampered by a strong current and extremely turbid water.

Triplicate cores were taken at all stations for biological and chemical analysis although the flood had scoured out approximately 1 m of sediment relative to the summer survey. Many of the bank stations sampled in the summer survey had either been washed away or were under water, necessitating modification of the sampling plan. High and low tide water sampling was carried out.

Because of flood conditions all samples had very low salinity even at the river mouth. One sample collected from the "side arm" of the river did however have a measurable salinity of 27 ‰ probably due to leaching of salt deposits left from summer evaporation. Dissolved oxygen concentrations were almost constant at saturation levels and nutrient levels were typical of fresh water flood conditions, *viz.* very low nitrate (<10 $\mu\text{mol l}^{-1}$), nitrite (<0,2 $\mu\text{mol l}^{-1}$) and total phosphorus (<1 $\mu\text{mol l}^{-1}$) and moderately high silicate (up to 50 $\mu\text{mol l}^{-1}$).

Flood conditions had a marked effect on meiofaunal numbers and groups of animals. The number of animals in the main channel had decreased markedly compared with the summer survey and some previously abundant groups had disappeared altogether, probably as a result of scouring. Interestingly, the number of animals in the "side arm" had increased compared to the summer levels. This was probably due to a combination of two factors. Firstly, the river sediments were very fine grained and the flood had removed much of the fine mud, leaving more space for animals to colonize in the interstices of the coarser sediment. Secondly, the increased water flow together with easier access for oxygen through the coarser sediment resulted in oxygenation of the previously anoxic sediments, thus facilitating colonization by harpacticoid copepods and other oxygen-sensitive groups. The suspended fine fraction of the sediment thus had a marked effect on meiofaunal communities and groups.

Orange River (west coast)

The Orange River is the largest of South Africa's rivers, with a catchment area of about 520 000⁵² km² and a mean annual runoff⁶⁷ of 9344 x 10⁶ m³. The river enters the sea at approximately 28° 38'S, 16° 35'E between the towns of Alexander Bay and Oranjemund on the South Africa/South West Africa border (Figure 33). Access to the mouth is restricted due to the diamond mining activities which are carried out in the vicinity. The river enters the sea through a narrow channel with a width of 100 m or less and a length of about 300 or 400 m. Upstream the river broadens out into a wide shallow area with numerous islands and sand banks. This area is up to 2 km wide with a depth of around 1 m or less in most places. In fact, this shallowness prevented the boat from penetrating more than 6 km from the mouth during the survey. This river also supports an extremely rich and varied bird life. The inaccessibility of the area probably makes it an ideal breeding ground for marine and land-based birds, many nesting among the reed beds of the banks and semi-permanent islands.

The extensive annual flooding which was a feature of the river in the past has largely been controlled by the construction of a series of large storage dams higher upstream. The area sampled should strictly be termed 'river mouth' rather than 'estuary' since, under the conditions of sampling, there was no incursion of salt water into the river at all, even

in the mouth at high spring tide. All 'estuarine' processes must therefore take place in the mixing area out to sea. Metal concentrations in the sediments were in the normal ranges and, with the exception of zinc, were highest in the fine anaerobic layer below the surface. The dissolved silicate content was lower than expected, probably because of removal by siliceous organisms in the large dams upstream. Meiofaunal counts in the estuary were found to be much lower than in west coast sandy beaches but were similar to those in the Olifants and Berg Rivers to the south.

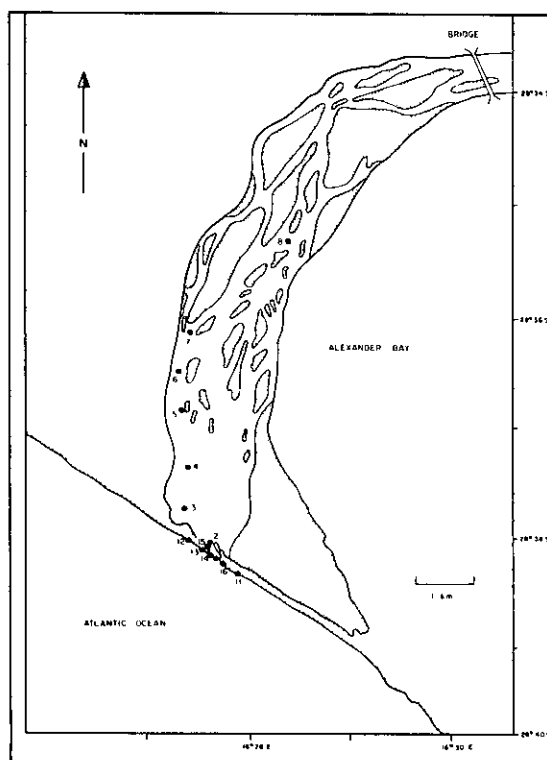


Figure 33. Orange River Estuary.

OCEANIC TRANSECTS

East Coast Oceanic reference transects and coastal monitoring surveys

Pollution surveys along the east coast have centred on a deep water reference transect extending 100 km offshore of Durban and seventeen coastal monitoring lines situated between Kosi Bay and East London. The east coast oceanic reference transect consists of stations situated 2, 4, 6, 8, 10, 25, 50, 75 and 100 km offshore on a line bearing 128°T off Cooper Light (Durban). Each coastal monitoring line is comprised of three stations bearing approximately at right angles to the coast and located where water depths are 20, 50 and 100 metres. Figures 34 and 35 illustrate the location of the sampling lines.

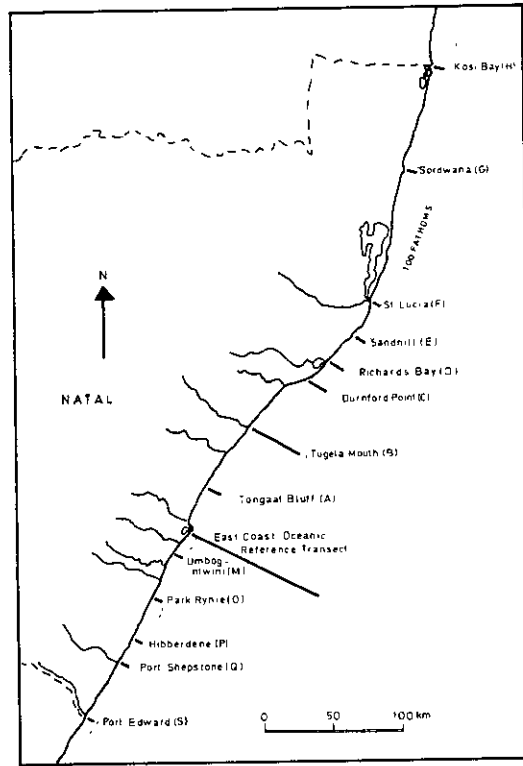


Figure 34. Location of sampling lines - Natal Coast.

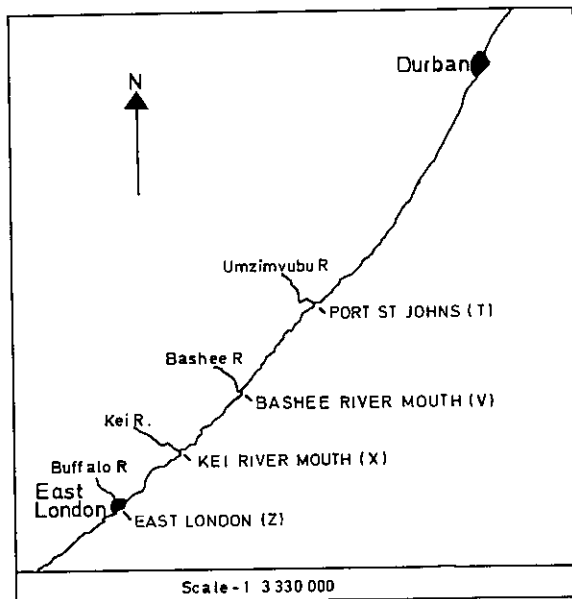


Figure 35. Location of Transkei and Eastern Cape sampling lines.

Eighteen cruises were completed between 1974 and 1978 as summarised in Table 19. (Some pre-1976 data is included for comparison). The east coast oceanic reference transect was surveyed on eleven occasions and each monitoring line was surveyed on between one and four occasions. A variety of physical, chemical and biological parameters were measured. The results have been detailed in earlier reports^{1,62,63,64,65}, and are

being included in a computerised data base as part of a continuing programme to monitor marine pollution along the east coast. Table 20 lists the means, minimums and maximums for some of the more important chemical parameters.

TABLE 19. SUMMARY OF CRUISES ALONG THE EAST COAST

Cruise No.	Date	Purpose
1. MN 74/07	11. 3.74	East coast oceanic reference transect 1
2. MN 74/16	3. 6.74	East coast oceanic reference transect 2
3. MN 74/26	23. 9.74	East coast oceanic reference transect 3 and coastal monitoring off Tongaat Bluff
4. MN 74/34	3.12.74	East coast oceanic reference transect 4 and coastal monitoring off Richards Bay and Tugela Mouth
5. MN 75/07	17. 3.75	East coast oceanic reference transect 5 and coastal monitoring off Umbogintwini, Park Rynie, Hibberdene, Port Shepstone and Port Edward
6. MN 75/11	5. 5.75	East coast ocean reference transect 6
7. MN 75/24	2. 9.75	Coastal monitoring off St Lucia, Sordwana Bay and Kosi Bay
8. MN 76/04	23. 2.76	East coast oceanic reference transect 7 and coastal monitoring off Umbogintwini and Park Rynie
9. MN 76/09	24. 4.76	Coastal monitoring off St Lucia, Sordwana Bay and Kosi Bay
10. MN 76/15	26. 7.76	East coast oceanic reference transect 8
11. MN 76/22	18.10.76	Coastal monitoring off Tongaat Bluff, Hibberdene, Port Shepstone and Port Edward
12. MN 77/01	10. 1.77	East coast oceanic reference transect 9 and coastal monitoring off Tongaat Bluff, Tugela Mouth and Durnford Point
13. MN 77/04	15. 2.77	East coast oceanic reference transect 10 and coastal monitoring off Richards Bay
14. MN 77/08	7. 3.77	Coastal monitoring off Port St Johns, Bashee, Kei Mouth and East London
15. MN 77/18	14. 6.77	East coast oceanic reference transect 11
16. MN 77/26	6. 9.77	Coastal monitoring off Tongaat Bluff, Umbogintwini, Park Rynie, Hibberdene, Port Shepstone and Port Edward
17. MN 78/04	21. 2.78	Coastal monitoring off St Lucia, Sordwana Bay and Kosi Bay
18. MN 78/21	18. 9.78	Coastal monitoring off Port St Johns, Bashee, Kei Mouth and East London

TABLE 20. SUMMARY OF MEAN, MINIMUM AND MAXIMUM VALUES FOR CHEMICAL PARAMETERS ALONG THE EAST COAST, 1974 TO 1978

Parameter	Units	Mean value	Minimum value	Maximum value	No. of Results
<u>A. Water Chemistry</u>					
Phosphorus	$\mu\text{g l}^{-1}$	21	2	180	854
Silica	$\mu\text{g l}^{-1}$	121	1	1300	853
Nitrate	$\mu\text{g l}^{-1}$	65	1	885	854
Ammonia	$\mu\text{g l}^{-1}$	15	1	900	812
pH		8,25	7,99	8,43	131
Dissolved oxygen	mg l^{-1}	7,13	3,60	9,40	483
Oxygen absorbed	mg l^{-1}	0,777	0,040	5,00	534
Kjeldahl nitrogen	$\mu\text{g N l}^{-1}$	248	36	926	400
Hg	$\mu\text{g l}^{-1}$	0,148	0,001	2,390	197
Cu	$\mu\text{g l}^{-1}$	0,886	0,001	8,500	234
Cd	$\mu\text{g l}^{-1}$	0,173	0,005	2,480	180
Pb	$\mu\text{g l}^{-1}$	1,643	0,001	10,970	211
Zn	$\mu\text{g l}^{-1}$	4,762	0,010	46,900	228
Fe	$\mu\text{g l}^{-1}$	24,6	0,01	259,8	185
Cr	$\mu\text{g l}^{-1}$	8,05	2,91	16,40	11
Co	$\mu\text{g l}^{-1}$	2,140	0,024	15,600	105
Ni	$\mu\text{g l}^{-1}$	7,365	0,689	21,000	29
<u>B. Sediment Chemistry</u>					
Oxygen absorbed	mg g^{-1}	0,556	0,016	7,520	144
Kjeldahl nitrogen	$\mu\text{g N g}^{-1}$	233	3	1410	168
Hg	$\mu\text{g g}^{-1}$	0,084	0,001	6,319	114
Cu	$\mu\text{g g}^{-1}$	5,00	0,20	36,59	124
Cd	$\mu\text{g g}^{-1}$	1,306	0,014	10,400	122
Pb	$\mu\text{g g}^{-1}$	12,370	0,428	69,000	124
Zn	$\mu\text{g g}^{-1}$	12,71	1,82	81,18	120
Fe	$\mu\text{g g}^{-1}$	6268	9	43975	116
Cr	$\mu\text{g g}^{-1}$	16,18	3,91	94,55	109
Co	$\mu\text{g g}^{-1}$	7,176	0,925	22,700	86
Ni	$\mu\text{g g}^{-1}$	13,65	1,65	43,21	68
Mn	$\mu\text{g g}^{-1}$	130	64	263	11

Salinities, temperatures and current velocities were measured to enable the characterisation of water masses in terms of the prevailing oceanographic regime. For example, warm southward flowing water would indicate Agulhas current water, whereas cooler less saline water would indicate an inshore water mass. The latter might be expected to contain higher pollutant concentrations.

Nutrient concentrations (phosphorus, silica, nitrate and ammonia) tended to reflect oceanographic conditions, with concentrations increasing with depth and being generally higher in the cooler southern waters. A notable exception was ammonia which was occasionally found at relatively high concentrations in surface waters at the inshore stations of the oceanic reference transect (Durban). This appears to be related to the discharge of sewage through offshore pipelines in the area.

Dissolved oxygen and pH were measured during some of the earlier cruises but were discontinued as the results were generally consistent and normal. OA and Kjeldahl nitrogen values, on the other hand, were very variable and followed no recognisable trend.

Trace metal concentrations in the water samples varied considerably. Despite this a few well defined trends were evident. Mercury, cadmium, lead, iron, cobalt and nickel tended to be more concentrated in the nearshore waters throughout the study area than in deep water off Durban. Lead concentrations tended to be slightly higher off the Transkei whereas mercury, cadmium, zinc, iron and cobalt were marginally higher in the shallow water off Durban than elsewhere. The concentrations of all the metals were, on the whole, comparable with those reported by other workers for unpolluted marine waters.

The sediments varied considerably in their content of nitrogenous and easily oxidisable organic material as reflected by Kjeldahl nitrogen and oxygen absorbed measurements. However, the results tended to be higher in deep water and near river mouths.

The benthic fauna was rich and diverse throughout the study area and on no occasion was evidence of toxic or enriched conditions found. There appeared to be a trend towards greater diversity and abundance at the deeper stations of the coastal monitoring lines.

Trace metal concentrations in the sediments showed wide spatial and temporal variation. Nevertheless the results were generally low and there was no evidence of trace metal pollution. Copper, cadmium, zinc, iron, nickel and manganese concentrations tended to be higher on the Tugela Banks and off Port St. Johns. This is presumably related to the presence of large rivers at both localities.

Pesticide residues (dieldrin, DDT and DDE) were present at very low concentrations in only a small percentage of the sediment samples. For this reason, routine analysis of these sediments for pesticide residues has been phased out and effort is being directed rather at their presence in marine biota (see General Studies section).

Surface oil residues in the form of tar balls were measured by surface hauls with a neuston net. The results varied between an absence of tar balls to a tar ball concentration of 5,01 mg m⁻². The residues appeared to be confined largely to within twenty five kilometres of the coast.

South and West Coast Oceanic reference transects

The aim of this study was to investigate the distribution of and seasonal variation in a number of chemical parameters, especially nutrients, trace metals, dissolved oxygen and salinity.

Samples were collected from two transects; the south coast line extended due south from Cape Infanta (20°50'E) and the west coast transect was due west from North Head, Saldanha Bay (33°03'S). Stations were 3, 8, 40, 70 and 100 km offshore as well as one inshore station on the south coast transect and two stations in Saldanha Bay (Figure 36). All cruises were

undertaken on the R.V. Thomas B. Davie, during the summer, autumn, winter and spring of each year from 1975 to 1980 (Table 21). Samples were collected in 8 l Niskin bottles at depths (depth permitting) of 0, 10, 20, 30, 50, 75, 100, 150, 200, 300 and 400 m. No samples were collected closer than 5 m from the bottom. On the south coast transect, where the continental shelf reaches a width of about 200 km, no station was deeper than 90 m. This means that the whole water column (down to 75 m) was sampled. However, on the west coast transect, where the shelf is much narrower the maximum water depth was 1 300 m. Thus, on the two outer stations, only the top 400 m was sampled.

Water samples were generally not filtered. Trace metal samples were acidified with nitric acid and stored frozen until analysed according to the method of Watling.^{85,88} Nutrient samples were stored frozen until analysed manually for nitrate, nitrite, phosphate and silicate, according to standard methods. Dissolved oxygen concentrations were measured by Winkler titrations.

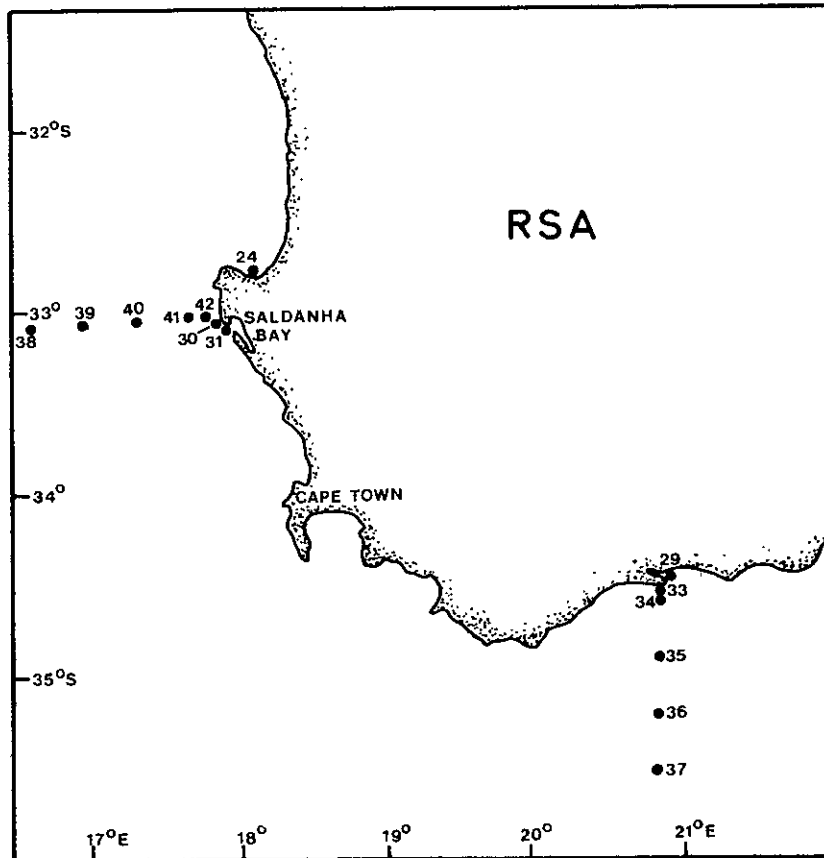


Figure 36. Location of the South and West Coast Oceanic Transects.

Nutrients

The results have revealed some notable differences between the south and west coast transects, and a definite seasonal pattern has emerged.

TABLE 21. CRUISE DATES

Cruise No.	Date	Cruise No.	Date
29	24. 2.75 to 28. 2.75	39	17. 7.77 to 20. 7.77
30	15. 4.75 to 19. 4.75	40	26. 9.77 to 29. 9.77
31	30. 6.75 to 3. 7.75	41	14. 2.78 to 17. 2.78
32	21.10.75 to 24.10.75	42	4. 4.78 to 7. 4.78
33	28. 1.76 to 31. 1.76	43	3. 7.78 to 6. 7.78
34	5. 5.76 to 8. 5.76	44	2 10.78 to 5.10.78
35	19. 7.76 to 22. 7.76	46	5. 2.79 to 8. 2.79
36	27.10.76 to 28.10.76	47	7. 4.79 to 10. 4.79
37	7. 2.77 to 11. 2.77	48	29. 1.80 to 1. 2.80
38	12. 4.77 to 14. 4.77		

South Coast

Distinct stratification of the water column was observed on most summer and autumn cruises. Temperature differences of up to 10°C were found within a depth range of 30 m (Figure 37). The water above the thermocline was generally well mixed and there were only slight differences between inshore and offshore water. Surface temperatures varied from about 21°C in summer to 15°C in winter. The nutrient concentrations in the mixed layer showed a marked seasonality, with maximum concentrations occurring in the winter (Figure 38). In spring there was a sharp drop in nutrient concentrations, a tendency which commonly occurs due to plankton growth. Nutrient concentrations rose again in summer, but during some years, a second drop was observed in autumn, presumably due to a second plankton bloom. The nutrient concentrations generally showed a sharp increase below the thermocline indicating that this forms a barrier to the free exchange between surface and bottom layers. Ratios of nutrient concentrations for each season were constant (e.g. Figure 39) but this was more apparent during autumn and winter when nutrient concentrations were higher. The high rate of nutrient uptake and the patchiness with which plankton blooms occur, presumably contributed to the greater scatter during spring.

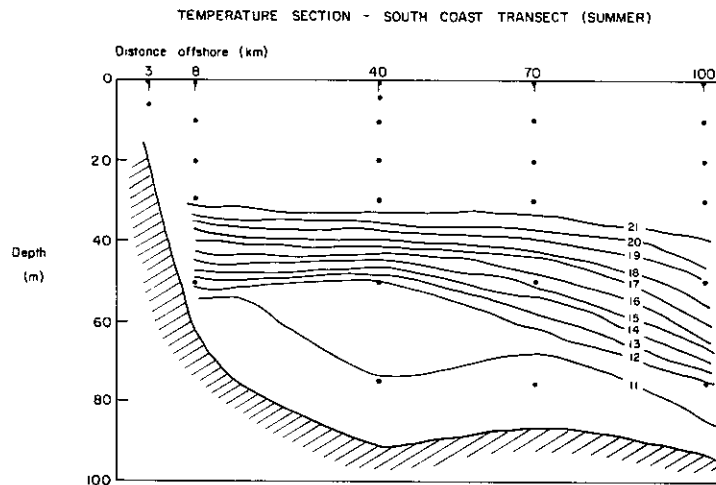


Figure 37. Temperature section - South Coast transect (summer).

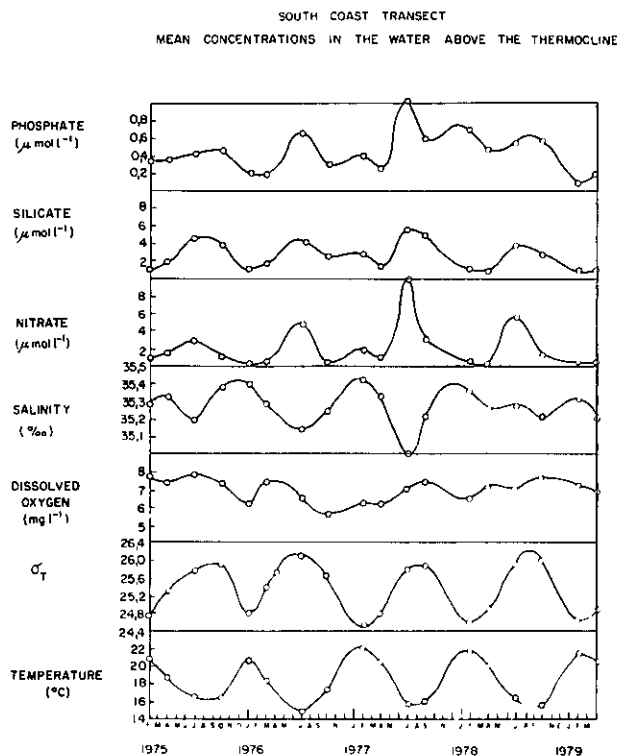


Figure 38. South Coast transect - mean concentrations in the water above the thermocline.

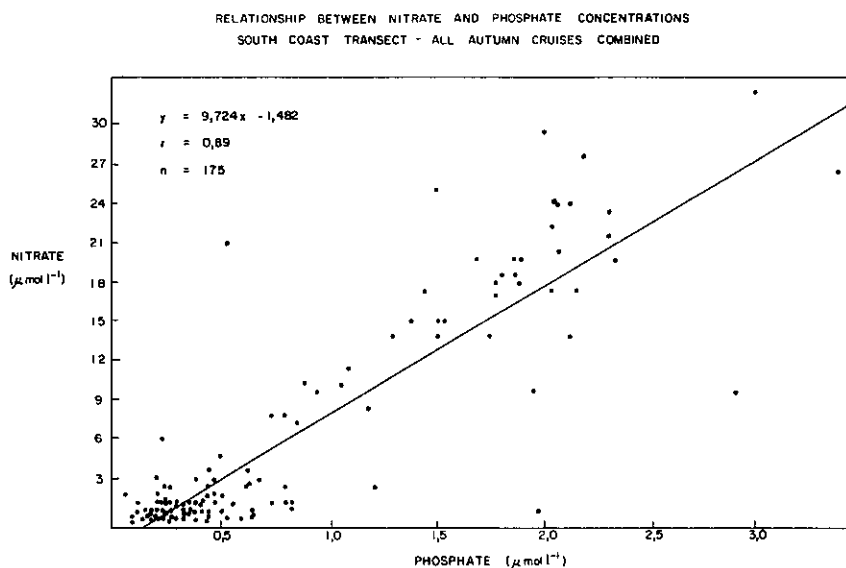


Figure 39. Relationship between nitrate and phosphate concentrations South Coast transect - all autumn cruises combined.

Definite inverse linear relationships were also found between nutrients and the dissolved oxygen concentrations (e.g. Figure 40), although in spring the relationship broke down to a large extent. This also demonstrates the biological controls which occur between these parameters. The highly

dynamic nature of the phytoplankton growth processes in spring presumably leads to a less ordered situation.

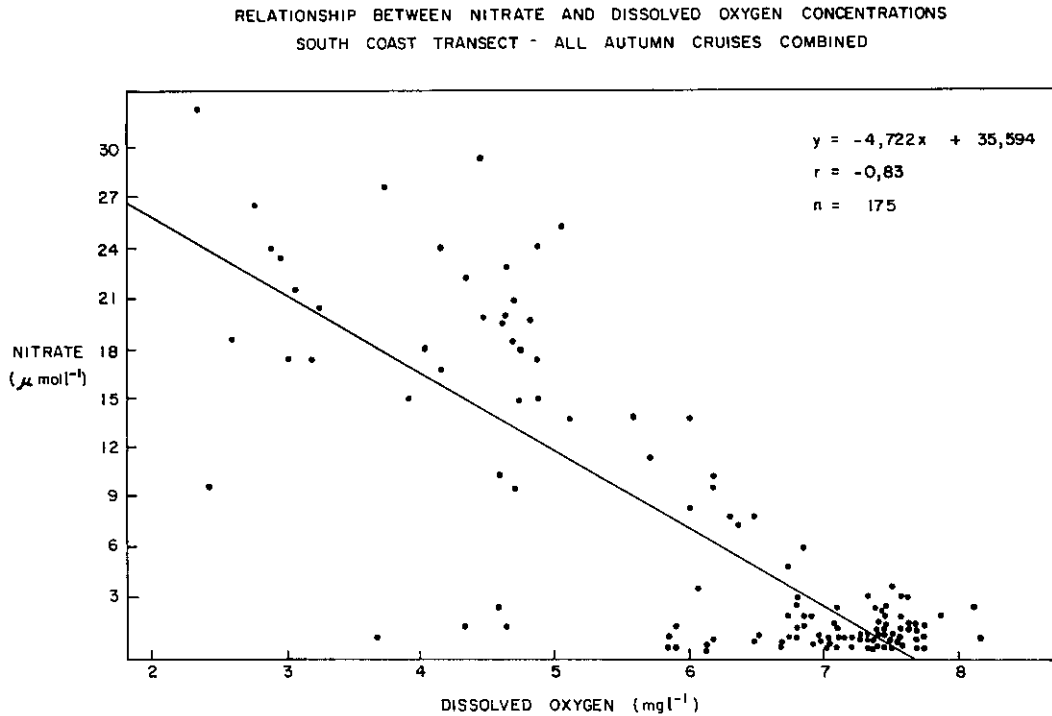


Figure 40. Relationship between nitrate and dissolved oxygen concentrations - South Coast transect - all autumn cruises combined.

West Coast

The water column on the west coast had a far more ordered thermal structure throughout the year. Inshore, surface temperatures were normally low, around 10-12°C, but increased to between 16 and 20°C, about 40 km from the shore. At the outer stations, temperatures dropped fairly regularly with depth to below 10°C (lower than 6°C on one occasion), and the thermocline was less pronounced than on the south coast. The rising isotherms towards the shore are an indication of upwelling (e.g. Figure 41).

The nutrient concentrations had a less regular seasonal pattern of variation than on the south coast, although again were generally lowest in spring. As before, nutrient concentrations increased with increasing depth, but were well mixed in the top 50 m or so of the water column. Good correlations were also found between the concentrations of the various nutrients.

TEMPERATURE SECTION - WEST COAST TRANSECT (AUTUMN)

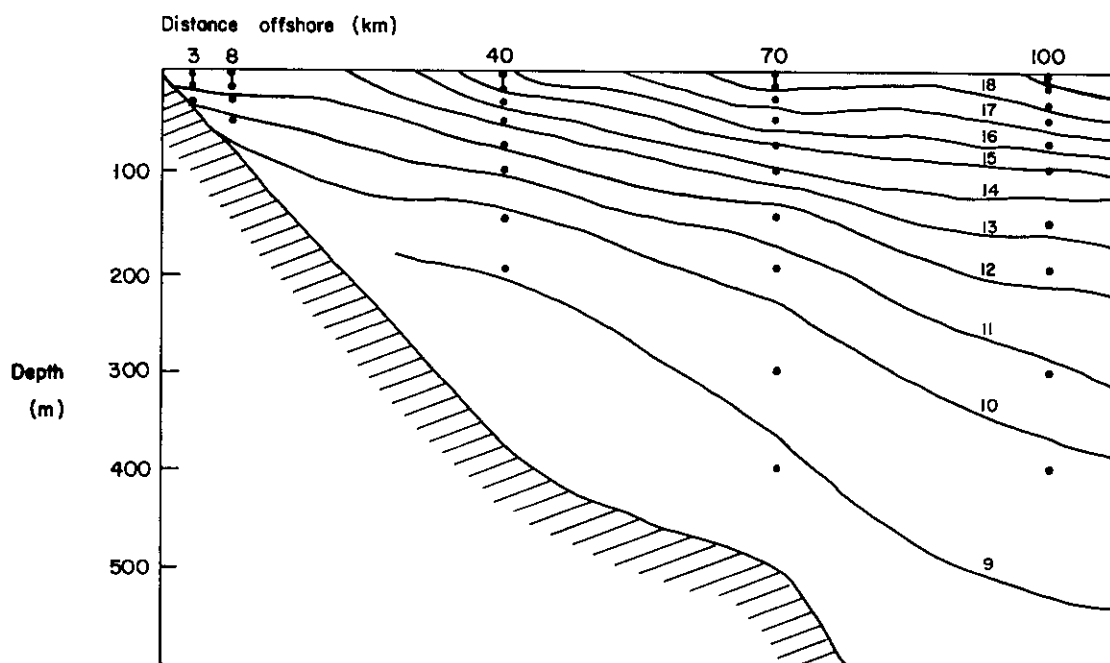


Figure 41. Temperature section - West coast transect (autumn)

Trace metals

Some problems were experienced initially with trace metal analyses and some contamination was found, particularly for lead. This has been found to be due to the rubber connection linking the two lids of the Niskin sampling bottles. The trace metal concentrations were variable and no definite trends have been observed. Levels of trace metals were generally of the same order of magnitude as those found by other workers in unpolluted coastal areas.

Tar balls

Samples were also collected for the determination of tar balls.⁶⁹ These were obtained in the Neuston net, which was hauled for a distance of one nautical mile at a speed of 3 knots. Hauls were only taken during daylight hours and the net operated successfully only under fairly calm conditions. Altogether 59 samples were collected. The results showed that the area was not heavily polluted with tar balls, despite the considerable oil tanker traffic.

GENERAL STUDIES

Goel 1

The stranding and loss of the Canadian research vessel "Goel 1" off Robben Island during the evening of 27th January 1976 provided an opportunity to investigate an oil spill soon after the event. Biologists from NRIO and zoologists from the University of Cape Town visited the island to undertake inter-tidal, tidal and sub-tidal transects over the shoreline. Because conditions of exposure, and faunal and algal assemblages, change rapidly around the shore, some difficulty was experienced in finding an area which was strictly comparable to the polluted site. The oil (over 200 tons of diesel fuel) spilling on the rocky shore had a dramatic effect on the biota, removing algae and the inter-tidal animals attached to them. This produced an aggravated picture of the effect of the oil spill. The subtidal life about 1 m below the water level appeared less affected, although numbers of rock lobster, and to a lesser extent abalone and octopus, were killed and later washed up. The brief dispersant spraying programme cannot be blamed for this since dead animals were noticed prior to spraying. A number of factors, besides the small scale of the spill, minimized the accident; the tide was low at the time, preventing the transport of oil high up the shore, and the prevailing wind and current pushed the main bulk of the slick past the island.

"Venpet-Venoil" Collision

At 09h39 on 16 December, 1977 the fully laden 330 954 dwt tanker "Venoil" collided with her sister ship the 330 869 dwt "Venpet" at a position 34°26'S, 24°04'E, 75 km southwest of Cape Seal and approximately 55 km from the coast. The resultant spill was estimated at 21 000 tonne of heavy Iranian Crude and 7 000 tonne of Bunker C oil from the "Venoil" and 4 000 tonne of Bunker C and an unknown quantity of slops from the "Venpet", (Bricknell, personal communication). The slick was originally carried westward by the Agulhas Current but on 4 January, 1978 large quantities of oil reached the coastline between Plettenberg Bay and Still Bay. Major clean up operations were conducted at Little Brak River, Great Brak River and Sedgfield, where the oil entered the estuaries. A sandy beach at Victoria Bay, which was also severely inundated, was left undisturbed by clean-up contractors and therefore chosen for a comparative study with the beach at Little Brak River. As no "before" data were available some other south coast unpolluted beaches were used for reference. The fate of the stranded oil and its influence on meiofauna ratio and density were examined on four different occasions over a period of one year.³⁹ The beaches were surveyed at low tide and three stations corresponding to high-, mid- and low-water marks were sampled. Undisturbed box cores (270x300x110 mm) were taken at each level. The closed cores were saturated with warm sea water (approximately 60°C) within half an hour of sampling in order to anaesthetise and relax the fauna. These were then fixed with formalin in the laboratory. Half of each core was embedded with resin for preservation and reference, while the other half was divided horizontally into 10 slices 25 mm thick and

each sample was examined for meiofauna and sediment particle size. Oil was extracted and examined according to a method developed by Hennig.⁴⁹ The core casts revealed that the oil, initially deposited as a sheet at the high water level underwent cycles of erosion and deposition gradually becoming buried. The oil sheet, originally visible as a narrow black band, broadened visibly with time.

At Victoria Bay, nematode populations (49% of total) compared favourably with those at reference beaches while harpacticoid copepods (26%) were well below 'normal' levels.⁷⁰ In general the top 50 mm of sediment contained fewer animals than deeper levels, but this is not unexpected since temperature variations and desiccation near the surface are appreciable under local climatic conditions. Samples from the mid-tide level stations contained fewer animals throughout the whole study period. By July 1978, the numbers, as well as the nematode/harpacticoid ratio had returned to normal. This situation was not maintained, however, and harpacticoids decreased again later, giving evidence of chronic oil pollution.

At Little Brak River the nematode numbers were again close to reference levels while harpacticoids were far more numerous (89%). This was the result of the whole area being disturbed during clean-up operations, favouring recolonization by harpacticoids. A decrease took place after July 1978, similar to that observed at Victoria Bay. Meiofauna were concentrated between mid- and low-tide levels and animal numbers increased with sediment depth. At both sites, no correlation could be found between population density, hydrocarbon concentration and sediment particle size.

The effects of this collision were also studied from a completely different aspect. Between August 1977 and August 1978, an extensive tar ball study was undertaken. Neuston samples, collected monthly by the Sea Fisheries Institute on their Cape Egg and Larval Programme cruises, were made available for the determination of tar ball concentrations.³² These samples were collected on twelve successive monthly cruises from 120 stations arranged in a grid of 20 lines, 37 km apart and ranging from 6 to 98 km offshore (Figure 42). For discussion purposes the sampling lines were divided into four quarters: first quarter-lines 8-24; second quarter-lines 28-44; third quarter-lines 48-64; fourth quarter-lines 68-84. Samples were collected in a 157 cm wide bongo net with an oval mouth. The net sampled approximately the top 200 mm of water. Hauls were made at 2 knots for 2 minutes, giving a total surface area sampled of about 194 m². The efficiency of the net was reduced by heavy seas and in very rough conditions hauls could not be made. After manual separation of tar balls, followed by frying at 40°C, the concentration of tar (in mg m⁻²) was calculated. Results were categorized as follows: <0,01 mg m⁻², 0,01-0,09 mg m⁻² (trace), 0,1-0,99 mg m⁻² (medium), 1-5 mg m⁻² (heavy) and >5 mg m⁻² (extra heavy). In this way the number of samples in each category was calculated and a good overall picture of the distribution of floating tar was obtained. The results from the first four cruises indicated that, apart from some isolated high concentrations which could not be explained, there was slightly more oil along the south than the west coast. Although the difference was not marked, it confirms the results obtained in the preliminary study.⁶⁹

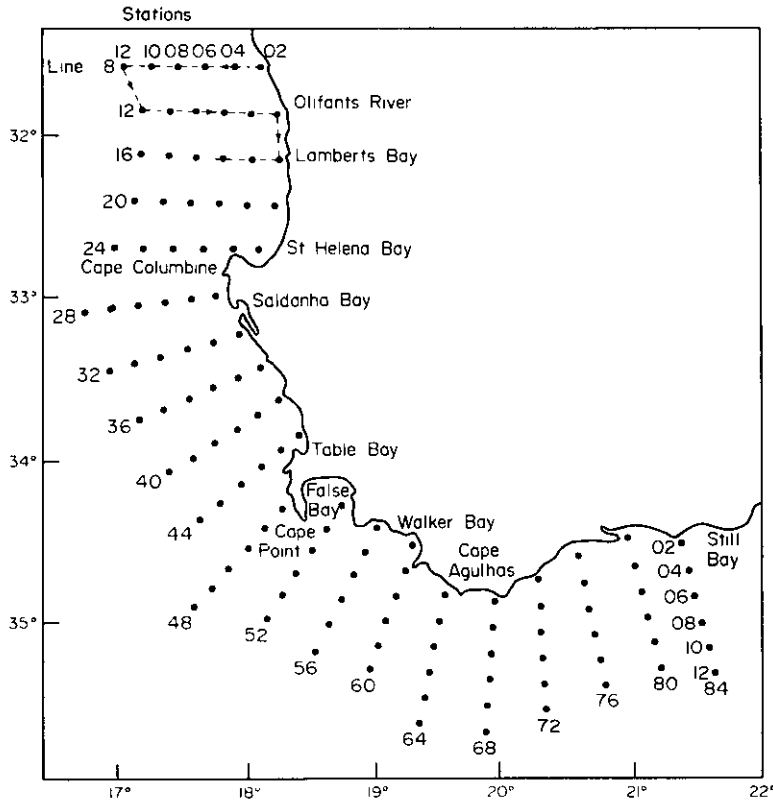


Figure 42. Sampling stations.

The effect of the tanker collision in December was clearly seen. Particularly high concentrations were found on lines 68-84 during the January cruise, where only seven samples fell within the 'trace' range, and the two worst samples 80-06 and 84-06, contained 139 and 232 mg m⁻² of tar, respectively.

If this oil originated from "Venoil" (and although no identification tests were carried out it seems logical to assume that it did), it indicates that at least a large part of the oil slick had drifted westwards. This oil must have travelled at least 240 km in approximately 30 days - an average speed of 0,35 km h⁻¹ (0,2 knots). Since the highest concentrations were obtained at stations 43 km (23 nautical miles) offshore, it appears that the oil had moved slightly towards the coast. A large amount of oil had already drifted ashore between Plettenberg Bay and Mossel Bay, fouling many south coast beaches, but the fact that oil was encountered this far offshore indicates that the main slick must have broken into a number of large pieces.

A surprising feature was the large increase in tar ball concentrations in the second and third quarters of stations, as far north as line 28. This illustrates two important facts:

- a) oil was transported by winds and currents around Cape Point;
- b) average speeds of approximately 1 km h⁻¹ (0,54 knots) were maintained.

The results of the February cruise indicated a slight improvement over those for January in the third and fourth quarters, while in the first and

second quarters further increases were found as the tar balls were driven around Cape Point and northwards along the west coast. This supports the suggestion by Harris⁴³ that during the summer the Benguela current may have its source as far east as Cape Agulhas. The main stream of the Agulhas Current generally follows the edge of the continental shelf and is very stable and persistent on the south-east coast of South Africa. Further south it becomes more variable as it flows south-westwards before being turned eastwards at a point about 22°E, 39°S, joining the Antarctic Circumpolar Current.⁵⁸ However, during summer it is apparent that surface currents move parallel to the coast between Cape Agulhas and Cape Point.

Between February and August there appeared to be a gradual improvement in conditions over the whole sampling area, but an interesting feature is the amount of oil, especially on the south coast, still encountered as late as August 1978.

No attempt was made to undertake identification of tar ball constituents using gas chromatography although UV spectra of eleven random samples in hexane were taken from the last cruise. These all had two absorbance peaks, at 228 and 256 nm. The ratios of the intensities of these two peaks ($R = I_{228}/I_{256}$) were calculated as described by Levy.⁵⁷ Of the samples tested, one had $R = 1,36$, similar to Bunker Oil ($R = 1,36$), six had R values between 1,42 and 1,50 (mean 1,45) similar to fuel oil from the "Venpet-Venoil" spill ($R = 1,45$) and four had R values between 1,60 and 1,65. These are close to the R value of 1,64 found in crude oil. Although this test is not definitive enough to fingerprint the oil, it is an indication that at least some of the tar balls may have originated from the tanker collision. The concentrations were generally high at stations 61 and 80 km (33 and 43 nautical miles) offshore, indicating that a fairly large amount of oil was still present off the south coast, and that this was not being carried in any particular direction. This suggests the presence of a large area on the Agulhas Bank where currents are not particularly strong or persistent. Apart from a large slick which drifted ashore soon after the accident, tar balls did not come ashore in excessive amounts, a fact which was confirmed by qualitative observations on beaches along the south coast. None of the beaches visited appeared to be contaminated by oil.

Chlorinated hydrocarbon residues

The chlorinated pesticides have been included as a pollutant to the environment due to their resistance to biodegradation and their tendency to accumulate in the food chain. They are virtually insoluble in water and thus the survey has covered sediments and as many species of the macro aquatic fauna as practical. While no pesticides (greater than $1 \mu\text{g kg}^{-1}$) were detected in the sediments, some pesticide residues were detected in most of the animal samples. The residue levels in any particular estuary tended to be higher in the mobile animals than in the benthic or sedentary types. In the fish there did not appear to be any trend according to feeding habits. This possibly indicates that the fish accumulate the pesticides more from the water than through the food chain (accumulations from water to animal of up to 2×10^6 times have been observed⁷⁵). Since concentrations found in animals in the environment seldom exceeded $100 \mu\text{g kg}^{-1}$ the concentration in the water was probably

less than 1 nanogram per litre (which was far below the detection limits of our present method of analysis). Generally higher concentrations were found in the liver than the flesh. This is possibly due to the liver being a superior storage medium for pesticide residues in bony fishes.

As stated previously¹⁰ the low concentrations detected in most of the estuaries and in the nearshore fauna are sometimes difficult to identify and quantify. The survey has shown firstly that generally there is very little pesticide accumulating in the environment. Secondly the higher levels (20 - 100 times levels in remote estuaries like Bashee¹⁴) recorded in places like Kosi estuary¹¹, Richards Bay¹² harbour and Durban harbour²⁴ and the Umgeni river show that the sources are local and the extent of their effect extremely limited.

The Sea Mammals

These animals are at the top of the food pyramid; they live at the sea surface where probably the best transfer of chlorinated hydrocarbons from the atmosphere to sea would occur and in their blubber layer they have an excellent storage medium for the accumulation of the chlorinated hydrocarbons. All these factors make these animals ideal accumulators and this has been confirmed by the relatively high levels found (Table 22). Unfortunately some of the dolphins in particular are mobile and therefore the levels found can only be used to indicate general levels rather than being specific to a particular area. Also planned sampling can not be undertaken but opportunistic samples are obtained fairly regularly. The seals which do remain fairly localised appear to be an excellent indicator species as suggested by Henry.⁵⁰ The mean level of DDE (7,7 mg/kg) in the Cape Fur seal *Arctocephalus pusillus* (Table 22) was higher than the mean DDE (1,45 mg/kg) in adult seal blubber reported by Henry,⁵⁰ while DDT and PCB concentrations were approximately similar. Due to the haphazard nature in which the samples were collected compared with those analysed by Henry, these differences might be misleading but perhaps a repeat survey similar to that undertaken by Henry could establish whether contamination levels are increasing. Along the Natal coast there are unfortunately no similar seal rookeries but concentrations of DDE and DDT in the dolphin *Tursiops aduncus* which frequents this coast were of a similar level. The mean PCB concentration (12,9 mg/kg) was considerably higher than the mean PCB concentration (1,7 mg/kg) found in the Cape Fur seal. These levels, although higher than those found in any other marine or estuarine animals, are still far lower than the PCB (147 mg/kg) and DDE (878 mg/kg) in a Pacific white-sided dolphin held captive in New York, reported by Taruski.⁸⁰

Seabird Eggs

The seabirds are of particular interest since not only are they, like the sea mammals, at the apex of the food pyramid, but they probably have been the most detrimentally affected of the higher animals. DDE at high concentration interferes with egg shell thickness and PCBs even at relatively low concentrations have been suspected of causing poor hatchability. A third interest related specifically to Marion Island birds will be discussed later.

TABLE 22. CHLORINATED HYDROCARBONS IN SEA MAMMALS FROM THE EAST COAST OF SOUTH AFRICA

Type	Tissue	Concentration in $\mu\text{g kg}^{-1}$ wet weight		DDT		DDE		PCB		DIELDRIN	
		Mean (n)	Range	Mean (n)	Range	Mean (n)	Range	Mean (n)	Range	Mean (n)	Range
<i>Arctocephalus pusillus</i>	Blubber	1 861 (7)	88-7 700	7 735 (8)	688-23 000	1 787 (7)	328- 3 493	34 (7)	0- 110		
	Muscle	2 (1)		5		13		ND			
	Liver	129 (4)	28- 259	751 (6)	51- 2 210	418 (5)	0- 1 210	ND(5)			
<i>Arctocephalus tropicalis</i>	Liver	37 (1)		355 (1)		488		ND			
<i>Tursiops aduncus</i>	Blubber	1 465(15)	0-4 800	9 243(15)	320-28 400	12 890(12)	1 760-30 600	430(10)	30-2 950		
	Liver	59(12)	0- 175	582(12)	45- 1 360	646(12)	0- 130	50 (8)	0- 104		
<i>Delphinus delphis</i>	Blubber	1 875 (1)		10 770 (1)		4 320 (1)		76 (1)			
	Liver	396 (2)	2- 788	3 408 (2)	7- 6 810	1 087 (2)	0- 2 175	21 (2)	0- 43		
<i>Lagenodelphis hosei</i>	Blubber	5 915 (1)		2 330		-		265 (1)			
	Liver	152 (1)		151 (1)		-		ND			
	Muscle	9 (1)		16 (1)		-		ND			
<i>Grampus griseus</i>	Blubber	699 (2)	521- 877	735 (2)	610- 860	ND		ND(2)			
	Liver	ND		37 (1)		ND		ND			
	Muscle	17 (2)	3- 32	40 (2)	23- 58	ND		ND(2)			
<i>Stenella attenuata</i>	Blubber	1 804 (2)	238-3 370	5 740 (2)	2 650- 8 830	4 875 (2)	4 600- 5 150	ND(2)			
	Liver	46 (2)	22- 70	595 (2)	500- 690	685 (2)	530- 840	ND(2)			
<i>Stenella coeruleocalba</i>	Blubber	432 (3)	201- 680	1 950 (4)	1 210- 2 490	ND		75 (4)	0- 160		
	Liver	ND		191 (3)	80- 303	ND		ND(3)			
<i>Kogia simus</i>	Blubber	225 (4)	35- 399	1 035 (4)	36- 3 090	324 (1)		1,3 (4)	0- 5		
	Liver	ND		789 (1)		ND		ND			
<i>Kogia breviceps</i>	Blubber	ND		1 010 (1)		ND		38			
<i>Orcinus orca</i>	Blubber	2 000 (1)		7 800 (1)		ND		36 (1)			
	Liver	ND		452 (1)		ND		ND			
<i>Planifors</i>	Blubber	708 (1)		1 220 (1)		ND		36 (1)			
<i>Mesoplodon densirostris</i>	Blubber	372 (2)	320- 426	2 250 (2)	1 712- 2 789	1 170 (2)	450- 1 890	16 (2)	14- 19		

TABLE 23. CHLORINATED HYDROCARBONS IN BIRDS' EGGS

Location	Type	Concentration in mg kg^{-1} (whole egg)		DDT		DDE		PCB		DIELDRIN	
		Mean (n)	range	Mean (n)	range	Mean (n)	range	Mean (n)	range	Mean (n)	range
St Croix	Kelp gull	-		1008 (2)	240-1930	4000 (2)	3400-4600	225 (2)	190-260		
	Jackass penguin	-		630 (2)	530- 740	ND		65 (2)	50- 80		
	Cormorant	80 (2)	16-145	146 (2)	71- 221	818 (2)	0-1636	4 (2)	0- 9		
Bird Island	<i>Morus capensis</i>	22 (6)	3- 51	100 (6)	74- 168	306 (6)	148- 753	7 (4)	5- 9		
St Lucia	<i>Larus cirrocephalus</i>	42 (2)	20- 54	50 (2)	42- 58	-		3 (2)	3- 3		
	<i>Platalea alba</i>	28 (4)	23- 32	69 (4)	52- 110	-		65 (4)	5- 86		
Gough Island	Yellow Nose Albatross	5 (4)	0- 8	39 (4)	27- 44	30 (4)	0- 121	2 (4)	0- 4		
	Sooty Albatross	28 (3)	6- 38	134 (3)	61- 183	182 (3)	42- 273	0,2 (3)	0-0,7		
	Skua	104 (3)	65-177	544 (3)	389- 737	1715 (3)	890-2900	2 (3)	0- 7		
	<i>Pterodroma brevirostris</i>	ND		17 (1)		ND		ND			
	Great Shearwater	8 (3)	5- 13	61 (3)	35- 105	301 (3)	115- 570	ND			
Jutten Island	Bank Cormorant	56 (2)	28- 85	209 (2)	122- 297	532 (2)	284- 780	ND			
	Cape Cormorant	8 (3)	0- 12	139 (3)	102- 176	46 (3)	0- 139	3 (2)	3- 3		
	Kelp gull	15 (1)		197		270		ND			
Marcus Island	White-breasted Cormorant	15 (3)	11- 18	54 (3)	42- 75	169 (2)	168- 210	ND			
	Bank Cormorant	82 (2)	0-164	178 (2)	156- 200	102 (2)	93- 112	ND			
	Crowned Cormorant	12 (3)	7- 16	76 (3)	62- 98	41 (2)	29- 62	ND			
	Jackass penguin	15 (4)	0- 56	162 (4)	115- 220	36 (4)	0- 108	8 (4)	4- 11		
Schaapen Island	Kelp gull	42 (6)	16- 84	316 (6)	84- 798	178 (6)	38- 415	17 (6)	0- 87		
Malgas Island	Gannet	13 (4)	10- 15	95 (4)	85- 114	34 (4)	26- 44	4 (4)	0- 7		
Dassen Island	Black Oyster Catcher	13 (2)	7- 18	101 (2)	48- 154	94 (2)	47- 142	5			
Berg River	Caspian Tern	12 (1)		1093		129		94			
Marion Island	<i>Pterodroma mollis</i>	23 (6)	2- 57	71 (6)	15- 128	31 (6)	0- 90	0,9 (6)	0- 4		
	<i>Pachyptila vittata salvina</i>	2,4(20)	0- 9	11(20)	4- 31	30(20)	0- 137	0,6(20)	0- 5		
	<i>Procellaria aequinoctialis</i>	43 (5)	0-147	183 (5)	14- 407	243 (5)	0-1001	1,1 (5)	0- 3		
	<i>Halobaena caerulea</i>	8 (9)	2- 25	16 (9)	7- 32	46 (9)	11- 167	0,6 (9)	0- 3		
	<i>Pterodroma brevirostris</i>	6 (9)	0- 22	24 (9)	10- 58	58 (9)	0- 165	0,5 (9)	0- 2		
	<i>Diomedea exulans</i>	70 (6)	22-110	227 (6)	84- 406	123 (6)	60- 211	1,3 (6)	0- 3		
	<i>Chionis minor</i>	1 (1)		348		75		1			
	<i>Pachyptila turtur</i>	3 (1)		10		26		7			

Thanks to the support of the Percy Fitzpatrick Institute, a fairly comprehensive collection of eggs from islands in the South Atlantic and Indian oceans, and from islands off the South African coast have been analysed (see Table 23). A large proportion were in an advanced stage of incubation, so no analysis of fat content could be done.

The levels found were relatively low and with the exception of the Kelp gull from St Croix and the Caspian tern from the Berg river, the DDE concentration did not exceed 1 mg kg^{-1} . The highest PCB concentration also occurred in the same Kelp gull egg ($4,6 \text{ mg kg}^{-1}$). These levels are far below those recorded in many of the seabird eggs from the Northern Hemisphere and especially the concentration of DDE ($1\ 176 \text{ mg kg}^{-1}$ lipid, 100 mg kg^{-1} whole egg) in Brown Pelican eggs which resulted in nesting failure.⁷⁹ A level of $1,94 \text{ mg kg}^{-1}$ (whole egg) DDE and up to $7,5 \text{ mg kg}^{-1}$ PCB in Herring Gull eggs was found by Szaro *et al*⁷⁹ to be insufficient to cause nesting failure.

Miscellaneous

Turtle eggs (*Caretta caretta*) from the Tongaland coast were expected to give interesting results since these turtles feed along the African east coast where DDT and similar pesticides are still widely used, but as can be seen in Table 24, virtually no pesticide was detected. An interesting study has been the cats of Marion Island. These cats, originally introduced because of the mice (brought ashore by visiting ships), are preying on the birds and can thus be considered as being at the peak of the food pyramid. The concentrations of DDE and PCB in these animals (Table 24) were the highest found in any animal we have so far analysed. The maximum concentration found was $43,4 \text{ mg kg}^{-1}$ DDE and 133 mg kg^{-1} PCB in the fat tissue. As the source could only be through the food chain, a survey of the seabirds has been undertaken. So far only the eggs have been collected but it is intended to include some birds in future. If the levels in the birds are anywhere near as low as the levels found in their eggs - especially of small birds, e.g. *P. vittata* (Table 23) - on which the cats are most likely to feed, then the cats must be very efficient accumulators and storers of chlorinated hydrocarbons.

Conclusion

As far as chlorinated hydrocarbons are concerned, the two estuaries which should be surveyed in greater depth and monitored at regular intervals are Kosi and the Durban Harbour/Umgeni estuary. At Kosi pesticide spraying is continuing and a periodic check after an initial comprehensive survey should reveal the rate at which bioaccumulation is occurring or whether the equilibrium state has been reached.

In the Umgeni/Durban harbour area there is still some DDT input but the main interest is the dieldrin concentration. There is evidence that dieldrin can be carcinogenic.⁵⁴ The maximum safe levels according to Water Quality Criteria⁸⁴ for human consumption is $0,021 \text{ mg day}^{-1}$. In one *mugil* taken in Durban bay this amount was contained in 50 g of muscle tissue. Further investigations as to the source (since the purchase of dieldrin is prohibited) and some monitoring of levels over the next few years appears

to be essential.

A further survey of the Cape Fur seal (*Arctocephalus pusillus*) to check whether the level of DDE has increased would be of interest. Occasional monitoring of the dolphins (*Tursiops aduncus* and/or *Delphinus delphis*) should be continued, as material comes available.

TABLE 24. CHLORINATED PESTICIDE AND PCB RESIDUES IN MISCELLANEOUS ANIMALS

Type	Tissue	Results in $\mu\text{g kg}^{-1}$ (wet weight)		Mean (n) range		PCB		Dieldrin
		DDT						
Gannet	liver	1 (4)	0- 3	189 (4)	27- 370	-		61 (3) 0-140
	muscle	29 (2)	25- 33	122 (2)	101- 144	-		8 (2) 8- 8
Cormorant	liver	123 (5)	0- 530	506 (5)	71- 1 340	-		50 (5) 0-110
	muscle	38 (2)	35- 42	500 (2)	330- 670	-		4 (2) 4- 4
<i>Caretta caretta</i>	eggs	2 (8)	0- 8	9,5 (8)	4- 29	-		1 (8) 0- 8
Cat*	fat	749(11)	75-9 350	12 288(11)	3 710-43 400	24 310(11)	6 350-133 000	40(11) 15-120
	liver	8 (8)	0- 53	880(10)	207- 2 410	1 625 (8)	0- 4 300	ND

* from Marion Island

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APPENDIX

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