Some ecological effects of two sewage outfalls in Algoa Bay

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Abstract

The concentrations of nutrients (ammonia, nitrate, nitrite and phosphate), metals (copper, lead, zinc, iron, manganese, cobalt, nickel, cadmium, chromium and mercury) and faecal bacteria (*Escherichia coli I*), and the abundance of selected biological species in the vicinity of the Cape Recife and Fishwater Flats sewage outfalls into the south-western part of Algoa Bay have been investigated. Both outfalls contribute significant amounts of nutrients, metals and bacteria to the coastal marine environment. However, the overall effects of these inputs on their immediate coastal environments do not appear to be deleterious but, rather, result in biological enrichment.

Introduction

Algoa Bay, bounded by Cape Recife and Cape Padrone on the southern coast of South Africa (Fig. 1), is in the transitional zone for marine fauna between the warmer tropics and the colder temperate zone, an important ecological position, and comprises open sandy beaches, rocky capes and several small islands. The two major rivers flowing into the bay are the Sundays and Swartkops Rivers. The Coega River is utilized for the production of both sea and estuarine salt for human consumption, and the river water is prevented from flowing into the bay by earth impoundments. The Baakens River flows into Algoa Bay in the dock area of Port Elizabeth; the volume of water is relatively small except

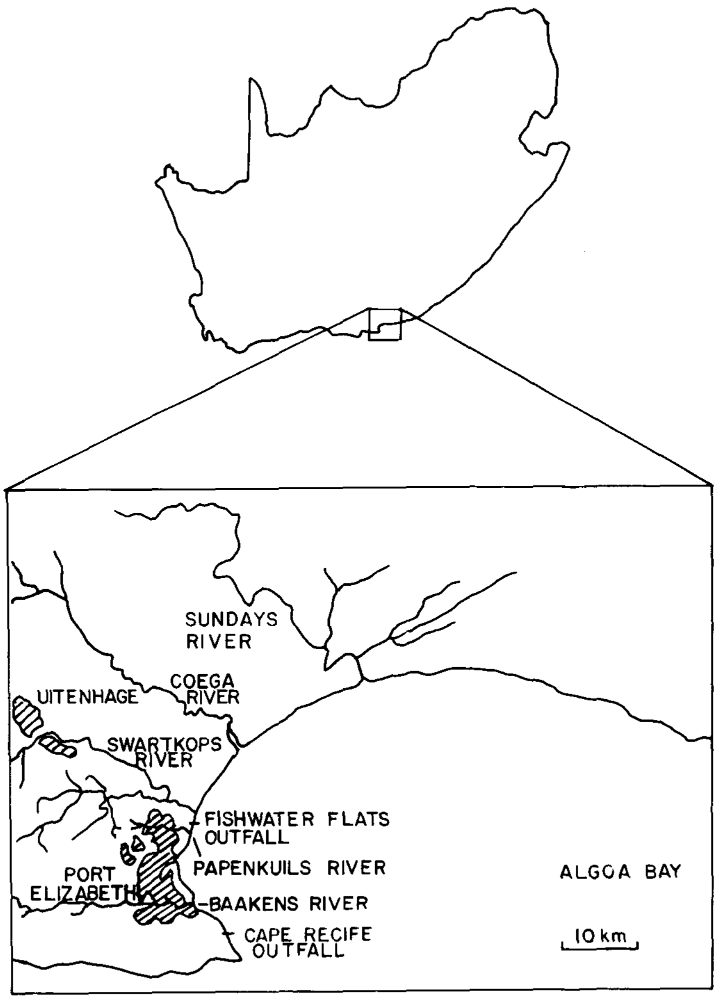

Figure 1
Location of study areas

during periods of flooding. Treated industrial and urban effluents from the towns of Uitenhage and Despatch and the Port Elizabeth municipal area are introduced to the bay via the Swartkops and Papenkuils Rivers and the Fishwater Flats sewage outfall. Treated urban sewage also enters the bay via the Cape Recife outfall.

The sewage works at Cape Recife receives from 8 to 32 Mℓ/d of raw domestic sewage and has an average output of 12 Mℓ/d. Some of the water is lost by evaporation and a further volume is used to water the grounds of a golf course and the University campus, so that the average input to the bay via the Cape Recife outfall is 8 Mℓ/d. This input of enriched water causes considerable macroalgal (seaweed) production downshore, much of which is washed up onto the beach to form a driftline.

The Fishwater Flats sewage works processes from 50 to 55 Mℓ/d of mixed domestic and industrial wastewater. About 20 Mℓ/d of mainly industrial waste is discharged into the Papenkuils River (Watling and Emmerson, 1981), while approximately 30 Mℓ/d of processed domestic sewage is discharged through the pier pipeline near Brighton Beach.

This paper describes the results obtained from surveys of selected sites adjacent to both outfalls (Fig. 2). The nutrient, heavy metal and bacterial enrichment in these two areas and their effects on the biota, with particular reference to macrofauna and meiofauna, have been investigated.

Materials and Methods

Bacteria: *E. coli* I were enumerated by standard membrane filter techniques and the identity of the organisms confirmed using the indole test (SABS, 1971).

Nutrients and Metals in Water Samples: The methods of collection, sample preparation and analysis of these samples have been described by Watling and Emmerson (1981).

Metals in Surface Sediments: Samples were collected using a stainless steel trowel and stored in sealed polythene bags. On return to the laboratory, the samples were transferred to pads of filter paper and air-dried, disaggregated and sieved through a 1 mm screen to remove large particles and plant debris. The frac-

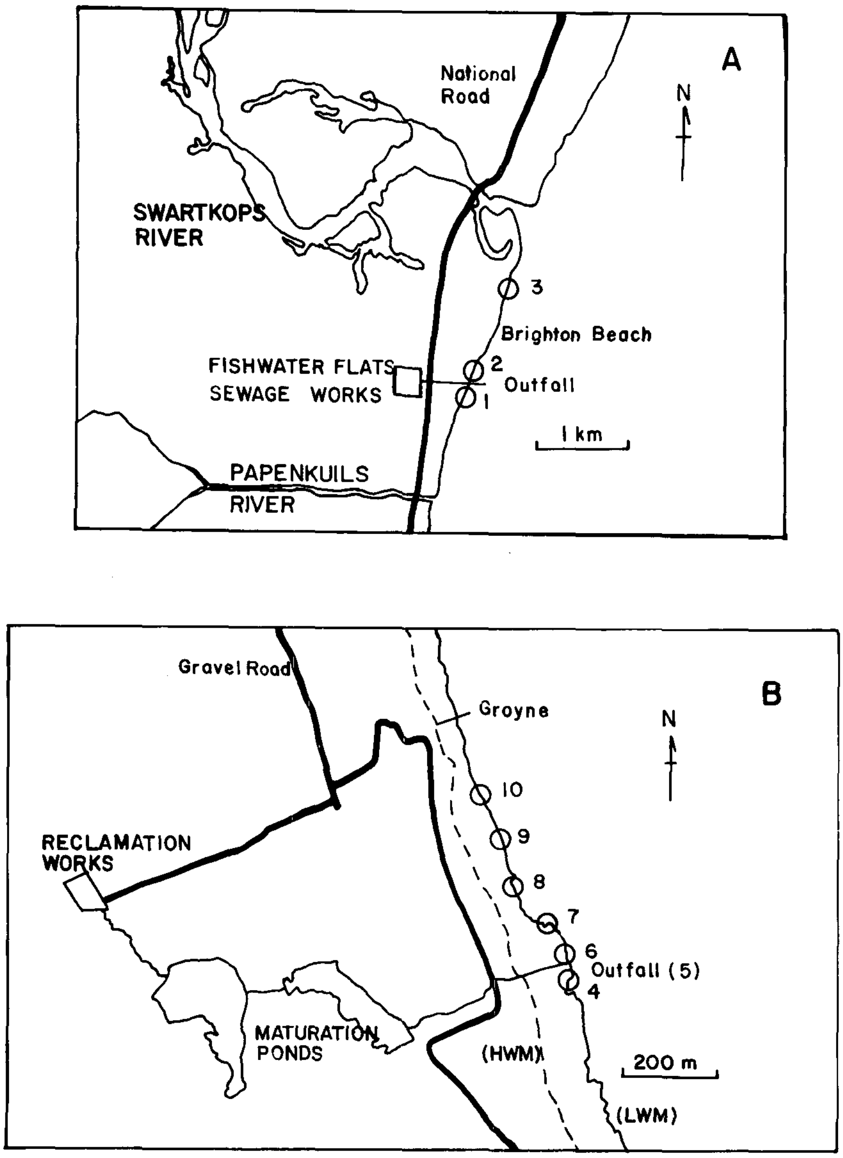

Figure 2
Sampling sites: A, Fishwater Flats outfall; B, Cape Recife outfall

tion which passed through the screen was reserved for analysis. The further preparation and analysis of these samples has been detailed by Watling and Emmerson (1981).

Meiofauna: Sand samples were collected near the Fishwater Flats outfall using a copper corer with a 10 cm^2 internal cross-sectional area. Four cores were collected at each site (Fig. 2A). Samples were taken at depths between 0-40 cm depending upon the depth of the pebble layer at each site. The meiofauna were narcotized with 7% magnesium chloride solution and fixed in 5% formalin. The extraction of animals was achieved by four decantations in the laboratory with a 90% efficiency. The meiofauna were then stained with Rose Bengal, identified and counted.

Macrofauna: Sampling sites at Cape Recife are shown in Figure 2B. The transect consisted of two sites (4 and 6) immediately adjacent to the outfall while sites 7-10 were situated downshore at 100 m intervals. Samples were collected at the low water spring tide mark by clearing three 0,25 m^2 quadrates, as the biomass and number of species are reported to be greatest at this point (McLachlan *et al.*, 1981b). Samples were collected at 100 m intervals at the Flat Rocks site as there is no clear intertidal zone. Sponges, isopods, amphipods and seaweed epifauna were not sampled as it was difficult to obtain representative numbers of these less abundant species.

Species were returned to the laboratory for identification and their ash-free dry mass values were calculated from the difference in mass after drying at 70°C for 24 h and ashing at 650°C for 12 h. Shell debris was removed prior to ashing in the case of molluscs. Data from each site were combined and the Shannon-Weaver species diversity indices $\bar{H}$, based on both number and biomass (ash-free dry mass), computed according to the method described by Southwood (1978).

Results and Discussion

Water Samples: The physico-chemical data and bacterial counts are summarised in Table 1. Differences between the two sampling areas are apparent from the results. For example, the sewage plume extends for a longer distance at the Fishwater Flats outfall (30 Mℓ/day) than at the Cape Recife outfall (8 Mℓ/day). The nutrient levels are considerably higher in water samples from the Cape Recife area than those from Fishwater Flats. Levels fall with distance from the Cape Recife outfall as might be expected but a slight increase with distance is observed at Fishwater Flats. This could be due to an inshore component of the sewage plume being swept along the beach as a result of wind and water movements interacting with a particular bottom topography at Fishwater Flats. The effluent plume is swept northward by a prevailing surface inshore current (CSIR, 1970) and may impact with beaches as far away as the Swartkops River mouth. A major factor at Fishwater Flats is the fact that the effluent is discharged to the sea from the end of a 70 m long pier.

E. coli I counts were usually higher in samples collected near the Cape Recife outfall, so that in terms of the effluent volumes discharged each day, it is concluded that the Fishwater Flats treatment is relatively efficient.

Eh levels at the Cape Recife outfall were high, indicating, oxygenated sediments, except for the furthest sites 8, 9 and 10 (Table 1) where pockets of black sand were found as a result of the large amounts of organic material from the seaweed in the area.

The concentrations of ten elements in water samples collected from the two areas are listed in Table 2. Metal concentrations were elevated in the areas near the outfalls and for distances up to 100 m at Cape Recife and more than 1 km at Fishwater Flats. Clearly the extent of this metal enrichment in the water depended upon the volume of effluent being discharged and the strength and direction of the current at the time of sampling. A further difference is that the Fishwater Flats outfall is situated at a sandy beach whereas the effluent from Cape Recife is discharged on a rocky shore.

It is possible to delineate the extent of the sewage plume at Cape Recife as there is an intermittent mercury input at this site (Table 3). There is a gradual decrease in mercury concentrations in the water samples with increasing distance from the outfall to site 7 (Table 2). Beyond this point there is a relatively short fall off in mercury concentrations. Consequently, at the time of sampling, site 7 represented the furthest significant down-current extention of the Cape Recife sewage plume. The small bay near site 7 may cause the sewage plume to be deflected seaward so that its effects are not detected beyond this point.

In the case of the Fishwater Flats, there is no convenient fingerprint element. Treated domestic waste is discharged at this outfall and it is only by reference to the general distribution and levels of metals in the area of site 3 that it can be inferred that the sewage plume extends this far from source. Elevated lead levels

TABLE 1
PHYSICO-CHEMICAL DATA AND *ESCHERICHIA COLI* I COUNTS

Site (Fig. 2)	Temp °C	Salinity	Eh mV	Total Ammonia mg/ℓ	NO_2-N mg/ℓ	NO_3-N mg/ℓ	PO_4-P mg/ℓ	*E. coli* I /100 mℓ
FISHWATER FLATS								
1	15,2	35	+400	0,001	0,004	0,06	0,5	5
2	15,2	35	+400	0,002	0,004	0,07	1,0	86
3	15,2	35	+400	0,005	0,003	0,08	1,2	1
CAPE RECIFE								
4	18,5	24	+450	1,6	0,10	0,24	4,3	423
5	20,2	0	+500	8,5	0,43	1,58	22,0	890
6	18,8	17	+420	3,0	0,20	0,55	8,4	960
7	19,5	34	+400	0,3	0,04	0,20	1,8	7
8	20,3	35	+100	0,1	0,02	0,10	1,0	1
9	20,4	35	+250	0,1	0,02	0,06	0,9	0
10	19,9	35	+110	0,1	0,01	0,01	0,6	0

TABLE 2
METAL CONCENTRATIONS IN WATER SAMPLES

Site (Fig. 2)	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Cr	Hg
				Concentration (μg/ℓ)						
FISHWATER FLATS										
1	1,2	0,3	1,2	4	2	0,1	0,2	0,1	0,6	0,005
2	1,4	4,7	3,6	127	6	0,4	2,1	0,7	3,6	0,006
3	0,9	1,0	0,6	10	3	0,1	0,2	<0,1	0,9	0,011
CAPE RECIFE										
4	1,3	0,7	0,9	12	6	<0,1	<0,1	0,2	0,9	0,008
5	2,6	1,3	12,7	115	37	0,1	1,4	0,7	2,1	0,168
6	1,2	0,6	1,6	12	4	0,2	0,2	0,2	3,6	0,092
7	0,9	0,5	2,1	11	3	0,1	0,3	0,1	2,0	0,016
8	0,7	0,6	1,3	9	2	0,1	0,1	<0,1	1,0	0,004
9	0,6	0,2	0,7	3	3	<0,1	<0,1	<0,1	0,9	0,009
10	0,4	0,2	0,2	4	4	<0,1	<0,1	<0,1	0,8	0,010

TABLE 3
VARIATION IN METAL CONTENT OF EFFLUENT FROM CAPE RECIFE OUTFALL

DATE	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Hg	Na	K	Ca	Mg
				Concentration (μg/ℓ)							(μg/mℓ)		
AUGUST, 1981													
15th	3,0	1,3	10,7	118	42	0,1	1,6	0,1	0,142	130	14	37	13
16th	4,3	1,7	12,2	169	49	0,1	2,1	0,3	0,012	130	14	39	13
17th	5,1	6,4	15,9	200	53	0,3	3,6	1,4	0,116	120	15	38	13
18th	0,1	<0,1	0,3	4	0,7	<0,1	<0,1	<0,1	0,016	120	14	39	12
19th	3,6	0,3	10,7	155	57	0,1	3,0	0,1	0,112	130	15	39	13
20th	2,7	0,9	9,9	155	41	<0,1	1,8	<0,1	0,026	130	14	47	12
21st	2,9	1,4	12,6	120	40	0,1	3,1	0,3	0,129	130	14	39	13
22nd	4,1	3,6	20,4	130	40	0,1	2,7	0,1	0,017	130	15	37	13
23rd	2,8	1,0	10,2	154	42	<0,1	1,8	<0,1	0,004	130	14	38	14
24th	2,1	1,4	11,2	183	41	0,1	2,5	0,3	0,014	130	14	39	14
25th	2,1	2,1	17,0	248	43	0,1	1,9	<0,1	0,007	130	14	39	14
26th	2,7	3,4	19,1	146	40	0,1	2,4	0,1	0,016	130	14	39	14
27th	2,8	2,8	16,0	199	37	0,1	2,7	<0,1	0,018	130	14	37	14
28th	3,3	1,3	10,3	168	41	0,1	1,7	<0,1	0,162	210	16	46	22

TABLE 4
METAL CONCENTRATIONS IN SEDIMENT SAMPLES

Site (Fig. 2)		Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Cr	Hg
					(Concentration μg/g)						
FISHWATER FLATS											
1		1,6	1,9	3,0	900	23	0,1	0,2	0,10	2,0	0,007
2		1,5	2,0	3,4	700	20	0,1	0,4	0,08	1,8	0,008
3		1,2	2,9	2,4	1590	11	0,1	0,1	0,03	1,3	0,029
CAPE RECIFE											
4		4,7	6,3	4,6	1270	17	0,2	0,5	0,06	5,3	0,032
5		5,3	8,4	5,2	1320	15	0,4	0,3	0,14	12,7	0,147
6		4,3	7,2	4,6	1220	12	0,1	0,3	0,04	7,2	0,032
7		3,1	5,7	4,6	780	13	0,1	0,2	0,03	6,4	0,008
8		2,9	4,1	4,1	1200	23	0,1	0,2	0,01	2,9	0,007
9		2,1	2,3	3,0	560	16	0,1	0,1	0,01	4,3	0,006
10		2,0	2,0	2,3	730	12	0,1	0,1	0,01	4,6	0,003
a) ST FRANCIS BAY n = 14	x̄	2,2	2,5	2,1	1010	26	0,2	0,3	0,04	6,2	0,003
	s	0,8	1,5	0,9	420	10	0,1	0,2	0,02	3,9	0,002
b) ALGOA BAY (north east of Sundays River) n = 10	x̄	1,9	2,0	4,3	1920	35	0,3	0,8	0,07	5,4	0,012
	s	0,6	1,4	2,2	930	8	0,2	0,8	0,03	1,5	0,008

a) data from Watling and Watling, 1982.

b) data from Watling and Watling, 1981.

relative to the concentrations of other elements were found in the site 2 sample, suggesting that the Fishwater Flats effluent contains high lead concentrations. A similar observation concerning lead in Fishwater Flats effluent entering the Papenkuils River has been reported (Watling and Emmerson, 1981).

Metal concentrations in the two Fishwater Flats outfalls should be relatively uniform because the effluent is processed before being discharged. However, both the metal concentrations in the Cape Recife outfall and the potential toxicity of this effluent are likely to be variable as input to the system varies according to the programmes being undertaken at research institutions in the area. A series of effluent samples were collected over a two-week period in August 1981 and analysed for thirteen elements in order to obtain a measure of any variations in the composition of the effluent. Analytical results are listed in Table 3.

Some variations in the trace metal composition of the effluent can be seen in the results, but these variations are within relatively close limits. There was a significant reduction in effluent metal concentrations on the 18th August. However, the fact that the minor element concentrations remained constant indicated that this reduction was not caused by dilution of the effluent.

The metal concentrations in *Perna perna* brown mussel collected at the Cape Recife outfall were not elevated significantly when compared with concentrations in the same species collected from other sites in Algoa Bay or the nearby coast (Watling and Watling, 1979). This suggests that the Cape Recife outfall is likely to have only a small sphere of influence on the rocky-shore biota, particularly with regard to metal contamination.

Sediment Samples: Metal concentrations in sediment samples collected near both outfalls are listed in Table 4. Heavy metals released from Fishwater Flats apparently did not become incorporated in the surface sediments of the beaches adjacent to the outfall, despite the fact that the site 2 water sample contained many of the highest levels of metals found during these surveys. The combination of a strong current and steep beach slope in this high energy environment are thought to disperse the effluent rapidly, thus inhibiting the build up of metals in the sediment column.

Metal levels decreased progressively in sediments collected at increasing distances from the Cape Recife outfall while background levels were measured at site 8. The sphere of influence of this effluent plume is therefore limited to a distance of about 200 m downcurrent from the outfall. The overall metal concentrations in these surface sediments are low and are unlikely to have an adverse effect on the sediment or rocky shore biota.

Meiofauna (Fishwater Flats): The physical conditions at the three sites associated with the Fishwater Flats outfall are summarised in Table 5. The three sites are very similar. A slightly steeper slope was recorded for site 2 and this is due to the coarser grained substrate. All slopes and particle sizes are close to the average values reported for sandy beaches in this area (McLachlan *et al.*, 1981a). The sands are very well sorted with no skewness and high calcium carbonate contents. All three sites are characterized by the presence of a horizon of coarse material (Md = 2 mm) below the surface. At site 2 this horizon is encountered closer to the surface and precluded the collection of meiofauna samples at depths greater than 20 cm.

All three sampling positions are near the mid-tide level, the water table depth being at 25 cm at each site. The interstitial water at each site has a high redox potential and is well oxygenated, showing no signs of reducing conditions. The higher oxygen value recorded for site 2 is the result of the coarser substrate having better water percolation. The salinity measurements indicated that there was no significant freshwater seepage from the backshore and the temperature range was normal, being close to the sea temperature of 15,2 °C measured during this survey.

The results of the meiofauna counts are summarized in Table 6. Nematode worms, harpacticoid copepods and turbellarian flatworms are dominant. There was a clear increase in

TABLE 5
SUMMARY OF THE PHYSICAL CONDITIONS FOR SITES NEAR THE FISHWATER FLATS OUTFALL

	Site 1	Site 2	Site 3
Intertidal slope	1/23	1/19	1/24
Sand			
Md (μm)	210	245	210
QDϕ	0,25	0,28	0,27
Skϕ	0,0	0,0	0,0
Water table depth (cm)	25	25	25
Interstitial water			
Eh (mV)	+400	+400	+400
Salinity (10^{-3})	35	35	35
Oxygen (% saturation)	65	92	68
Sand temperature			
At surface (°C)	14,2	14,9	15,5
At water table (°C)	14,2	14,3	14,3
Pebble layer depth	*at* 35 cm	*at* 20 cm	*at* 35 cm

TABLE 6
MEIOFAUNA COUNTS FOR THE THREE SITES NEAR FISHWATER FLATS OUTFALL (numbers/100 cm³)

TAXON	DEPTH IN SUBSTRATE			
	0-10 cm	10-20 cm	20-30 cm	30-40 cm
Site 1				
Nematodes	27	23	10	7
Harpacticoids	54	15	6	7
Turbellarians	108	45	17	18
Archiannelids	31	6	2	8
Others	0	1	1	3
TOTAL	220	90	36	43
Site 2				
Nematodes	14	12	-	-
Harpacticoids	45	156	-	-
Turbellarians	120	62	-	-
Archiannelids	58	25	-	-
Others	0	1	-	-
TOTAL	237	256	-	-
Site 3				
Nematodes	49	97	100	34
Harpacticoids	50	624	138	58
Turbellarians	185	168	84	34
Archiannelids	151	33	15	9
Others	0	3	1	2
TOTAL	435	925	338	137

TABLE 7

SPECIES DIVERSITY DATA FOR A HORIZONTAL TRANSECT ACROSS THE CAPE RECIFE SEWAGE OUTFALL

Species	Site 4			Site 6			Site 7			Site 8			Site 9			Site 10		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Pseudactinia varia	-	5	-	7	36	11	6	1	3	2	1	-	9	8	5	2	3	8
Anthothoe stimpsoni	-	-	-	-	-	-	-	-	-	-	-	-	1	1	2	-	2	1
Molgula sp.	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	2
Chthamalus dentatus	-	-	1	31	-	12	-	2	-	-	-	-	-	-	-	8	-	-
Tetraclita serrata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Parechinus angulosus	-	1	-	-	-	-	15	-	3	7	4	7	12	7	8	-	19	10
Asterina exigua	-	-	-	-	-	-	-	-	-	1	-	1	1	1	1	-	1	1
Henricia ornata	-	-	-	-	-	-	1	-	-	-	-	1	-	-	1	-	-	-
Marthasterias glacialis	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Ophiarachnella capensis	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	4
Ophiothrix fragilis	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Chiton tulipa	-	-	-	-	-	-	1	-	-	2	-	-	-	-	-	-	-	-
Ischnochiton textilis	-	1	-	-	-	-	1	-	-	1	-	2	1	-	-	-	-	3
Dinoplax gigas	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Cucumaria sykion	1	1	2	-	-	-	17	-	-	5	1	5	8	3	5	1	-	5
Pentacucumis spyridophora	1	-	-	-	-	-	4	-	1	-	-	2	-	-	-	-	1	1
Perna perna	-	-	-	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-
Patella concolor	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Patella longicosta	1	1	1	1	-	-	7	10	5	8	5	22	10	5	12	40	-	2
Patella granatina	1	1	-	-	-	-	1	1	-	-	-	1	-	1	-	-	-	-
Patella oculus	1	-	-	-	-	-	-	-	-	-	-	-	-	-	10	5	-	-
Patella miniata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Siphonaria capensis	1	1	4	73	-	106	-	56	21	-	17	4	-	1	16	1	-	-
Siphonaria deflexa	-	-	-	-	-	-	-	-	-	-	-	-	-	2	6	9	-	-
Siphonaria oculus	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-
Siphonaria aspera	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	35	-	-
Crepidula porcellana	1	2	-	-	-	-	-	-	-	2	-	2	1	-	1	-	-	1
Helcion pruinosus	11	7	1	-	-	-	2	-	6	1	-	6	-	1	7	-	-	1
Helcion pectunculus	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Fissurella mutabilis	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-
Diodora spreta	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-
Burnupena lagenaria	9	18	8	1	-	-	-	3	5	-	2	1	3	1	11	4	4	8
Burnupena cincta	-	-	-	-	-	-	1	-	1	1	-	-	-	1	-	-	-	4
Burnupena papyracea tigrina	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Burnupena delalandii	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Oxystele sinensis	-	-	-	-	-	-	7	3	2	11	2	9	4	-	2	2	-	-
Oxystele tigrina	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Turbo sarmaticus	1	3	-	-	-	-	2	-	-	2	-	3	1	-	-	1	6	7
Haliotis midae	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-
Conus tineanus	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-
Gibbula cicer	-	2	-	-	-	-	2	-	1	1	-	-	1	1	3	-	-	6
Natica genuana	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Tricolia capensis	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-
Clionella rosario	-	-	-	-	-	-	-	-	-	-	-	-	1	3	-	-	-	-
Pyrene kraussii	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	2
Haminea alfredensis	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Thais castanea	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	1	-
Clavatula subventricosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Nassa capensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Aplysia parvula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Euphrosine capensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Ochaetostoma formulosum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Polychaete sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
TOTAL NO. PER 0,25 m^2	28	43	18	113	37	129	68	82	51	45	39	68	56	45	91	109	40	69
MEAN NO. PER m^2		120			372			268			204			256			290	
TOTAL NO. SPECIES	10	12	7	5	2	3	15	10	13	14	12	16	16	21	16	11	11	20
MEAN NO. SPECIES		10			3			13			14			18			14	
TOTAL NO. SPECIES PER SITE		16			6			22			26			30			30	
SHANNON- WEAVER INDEX, $\bar{H}$*		4,0000			2,5849			4,4594			4,7004			4,8579			4,9069	

*(N based)

numbers downshore which corresponded with the increase in nutrient levels (and presumably organic levels) reaching this beach. This increase in total numbers, which included all taxonomic groups, was five-fold from site 1 to site 3. If only the top 20 cm are examined, nematode numbers increase by a factor of 2,9; harpacticoids by a factor of 9,8; turbellarians by a factor of 2,3 and archiannelids by a factor of 5,0 from site 1 to site 3. For each of these faunal groups this increase in numbers was statistically significant (t-test $p < 0,05$).

This simple survey shows clearly that enrichment of the beach increases downshore, that is north of the outlet, to a distance of at least 1 km, as a result of the northward inshore current and wave action which combine to sweep the effluent inshore; that the enrichment does not seem to have had any adverse effects on the beach, as Eh levels and oxygen tensions remain normal and there are no traces of reduced layers in the sediment, and that the enrichment has caused a significant increase in meiofaunal abundance.

Although high at site 3, meiofauna numbers are within the range recorded elsewhere along the south-eastern Cape coast (McLachlan *et al.*, 1981c). It is known that exposed beaches can tolerate a reasonable amount of organic loading without disturbing the quilibrium or developing adverse conditions (Oliff *et al.*, 1967). This appears to be the case here, where all that has happened has been a shift in meiofauna abundance to higher levels without any development of anaerobic conditions. Particularly important in this respect is the increase in harpacticoid copepods which are generally the most sensitive group to pollution (Jansson, 1968; Raffaelli and Mason, 1981).

Generally any disturbance, but particularly one causing low oxygen tensions and reduced conditions as is the case with organic loading, results in a decrease in harpacticoid numbers and an increase in nematode numbers. For this reason the nematode/copepod ratio has been proposed as a pollution index (Raffaelli and Mason, 1981; Hennig *et al.*, 1982). Although the use of this index has met with critisism (Warwick, 1981; Coull *et al.*, 1981) decreased abundance of harpacticoids and increased abundance of nematodes is well documented in cases of pollution. Consequently, the abundance of harpacticoid copepods and high Eh and oxygen values at site 3 indicate that this enrichment is still within "healthy" limits. It has caused an upward shift in the abundance of meiofauna and benthic metabolism but has not affected the basic interstitial equilibrium.

Macrofauna (Cape Recife): Fifty-three species of macrofauna were recorded during the survey of the Cape Recife outfall area (Table 7). The total number of species per site varied from sixteen on the upshore side of the pipeline (site 4), through nil at the mouth of the pipeline to six on the downshore side of the pipeline (site 6). Numbers then increased up to 30 species per site with increasing distance from the outfall. Ash-free dry mass values also follow this trend (Table 8). This pattern is the reverse of that shown by the nutrient, metals and bacteria data (Table 1) and it must therefore be concluded that species diversity is affected by some or all of these parameters.

The area immediately adjacent to the treated sewage outfall was found to be devoid of macrofauna due to the freshwater input and the high nutrient levels, especially of ammonia which is toxic. For example, Wickins (1976) has shown that a level of $>0,1$ mg/ℓ NH_3-N adversely affects prawn survival and growth. Although certain species of macrofauna are possibly more resistant to higher ammonia levels as a result of adaptation of tidal exposure, the synergistic effect of continued exposure to both freshwater and high ammonia levels appears to be too much for even the most hardy species.

A different pattern emerges if the total numbers of individuals, rather than the numbers of species, per site are considered. The greatest numbers of macrofauna ($372/m^2$) were recorded at site 6 immediately downshore of the outfall, although the least number of species was found at this site (Table 7). Three species, *Pseudactinia varia, Chthamalus dentatus* and *Siphonaria capensis* not only survived the variable salinities and high nutrient levels but actually flourished under these conditions of low competition for the plentiful food supply; they may be considered as typical "indicator" species or polysaprobes (Järvekülg, 1970). Rocks are covered in blue-green algae at this site upon which *S. capensis* appear to thrive (Littler and Murray, 1975).

TABLE 8
TOTAL DRY MASS AND AVERAGE ASH-FREE DRY MASS VALUES FOR THE SIX SITES NEAR THE CAPE RECIFE OUTFALL

SITE	n	Total dry mass (g/m^2)	Ash-free dry mass (g/m^2)	Average ash-free dry mass (g/m^2)	Shannon-Weaver Index H̄ (based on biomass)
4.1	28	7,55	6,14		
4.2	43	16,37	9,19	32,95	4,9831
4.3	18	23,21	9,38		
6.1	113	8,88	4,77		
6.2	37	12,76	10,13	31,68	1,8074
6.3	129	10,04	8,85		
7.1	68	123,62	47,97		
7.2	82	10,71	8,73	92,57	4,7981
7.3	51	34,72	12,72		
8.1	45	60,86	20,25		
8.2	39	17,56	11,18	103,27	4,5628
8.3	68	95,54	46,02		
9.1	55	39,39	24,99		
9.2	45	60,16	24,09	92,00	4,9197
9.3	81	32,92	19,92		
10.1	108	14,78	11,74		
10.2	39	59,30	29,68	89,42	4,0944
10.3	69	36,58	25,65		

The effect of the outfall was also discernible on the adjacent upshore side of the outfall (site 4) as a result of spill-over by wind, wave and tidal action. However 100 m downshore (site 7), most of the effluent has been diluted by the seawater, thus enabling more species to survive as the distance from the outfall increases. Indeed, at sites 9 and 10 some of the sensitive species or oligosaprobes (Järvekülg, 1970) such as *Tricolia capensis, Clionella rosario, Pyrene krausii, Haminea alfredensis, Thais castanea, Clavatula subventricosa* and *Nassa capensis* were found, and only at the furthest site (site 10) were a few worms such as *Euphrosine capensis* and *Ochaetostoma formulosum* found.

When an n-based Shannon-Weaver species diversity index $\bar{H}$ is computed for these data (Table 7), a value of 4 is obtained for site 4; this index falls to 2,58 for site 6 but then increases progressively from 4,46 to 4,91 for sites 7 to 10 inclusive. A similar trend is found when a biomass (ash-free dry mass) based index is applied (Table 8). These observations are in agreement with those of Sanders (1968) who noted that species numbers diminished with increasing environmental stress and with Leppäkoski (1975) and Moore (1978), both of whom noted that fewer species were found as pollution increased but that the numbers of individuals of those species increased. Littler and Murray (1975), who investigated the impact of sewage on a rocky-shore community also found fewer species and lower diversity at the outfall site.

McLachlan *et al.*, (1981b) obtained an average value of 26 g/m^2 ashfree dry mass for Flat Rocks and 46 g/m^2 for Schoenmakerskop, whereas in the present survey the biomass averaged approximately 32 g/m^2 even at the polluted sites (Table 8). It may be concluded that the effluent has caused enrichment of the downshore macrofaunal biomass just as it has caused a visible enrichment of the macroalgal (seaweed) biomass.

McLachlan *et al.*, (1981b) also noted that the observed difference in biomass estimates between Flat Rocks and Schoenmakerskop was partly due to bait gathering at the former site. The area of Flat Rocks sampled in the present survey is probably only slightly affected by bait gatherers as the outfall lies within the Cape Recife Nature Reserve to which entry is restricted.

Summary

Both the sewage outfalls investigated are located in Algoa Bay near the City of Port Elizabeth, a centre of industry on the south-eastern Cape coast. Approximately 30 Mℓ/d of treated effluent are discharged into the surf-zone at Brighton Beach via the Fishwater Flats outfall while about 15 Mℓ/d of partially-treated sewage effluent are discharged onto the rocky shore within the Cape Recife Nature Reserve environs.

The Fishwater Flats effluent enters the sea in an area of moderately-high wave energy. The effluent plume can often be detected for distances of up to 1 km downcurrent of the pipeline and on some occasions, when wind and tide movements are favourable, it may reach the mouth of the Swartkops River. The area of discharge is one of sandy beaches and a study of the beach meiofauna indicated that the effluent has an enriching rather than a deleterious effect.

A community survey of the rocky shore macrofauna near the Cape Recife outfall indicated that the effluent adversely affected species diversity and numbers for a distance of approximately 300 m downcurrent. Beyond this point, however, both species numbers and diversity increased to normal levels. *P. perna* growing adjacent to the outfall appears not to have accumulated trace metals excessively, indicating the absence of metals contamination. The results of the survey indicated that the effect of this effluent tends to be one of biological enrichment.

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