Trace metal surveys in Mossel Bay, St Francis Bay and Algoa Bay South Africa

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Abstract

Surveys to determine trace-metal levels in Mossel Bay, St Francis Bay and Algoa Bay were undertaken during 1978-1979. Water, sediment and biological samples were analysed for up to 16 elements by atomic absorption spectrophotometry.

Metal concentrations are low along the entire Mossel Bay coast and no significant sources of metal pollution were discovered. Some variations in concentrations occur but these are often due to catchment mineralization and, in any case, are only slightly elevated above background levels. St Francis Bay is unpolluted with respect to metals, the levels of which are generally lower than those found in equivalent samples from Algoa Bay.

The results obtained for Algoa Bay indicate that the Swartkops and Papenkuils Rivers and the Cape Recife sewer outfall contribute considerable amounts of metals to Algoa Bay. However, with the exception of the Papenkuils River, these amounts are too small to cause significant environmental stress to the Algoa Bay ecosystem. The diverse fauna and flora of the bay are indicative of an unpolluted environment.

Introduction

The general programme to monitor marine pollution along the coast of South Africa has been described in detail (Cloete and Watling, 1981). The aims of this programme are to discover and to monitor sources of marine pollution, to establish coastal monitoring stations and to institute a national data centre where all the information which is being obtained from the current studies can be collected most effectively. The discovery and continued monitoring of the effects of industrial and urban coastal developments is necessary if we are to protect indigenous flora and fauna.

Trace metals are so named because they generally occur in very small quantities. They naturally enter the marine environment via rivers or as wind-blown material following the weathering of rocks. However, mining and agricultural activities, industrial and sewage effluents and airborne pollutants may all contribute additional metals to the coastal marine environment. In this way the relatively soluble trace metals which are frequently introduced into the environment in easily assimilable organic forms, may accumulate unnoticed to toxic levels.

Potential biologicial monitors for the South African marine and estuarine environment have been discussed in general terms on the basis of the reported use of related species (Darracott and Watling, 1975). Trace metal concentrations in a number of species of molluscs are already being determined in several laboratories as part of the National Marine Pollution Monitoring Programme (Cloete and Watling, 1981). The use of certain biological species to monitor metal pollution in the marine environment has the advantage that accumulation will reflect the presence of "available" metal over a period of time. Such organisms can be sampled at convenient time intervals and will give an indication of pollution input, even if this is intermittent, as they provide an integrated measure of the trace metal load of a water mass.

The results of surveys to determine the trace metal levels in water, sediment and biological samples collected from three bays, Mossel Bay, St Francis Bay and Algoa Bay on the southern coast of South Africa (Fig. 1) are summarised in this paper. The three study areas represent different stages in the development of the southern Cape coast. Port Elizabeth, on the south-west Algoa Bay coast, is the largest urban and industrial centre in the south-east Cape. The recent construction of a large dock and transport facility almost certainly ensures the further expansion of both urban and industrial areas and as a consequence of this, there will be a greater impact on the Algoa Bay coastal ecosystem. Mossel Bay is relatively undeveloped but many changes are taking place. The urban area has been increased substantially with the development of a new town to the west of the present centre and the Diaz industrial complex to the east of Mossel Bay is also likely to be expanded. No major towns or industrial areas are situated on the St Francis Bay coast and the rivers drain agricultural land. This part of the coast is expected to provide an unpolluted "control" area for the comparative study.

The data obtained during these surveys, carried out in the period 1978-1979, are expected to serve as a baseline for the future monitoring of selected areas on this coast in the event that they are subjected to further urbanization and industrialization.

Study areas

Mossel Bay

The largest urban and industrial settlement on the south coast of South Africa between Port Elizabeth and Cape Town is Mossel Bay. The town has a population of approximately 23 000 and supports diverse industrial concerns. Sewage enters the sea near the harbour at Mossel Bay and also from three main settlements in the Bay, Hartenbos, Little Brak River and Great Brak River

The three major rivers which enter the Bay are also known by the same names (Fig. 1A). The environmental conditions in these estuaries have been summarised by Day (1981), together with brief ecological descriptions of their flora and fauna. In 1977 all three estuaries were polluted with oil drifting in from the sea as a result of the VENPET-VENOIL collision. The oil spill resulted in serious destruction of the estuarine fauna (Moldan *et al.*, 1979).

The small holiday resort of Vlees Point is situated to the west of Mossel Bay and a larger township is being developed between

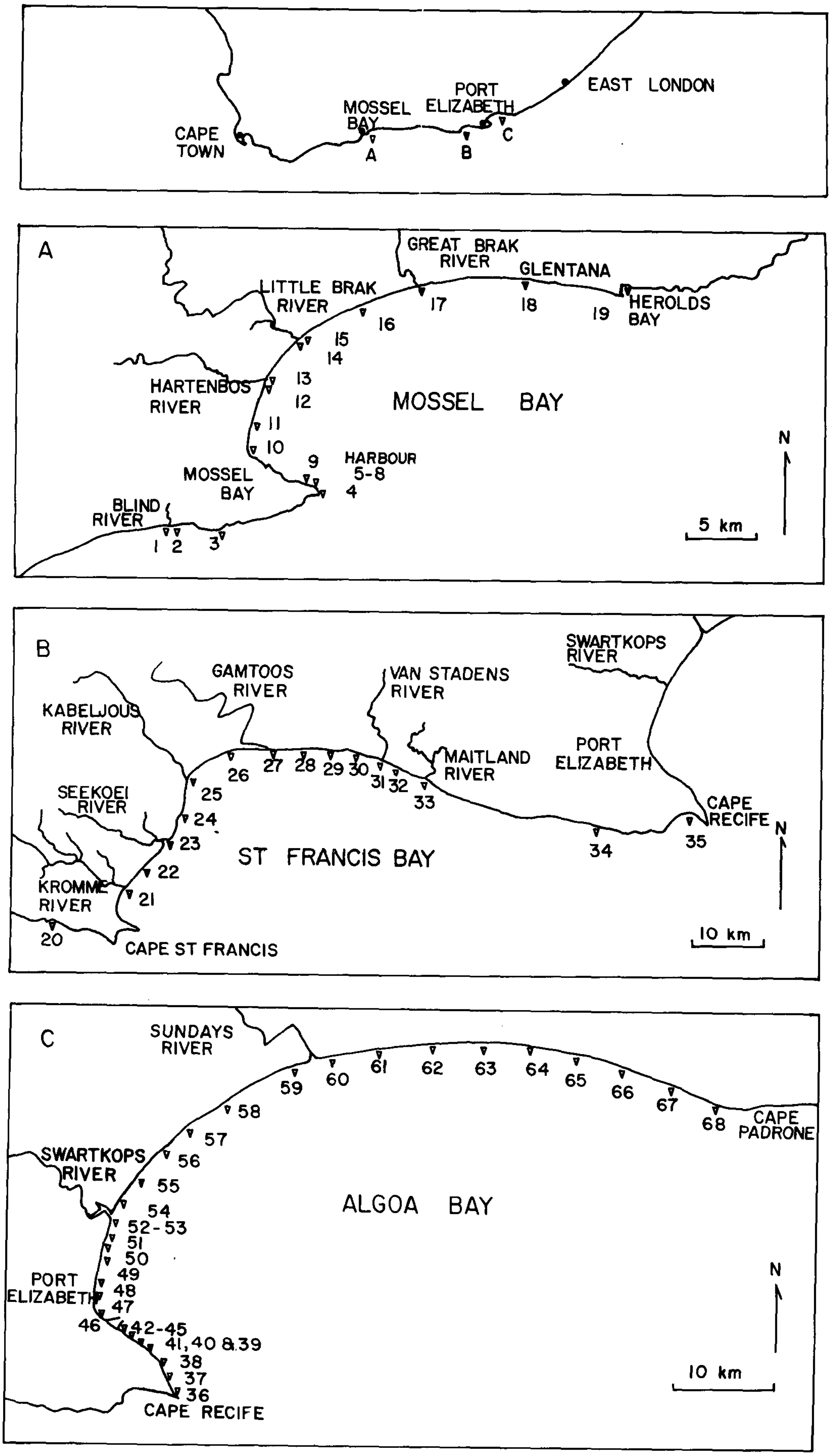

Figure 1
Study area and sampling sites

Vlees Point and Mossel Bay. Other resorts to the east of Mossel Bay include Tergniet, Glentana and Herolds Bay.

A preliminary survey of the Mossel Bay coastal area, including the three main rivers, has been undertaken and the results of meiofaunal and chemical analyses (other than for trace metals) of samples collected during the survey have been reported (Eagle *et al.*, 1979). Surveys to study the metal contents of the three rivers have also been carried out and the results indicate that all three rivers experience some degree of metal contamination (Watling and Watling, 1982 *c*).

St Francis Bay

St Francis Bay is an extensive, south-facing bay bounded by Cape St Francis to the south-west and Cape Recife to the north-east (Fig. 1B).

The two major rivers which flow into the bay are the Kromme and Gamtoos Rivers, the mouths of which are open to the sea. The physical characteristics and general ecology of these rivers have been described by Day (1981) and a detailed community analysis of the Kromme estuary has been compiled from published and unpublished data (Emmerson *et al.*, 1982). Preliminary surveys to study the distribution of metals in both the Kromme and Gamtoos Rivers have been undertaken (Watling and Watling, 1982 *f*). The results indicate that neither estuary is contaminated significantly with respect to metals. Elevated metal levels in the Geelhoutboom River (Kromme tributary) are thought to be of geochemical origin while increased metal concentrations in the lower reaches of the Gamtoos estuary may be partially derived from the application of certain chemical seed dressings to the cultivated areas of the flood plain.

The Seekoei, Kabeljous, Van Stadens and Maitland Rivers are all closed to the sea by sand bars. Background information about these rivers is exceedingly scarce and they are not described by Day (1981).

The town of Jeffreys Bay is the major urban development on the St Francis Bay coast but a number of small holiday resorts are to be found, often in the vicinity of the river mouths. A marina has been constructed on the west bank of the Kromme River near the mouth and some of the possible effects of the associated canal system on the estuary have been investigated (Baird *et al.*, 1981). It is expected that future developments on the St Francis Bay coast will consist mostly of the extension of existing holiday resort facilities rather than of industrialization. The surrounding inland area supports a considerable variety of farming and agricultural activities.

Algoa Bay

Algoa Bay is situated on the south-eastern coast of South Africa between Cape Recife and Cape Padrone (Fig. 1C). The bay is part of 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 shores and several small islands.

The two major rivers flowing into the bay are the Swartkops and Sundays Rivers. Both these rivers are described by Day (1981) and a detailed community analysis of the Swartkops River has been compiled (Emmerson *et al.*, 1982). The Coega River is utilised 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. Industrial and urban effluents from the towns of Uitenhage and Despatch and the City of Port Elizabeth are introduced into the bay via the Swartkops and Papenkuils Rivers (Watling and Emmerson, 1981; Watling and Watling, 1982 *b*) and the Fishwater Flats and Cape Recife sewer outfalls (Emmerson *et al.*, 1983).

St Croix Island is one of the few breeding grounds of the Jackass penguin (Randall *et al.*, 1980) and considerable importance must be attached to the preservation of this ecosystem.

Materials and methods

The methods used for the collection, preparation and analysis of water, sediment and biological samples have been described by Watling and Watling (1982 *b).*

Results and discussion

Metals in Water Samples

The trace metal concentrations in surface water samples collected from Mossel, St Francis and Algoa Bays (Figs. 1A, B and C) are listed in Table 1. Metal concentrations are generally low but some anomalous results are obtained for each of the bays.

The water sample collected from the inner harbour area at Mossel Bay (site 5) contains elevated levels of copper, lead and mercury. It is probable that these metals are derived from boats and trains which use the area extensively. With the exception of mercury, the concentrations are well below the levels which would be hazardous to the biota. The higher levels are apparently restricted to the harbour area so that the marine biota on the adjacent shores are not endangered. Elevated zinc and cadmium levels were found in the sample from the mouth of the Hartenbos River (site 12) and these may be associated with the urban settlement. There is no indication of the chromium anomaly in the Great Brak River (Watling and Watling, 1982 *c*) in the coastal water sample, so that the effects of this contamination are restricted to the estuary.

Metal concentrations in surface water samples from St Francis Bay are generally lower than those determined for Mossel Bay and the south-western part of Algoa Bay, as might be expected. However, the samples collected near the mouths of the Gamtoos and Van Stadens Rivers contain slightly elevated levels of several metals. The results obtained in the present survey are very similar to those reported by Orren *et al.*, (1981) for Jeffreys Bay.

The water sample from the inner harbour at Mossel Bay contains the second highest concentration of mercury found during the present surveys. At the same time it is worth noting that all the coastal water samples collected in Mossel Bay contain elevated mercury levels. In contrast, the samples from St Francis Bay contain overall lower concentrations while in Algoa Bay, the samples collected in the industrialized south-western region have higher mercury concentrations than those from the undeveloped north-eastern part of the bay. It is assumed, therefore, that the presence of mercury is associated with human activities and that sources may be the various sewage outlets to each of the bay systems. In support of this, it is noted that the samples from the Cape Recife sewer outfall and from the Papenkuils River mouth (sites 38 and 49 respectively) both contain high mercury concentrations.

The relatively high cadmium concentration in the sample from Herolds Bay (site 19) and the elevated level in the Blind River sample (site 2) are surprising as there are no obvious sources of this element at either site.

Cadmium is also released into Algoa Bay via the Cape Recife sewer outfall (site 38) and this concentration is the highest found

TABLE 1
METAL CONCENTRATIONS IN WATER SAMPLES ($\mu g/\ell$)

	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Hg
Mossel Bay									
1	2,1	0,2	0,9	62	1,0	<0,05	0,10	0,4	0,035
2	1,5	0,1	1,0	52	3,8	<0,05	<0,05	1,0	0,028
3	1,1	0,7	1,8	20	0,7	0,05	1,00	0,3	0,028
4	2,5	0,2	0,7	74	1,1	<0,05	<0,05	0,2	0,032
5	3,2	1,0	3,0	44	1,7	0,05	0,40	0,2	0,196
6	1,5	0,5	2,8	38	1,5	0,05	0,05	0,8	0,012
7	0,5	<0,1	0,6	34	1,1	0,05	0,05	0,4	0,010
8	0,8	0,2	1,4	28	0,7	0,05	0,20	0,3	0,004
9	1,3	0,1	1,3	23	0,8	0,05	0,05	0,4	0,028
10	2,6	<0,1	0,8	50	1,3	<0,05	<0,05	0,1	0,032
11	2,7	0,1	0,6	43	1,2	0,05	0,10	0,2	0,041
12	1,2	0,7	5,8	29	0,9	0,05	0,05	1,8	0,025
13	1,1	0,2	0,8	58	8,3	<0,05	0,10	0,4	0,038
14	2,6	0,2	1,8	44	4,8	<0,05	<0,05	0,7	0,046
15	2,0	<0,1	0,9	53	6,9	0,05	0,10	0,1	0,030
16	2,6	0,7	2,9	58	1,1	<0,05	0,05	0,3	0,028
17	1,9	0,6	2,0	53	1,2	<0,05	0,10	0,2	0,025
18	1,7	0,1	2,0	58	0,9	0,05	0,60	0,1	0,034
19	1,0	0,6	2,7	41	1,2	0,05	0,10	3,4	0,032
St Francis Bay									
20	1,1	0,1	0,2	72	0,9	<0,1	0,1	<0,1	0,002
21	0,9	0,2	0,2	97	3,4	<0,1	<0,1	<0,1	0,002
22	1,5	0,2	0,2	135	1,3	0,2	<0,1	<0,1	0,001
23	0,9	<0,1	0,3	189	2,7	0,1	<0,1	0,3	0,010
24	1,2	<0,1	0,4	162	1,7	0,2	0,1	0,1	0,010
25	1,3	<0,1	0,6	129	6,0	<0,1	0,3	0,2	0,016
26	1,4	0,2	0,8	226	3,3	0,2	0,2	0,3	0,001
27	1,6	0,2	2,2	590	11,6	0,2	0,5	0,1	0,004
28	1,3	0,4	1,6	410	6,9	0,1	0,3	0,1	0,022
29	1,2	0,5	0,9	460	4,5	<0,1	0,4	0,1	0,024
30	1,5	0,2	0,8	221	2,7	0,4	<0,1	0,5	0,004
31	1,5	0,7	3,1	102	5,3	0,9	<0,1	0,5	0,012
32	2,1	0,6	9,3	262	2,5	0,6	0,1	0,3	0,028
33	1,2	0,5	0,9	540	4,8	0,7	0,1	1,2	0,014
34	1,5	<0,1	0,4	76	0,8	<0,1	<0,1	0,2	0,014
35	1,0	0,4	0,8	730	8,1	0,3	0,1	1,3	0,010
Algoa Bay									
36	2,0	0,5	1,4	37	1,6	0,1	0,8	0,2	0,006
37	0,8	1,1	2,2	62	4,5	<0,1	0,9	0,3	0,003
38	2,6	1,1	2,2	8	6,2	<0,1	0,6	47	0,143
39	10,4	1,0	1,4	7	2,7	0,2	0,7	0,2	0,003
40	<0,1	<0,1	1,3	12	2,7	<0,1	0,4	0,2	0,003
41	<0,1	<0,1	1,5	21	6,2	<0,1	0,4	0,2	0,017
42	1,0	0,9	1,7	268	18,9	0,1	1,3	0,2	0,029
46	0,8	0,6	1,7	91	7,9	<0,1	1,3	0,1	0,002
47	2,0	1,0	3,2	354	4,4	<0,1	0,8	0,3	0,032
48	6,8	4,2	9,2	503	24,1	<0,1	1,2	0,4	0,069
49	11,3	41,0	430	680	170	0,8	52	0,2	0,216
50	<0,1	0,9	1,4	41	3,2	<0,1	0,7	0,2	0,003
51	<0,1	0,2	1,2	7	2,3	<0,1	0,5	0,2	0,004
52	1,2	0,6	1,3	19	12,9	<0,1	0,8	0,2	0,017
53	1,4	4,7	3,1	155	6,0	0,5	2,2	0,6	0,002
54	0,2	0,1	1,0	3	2,3	<0,1	0,5	0,2	0,034
55	0,6	0,1	1,2	2	1,3	<0,1	0,2	0,1	0,003
56	4,0	3,5	11,9	431	15,9	0,2	1,7	0,4	0,002
57	3,6	2,9	7,1	163	10,2	0,2	0,8	0,4	0,003
58	<0,1	0,1	1,4	42	2,2	<0,1	0,4	0,1	0,001
59	1,7	0,8	1,4	7	1,3	<0,1	0,5	<0,1	0,001
60	1,9	0,5	1,8	4	7,9	0,3	<0,1	<0,1	0,008
61	2,2	<0,1	1,0	3	4,1	<0,1	0,1	<0,1	0,002
62	2,1	0,1	0,2	15	3,4	0,3	0,3	<0,1	0,005
63	1,6	<0,1	0,7	20	2,2	0,1	0,1	<0,1	0,001
64	2,0	0,3	1,4	16	1,9	0,1	0,4	0,1	0,002
65	1,6	<0,1	0,6	16	2,1	0,1	0,3	<0,1	0,012
66	1,7	<0,1	0,4	16	2,0	0,1	0,1	<0,1	0,001
67	1,5	<0,1	0,3	16	1.5	0,1	<0,1	<0,1	0,001
68	1,4	0,1	0,2	14	1,9	<0,1	<0,1	<0,1	0,001

during the present surveys. As a result of this, the Port Elizabeth municipality and several other major contributors to the Cape Recife sewer were notified and requested to locate and reduce any possible sources of cadmium-rich waste which might be entering the sewer. When metal concentations were monitored during a two-week period in August 1981 (Emmerson *et al.*, 1983) the cadmium concentrations were seen to vary considerably but were an order of magnitude lower. This is a significant reduction which was achieved by voluntary cooperation between the parties concerned.

The main source of metals being released into coastal waters is the Papenkuils River. This river is essentially a canal carrying sewage and industrial effluents. The river has been surveyed and the main sources and types of effluents identified (Watling and Emmerson, 1981). The polluted river water is toxic to marine biota and no macrofauna live in the river itself. However, because of the strong, clockwise current in the bay, dilution of the effluent takes place rapidly and the sphere of influence of this outfall extends for only about 100 m upcurrent.

Samples collected in the Swartkops and Coega River mouths also contain elevated levels of some metals. The Swartkops River has been surveyed and four main sites of metal contamination have been identified (Watling and Watling, 1982 *b*). In the case of the Coega River, the higher metal concentrations are thought to be the result of seepage rather than of direct flow.

The sources and extent of metal pollution in surface water samples are few and of localised effect. On the whole, the metal levels determined in these coastal samples are low and will serve as a baseline for the future monitoring of the area.

Metals in Sediment Samples

Metal concentrations in surface sediment samples are listed in Table 2. Metal levels are generally low, as is expected for high-energy coastal environments.

In Mossel Bay samples collected between Voorbaai and the mouth of the Hartenbos River (sites 11-13) contain elevated levels of a number of elements relative to the bay as a whole. The higher concentrations are found at site 11, 50 m north of a factory effluent outfall onto the beach. A considerable reduction in the numbers of sandy-beach meiofauna has also been reported for this area (Eagle *et al.*, 1979).

In general, the concentrations determined in this survey are very similar to those reported by Orren *et al.*, (1981). However, there is some evidence of contamination by metals in the area of St Francis Bay between the mouths of the Kabeljous and Gamtoos Rivers (sites 25-26). High chromium concentrations were determined in these samples but there were no corresponding increases in the concentrations of other elements particularly of cobalt and iron, which would be expected if this anomaly was of geochemical origin (Watling and Watling, 1982 *g*). Metal concentrations in the sample from the mouth of the Gamtoos River (site 27) are elevated relative to the levels determined in the other coastal samples. It is thought that these metals are derived from a combination of catchment weathering and also run-off from cultivated land which has been treated with fertilizers and seed dressings (Watling and Watling, 1982 *f*).

In general, the metal concentrations in sediments from Algoa Bay are similar to those found in the other two bays. However, because part of the Algoa Bay area is industrialized, there is likely to be some evidence of contamination. Sediments collected near the Cape Recife sewer outfall (sites 38 and 39) contain increased concentrations of cadmium and mercury and indeed mercury concentrations are elevated in the extended area to the harbour (sites 38-44). Although contamination by metals is evident in the samples from the dock area (sites 42-45), this is surprisingly light in view of the size of this ore-loading and dock facility.

Elevated metal levels are also found in sediments collected near the mouth of the Papenkuils River (site 49) and at the Fishwater Flats sewer outfall (site 51). However, the presence of a strong current and steep beach slope in this high energy environment combine to disperse these effluents rapidly, thus inhibiting the build-up of toxic metals in the sediment column.

Cobalt and cadmium concentrations in sediments from the Coega River mouth (site 57) indicate that these metals are derived from local anthropogenic sources, an observation which is supported by the fact that cobalt levels are elevated relative to nickel levels. The reverse would be the case if the metals were derived entirely from the weathering of mineralized or unmineralized rocks (Watling and Watling, 1982 *g*). The area associated with the mouth of the Coega River is used almost exclusively for the production of sea and estuarine salt and seepage of impounded water contaminated by metals as corrosion products from the salt works, may be the source of contamination.

Samples from the remainder of Algoa Bay beach (to site 68) show no signs of metal contamination.

With the exception of a few isolated anomalies, none of which are great enough to be deleterious to the marine biota, the sediments of Mossel, St Francis and Algoa Bays contain background levels of these metals. The data obtained in these surveys will serve as baseline for the future monitoring of these areas.

Metals in Molluscs

Metal concentrations in *Crassostrea margaritacea, Perna perna, Patella granularis, P. oculus, P. barbara, P. longicosta, P. miniata, P. argenvillei, P. cochlear* and *P. tabularis* collected from rocky shore sites and *Donax serra* and *Bullia rhodostoma* collected from sandy beaches have been determined. The complete data are reported by Watling and Watling (1981; 1982 *a* and *e*) and are summarised in Table 3. Mean concentrations have been calculated for Mossel Bay and St Francis Bay but the Algoa Bay coast has been divided into two parts. The Algoa Bay A region includes sampling sites in the industrialized part of the bay to the south of the Swartkops River mouth while the remaining sites north-east of the Swartkops River mouth along the beach to Cape Padrone make up the Algoa Bay B Region.

The ability of molluscs to accumulate metals in their tissues is a characteristic which can sometimes be used to indicate areas of the coast which are being subjected to pollution by metals. Oysters in particular have been found to accumulate very high levels of metals if they are growing in polluted areas (Darracott and Watling, 1975) and it has been shown that *C. margaritacea* is no exception (Watling and Watling, 1982 *b*). The concentrations found in this species growing on the Mossel Bay coast are all low (Watling and Watling, 1982 *d*), suggesting that the Bay as a whole is not polluted significantly with metals. The same situation exists for *C. margaritacea* growing in St Francis Bay (Watling and Watling, 1982 *e*). Oysters growing at the mouth of the Papenkuils River have accumulated zinc, copper, lead and chromium (Watling and Watling, 1981). A recent pollution survey of this river (Watling and Emmerson, 1981) has shown that considerable quantities of a number of metals, most notably zinc and chromium but also lead, cadmium and mercury, are entering the river via the many drains which are to be found both in and above the canalized section. *C. margaritacea* growing at

TABLE 2
METAL CONCENTRATIONS IN SURFACE SEDIMENTS ($\mu g/g$)

	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Cr	Hg
Mossel Bay										
1	1,0	2,5	3,0	1270	12	0,2	0,5	0,005	3,7	<0,001
2	1,2	0,9	2,9	2210	15	0,3	0,5	0,006	2,9	0,003
3	1,3	0,9	2,1	2210	17	0,2	0,4	0,003	2,1	0,001
4	1,4	0,8	6,2	2160	15	0,3	0,6	0,009	2,7	0,001
9	2,4	0,7	3,6	2970	26	0,4	0,9	0,100	2,3	0,001
10	2,7	1,4	4,6	4130	22	0,4	0,9	0,016	2,7	0,001
11	2,3	4,6	9,2	8500	56	1,2	2,7	0,003	5,2	0,001
12	2,4	6,7	4,9	7210	57	0,9	1,4	0,010	3,6	0,001
13	2,7	10,2	5,9	1320	36	0,9	1,7	0,021	1,8	0,003
14	1,7	9,6	3,1	1520	26	0,3	0,9	0,023	2,4	0,001
15	2,4	6,3	4,7	1270	12	0,2	0,6	0,009	3,9	0,003
16	2,7	3,6	3,8	1160	10	0,2	0,6	0,012	2,7	<0,001
17	0,8	1,5	2,4	1500	10	0,1	0,6	0,015	1,4	0,001
18	2,0	12,1	3,6	390	26	0,2	0,6	0,032	1,5	0,001
19	1,2	2,8	1,7	850	20	0,3	0,5	0,046	2,2	0,002
St Francis Bay										
20	2	2	2	1760	24	0,1	0,2	0,037	4	0,001
21	2	3	2	920	20	0,1	0,1	0,031	7	0,002
22	2	6	3	1520	36	0,1	0,1	0,066	10	0,003
23	1	2	1	620	15	0,2	0,3	0,031	6	0,003
24	1	1	1	520	16	0,1	0,1	0,020	7	0,002
25	2	4	1	1200	37	0,4	0,6	0,031	210	0,003
26	4	3	2	1110	28	0,2	0,4	0,063	200	0,002
27	8	7	16	7600	100	3,2	5,8	0,465	17	0,004
28	3	1	4	1200	27	0,2	0,4	0,041	3	<0,001
29	3	2	3	1500	30	0,1	0,3	0,066	3	<0,001
30	2	1	1	920	18	0,2	0,4	0,062	3	<0,001
31	3	4	2	840	24	0,2	0,3	0,039	5	0,001
32	2	2	2	650	18	0,2	0,3	0,006	3	0,002
33	2	3	3	290	52	<0,1	<0,1	0,072	7	0,019
35	2	1	2	1120	16	<0,1	<0,1	0,050	6	0,004
Algoa Bay										
36	2,4	0,7	7,2	2210	40	<0,1	1,4	0,038	2,2	0,016
37	1,8	0,6	5,8	1830	40	<0,1	1,2	0,051	1,8	0,028
38	1,8	0,7	3,6	2420	37	<0,1	1,6	2,93	2,0	0,412
39	1,6	0,9	3,8	2210	36	<0,1	<0,1	1,64	1,6	0,121
40	1,0	0,7	4,3	1870	32	<0,1	<0,1	0,013	2,8	0,112
41	2,4	0,6	7,2	2010	47	<0,1	2,8	0,072	2,0	0,361
42	1,0	0,7	5,2	4000	53	0,4	0,6	0,039	2,0	0,171
43	1,6	6,3	2,2	1560	460	0,2	0,4	0,026	2,7	0,038
44	2,3	7,6	15,2	3920	1700	0,3	1,6	0,092	7,3	0,121
45	3,6	0,9	5,2	750	80	<0,1	0,3	0,121	2,2	0,016
49	2,0	10,3	9,6	1980	23	0,1	0,8	0,062	10,3	0,016
51	1,0	1,6	8,0	4000	40	<0,1	<0,1	0,820	1,8	0,032
52	2,6	7,2	8,2	4010	67	<0,1	2,8	0,063	2,4	0,036
53	1,2	2,9	2,4	1590	11	<0,1	<0,1	0,025	1,3	0,029
54	2,1	6,3	8,4	4000	76	<0,1	1,3	0,027	2,6	0,032
55	1,8	2,0	5,2	4160	43	<0,1	0,2	0,042	1,2	0,027
56	1,4	2,8	5,6	4170	46	<0,1	0,4	0,032	2,6	0,041
57	0,8	0,9	6,2	4000	42	1,4	0,6	2,130	1,8	0,017
58	0,9	3,2	6,4	3790	39	<0,1	0,4	0,630	1,8	0,032
59	1,6	1,7	5,3	3900	52	0,6	0,8	0,061	5,3	0,029
60	1,2	1,2	4,3	2500	32	0,4	0,7	0,051	6,3	0,016
61	1,8	3,2	6,2	1390	37	0,5	0,9	0,062	3,2	0,009
62	1,6	2,2	5,7	2500	39	0,5	0,9	0,050	7,7	0,021
63	2,1	5,3	8,6	2500	39	0,7	1,6	0,070	7,9	0,008
64	1,3	1,8	3,6	1500	28	0,2	2,7	0,071	4,9	0,008
65	3,2	1,5	3,6	1750	39	0,2	0,4	0,076	5,2	0,009
66	2,7	0,9	2,1	1120	37	0,1	0,1	0,132	3,7	0,007
67	1,7	0,6	1,3	800	22	<0,1	0,1	0,037	5,3	0,007
68	1,4	1,3	2,2	1200	29	<0,1	<0,1	0,037	4,6	0,003

TABLE 3
MEAN METAL CONCENTRATIONS (μg/g IN WET TISSUE) IN MOLLUSCS

Species and Area	No. of Sites Sampled	Wet Mass (g)	Dry Mass (g)	Zn	Cd	Cu	Pb	Fe	Mn	Ni	Co	Cr
Crassostrea margaritacea												
Mossel Bay	3	4,59	0,76	178	1,72	5,4	0,01	18	0,9	0,05	0,01	0,3
St Francis Bay	3	2,03	0,41	114	1,57	4,4	0,04	39	1,0	0,10	0,11	0,8
*Algoa Bay A	2	3,74	0,62	1054	0,24	7,9	0,69	50	1,6	0,16	0,06	2,5
*Algoa Bay B	1	4,59	0,86	249	0,99	2,7	0,13	21	1,7	0,17	0,07	0,4
Perna perna												
Mossel Bay	10	4,87	0,93	14,1	0,65	1,2	0,11	68	1,3	0,90	0,09	0,7
St Francis Bay	8	3,02	0,58	19,0	0,58	1,2	0,10	94	1,5	2,02	0,17	0,5
Algoa Bay A	5	2,41	0,45	24,6	0,23	1,4	0,62	88	2,4	1,52	0,12	0,8
Algoa Bay B	2	6,01	1,23	17,8	0,22	1,3	0,20	107	2,2	1,36	0,21	0,9
Patella granularis												
Mossel Bay	1	0,88	0,44	13,6	7,6	1,2	0,42	427	2,1	0,97	0,04	2,2
St Francis Bay	6	0,89	0,22	12,0	8,9	1,3	0,09	518	1,4	1,14	0,06	1,6
Algoa Bay A	3	1,27	0,33	13,9	3,1	2,0	0,23	403	2,4	1,15	0,07	3,3
Patella oculus												
Mossel Bay	5	5,07	1,22	9,9	2,8	0,8	0,27	517	2,8	0,53	0,11	1,0
St Francis Bay	6	5,04	1,14	11,2	3,8	0,7	0,06	466	1,0	0,51	0,12	0,8
Algoa Bay A	5	8,06	1,76	15,9	1,2	1,2	0,35	581	2,2	0,64	0,13	1,4
Algoa Bay B	1	5,21	1,13	10,7	1,7	1,1	0,04	574	2,0	0,99	0,12	1,6
Patella barbara												
Mossel Bay	8	10,50	2,43	13,4	3,9	0,8	0,29	380	2,3	0,42	0,17	0,5
St Francis Bay	5	5,37	1,20	14,4	5,9	0,8	0,11	208	1,1	0,79	0,10	1,4
Algoa Bay A	5	8,07	1,91	26,7	2,5	1,0	0,40	255	2,4	0,77	0,10	1,7
Algoa Bay B	1	6,62	1,63	24,9	4,0	0,9	0,32	380	1,9	0,78	0,24	1,5
Patella longiscosta												
Mossel Bay	10	4,09	0,96	12,6	9,0	1,0	0,13	213	1,3	0,46	0,12	1,1
St Francis Bay	4	3,34	0,78	13,7	14,3	0,8	0,05	149	0,9	0,44	0,08	1,2
Algoa Bay A	4	2,83	0,68	15,0	2,6	1,1	0,27	215	1,6	0,40	0,18	1,1
Algoa Bay B	2	2,80	0,62	16,2	2,9	1,9	0,36	268	1,6	0,68	0,09	1,3
Patella miniata												
Mossel Bay	3	7,48	1,59	7,8	6,6	0,7	0,11	440	2,0	0,36	0,10	1,0
St Francis Bay	3	5,26	1,17	10,3	6,3	1,0	0,05	286	1,5	0,70	0,04	1,2
Algoa Bay A	3	10,57	2,50	9,6	3,7	0,8	0,07	177	0,9	0,31	0,04	0,6
Algoa Bay B	1	5,63	1,45	10,3	3,3	1,3	0,12	675	3,0	0,87	0,05	1,6
Patella argenvillei												
Mossel Bay	3	9,65	2,15	14,6	5,7	0,8	0,07	121	1,1	0,42	0,16	0,6
St Francis Bay	3	7,88	1,81	10,1	10,5	0,7	0,01	85	0,7	0,53	0,05	0,5
Patella cochlear												
Mossel Bay	8	3,17	0,89	10,6	5,5	0,9	0,09	197	1,5	0,50	0,09	0,7
St Francis Bay	4	1,80	0,40	9,7	9,6	1,4	0,04	86	0,6	0,64	0,06	1,6
Algoa Bay A	4	1,91	0,44	10,2	6,3	0,9	0,08	99	0,6	0,75	0,10	0,7
Patella tabularis												
Mossel Bay	1	16,96	3,37	11,5	1,8	0,7	0,27	107	0,5	0,11	0,02	0,1
St Francis Bay	2	24,49	6,20	8,9	9,9	0,8	0,03	40	0,6	0,17	0,04	0,7
Algoa Bay A	2	24,43	5,78	17,0	1,4	1,1	0,39	145	1,0	0,28	0,08	0,4
Donax serra												
Mossel Bay	3	5,85	1,01	16,0	0,11	1,1	0,14	81	1,3	0,38	0,11	0,6
St Francis Bay	12	9,20	1,68	13,2	0,04	1,0	0,06	231	2,2	0,33	0,07	0,8
Algoa Bay B	1	4,36	0,85	10,9	0,05	0,9	0,03	81	1,5	0,28	0,03	0,6
Bullia rhodostoma												
Mossel Bay	7	2,20	0,51	35,5	4,5	1,5	0,14	66	1,5	0,18	0,10	2,7
St Francis Bay	15	2,07	0,48	42,4	5,9	1,7	0,10	39	1,6	0,18	0,08	1,8
Algoa Bay A	2	1,17	0,24	36,9	4,2	2,0	0,10	50	1,5	0,19	0,13	0,8
Algoa Bay B	7	1,53	0,34	46,3	3,1	1,7	0,12	48	1,5	0,16	0,10	2,3

*Algoa Bay A : sites south of the Swartkops River mouth
*Algoa Bay B : sites north-east of the Swartkops River mouth

the mouth of the Swartkops River are also found to contain considerably more zinc, copper and lead than had been determined for the same species growing at other locations on the South African coast. Again the results of a survey of this river indicate the presence of four areas of contamination by metals (Watling and Watling, 1982 *b*). Oysters collected at Woody Cape (site 68) do not contain elevated metal concentrations.

The relative differences between the levels of metals in molluscs from the three study areas are indicated clearly by the distribution of metals in *C. margaritacea*. Concentrations of zinc, copper and lead, three commonly occurring anthropogenic metals in the south-eastern Cape, are between five and ten times greater in the samples from the Algoa Bay A area than from the other areas. (Table 3).

The brown mussel *Perna perna* has also been collected from several sites in each bay. Metal concentrations in the suite of samples from Mossel Bay are variable with only a suggestion of lead and chromium accumulation at Mossel Bay harbour and of chromium accumulation near Little Brak River. There is no indication of accumulation in the samples collected from St Francis Bay. Copper, lead, zinc and chromium concentrations in *P. perna* from the mouth of the Papenkuils River are high, as might be expected. Otherwise, the differences in concentrations between the various samples are not great as in the case of the oysters and it is concluded that, for the most part, Algoa Bay is not polluted by metals. It has already been noted that metal accumulation is generally not as great in mussels as in oysters (Darracot and Watling, 1975) so that this species is perhaps less useful as an indicator of metal pollution.

Metal concentrations in seven *Patella* species are also summarised for each of the bays (Table 3). The metal concentrations differ between the species and are also variable within the same species from different sites. For example, cadmium concentrations are generally higher in *P. longicosta* than they are in *P. oculus*. These variations in metal concentrations for a single species do not seem to be related to metal concentrations in the water at that site. For example, concentrations in *P. oculus* from the mouth of the Papenkuils River are not elevated, as might be expected from the data obtained for both oysters and mussels. The problem here may be that *Patella* spp are herbivorous grazers so that metal accumulation is more likely to be related to the metal content of their substrate.

Specimens of *D. serra* and *B. rhodostoma* were also collected during the beach surveys. These species are included in the South African Marine Pollution Monitoring Programme (Cloete and Watling, 1981) but few comparative data are available. The data presented here are variable but in view of the results obtained for sediment and water analyses, it must be concluded that the metal concentrations found in these two sandy beach molluscs are normal.

The summarised data presented in this paper on the metal concentrations in molluscs collected from Mossel, St Francis and Algoa Bays are intended to complement the sediment and water analyses and to serve as a baseline for the future monitoring of these areas.

Conclusions

The southern Cape coast in the region of Mossel Bay is as yet unpolluted with respect to metals. Although there are urban developments at Mossel Bay, Hartenbos, Little Brak River, Great Brak River, Herolds Bay and a few other small holiday resorts, the discharges from these areas do not seem to have affected the coastal environment significantly. This is probably because the bay is open and strong water-current patterns sweep away the small amounts of waste materials which are introduced into the bay. Future monitoring surveys should be undertaken, possibly annually, because Mossel Bay is a growth point on the South African coast.

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

The results which have been obtained in this survey will provide a useful background against which changes in the metals status of St Francis Bay can be measured and monitored in the event that the area is developed further. They will also provide a useful comparison with the results obtained from Algoa Bay, an area which continues to be subjected to both urban and industrial developments.

Algoa Bay is relatively unpolluted with respect to metals. Five sites of metal input have been found. These are Cape Recife sewer outfall, the manganese ore dumps at Kings Beach, Papenkuils River, Swartkops River and Coega River. The Papenkuils River is the most serious of these. A detailed survey has revealed that high concentrations of nickel, lead, zinc, copper, chromium and mercury are present in sediment and water samples (Watling and Emmerson, 1981). Macrofauna is absent in the river but some molluscs living near the mouth have anomalously high tissue metal concentrations even though this area is subjected to a strong tidal sweep. Control measures are definitely required to improve the condition of this river and minimise further pollutant input to Algoa Bay.

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

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