Metal Surveys in South African Estuaries
II. Knysna River

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Abstract

On the basis of metal concentrations in water, surface sediments and sediment cores, the Knysna estuary is, as yet, relatively unpolluted. There are indications that transient anomalies occur which represent point sources of input. In addition, certain of the Knysna town drains are responsible for the input of zinc, copper, lead, nickel, cobalt and mercury to the estuary. The anomalous areas associated with these drains are small and consequently their ecological impact is slight.

Four sites of metal accumulation in the sediments which are of a more permanent nature have been identified. These are Thesen's Island point, Thesen's Island jetty, the railway bridge and the national road bridge. However, concentrations at these sites are only slightly elevated above background.

Metal concentrations in molluscs growing in the Knysna estuary have been determined and these data will serve as a baseline for the future monitoring of the area.

Introduction

The Knysna River rises in the Outeniqua Mountains. It is 60 km in length but has a small drainage basin and is tidal for the final 20 km. The tidal region, known as Knysna Lagoon, is a broad valley between sandstone and conglomerate escarpments. Two high sandstone cliffs, the Knysna Heads, constrict the valley where the estuary joins the sea (Fig. 1). The estuary reaches its greatest width of 3 km south-east of the railway bridge and the two permanent islands are situated in this region. Thesen's Island is occupied by Thesen and Company, a major wood distributor and marine timber treating business, the Knysna Oyster Company and a regional office of the Fisheries Development Corporation of South Africa. Leisure Isle is covered by a high-density housing development. Both of these islands are connected to the mainland by causeways which have aggravated siltation problems in the estuary.

The first detailed account of the ecology of the Knysna estuary was published by Day *et al.* (1952). By comparing this estuary with many others in South Africa, these authors were able to state that Knysna "has the richest fauna we have seen" and that the greatest species diversity was to be found between the Heads and Lesiure Isle where the fauna had both a marine and an estuarine component. Day (1967) further 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.

The estuary is the site of South Africa's foremost aqua culture venture, but it is also a prime area for urban development.

The aim of the present survey, carried out during several field seasons between May 1975 and August 1978, was to determine metal levels in the river and estuary. In general it is con-

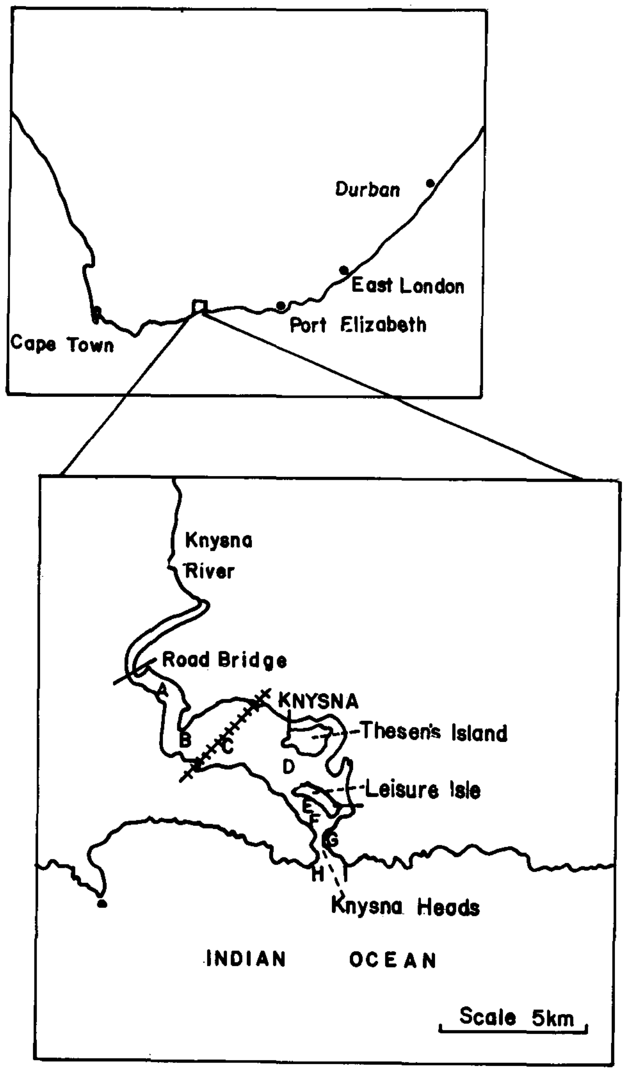

Figure 1
Map of Knysna estuary showing locations of biological samples. A, Belvedere; B, the Point; C, railway bridge; D, Thesen's Island point; E, Leisure Isle sand; F, Featherbed; G, Beacon Point; H, west Head; I, east Head

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sidered that the extent to which the three species of oysters growing in the Knysna estuary have accumulated metals is minimal (Watling and Watling, 1976). On the basis of these data, samples of several other molluscs have been collected from sites in the estuary and from the rocky shore near the Heads. The data obtained from the analysis of water, sediment and biological samples will serve as a baseline for future monitoring surveys should further industrialization or urban development take place in this region of the South African coast.

Materials and Methods

Water samples were collected at one low tide in May, 1977. Surface water samples were collected in 2,5 ℓ high-density polythene bottles. Water samples were also collected 200 mm above the bottom sediment using an NIO bottle suspended from the boat by a length of nylon steering cable. Two subsamples were separated from each bulk. These were a 500 mℓ sample, acidified with 2 mℓ nitric acid, for the determination of mercury; and a 1 000 mℓ sample for the determination of zinc, cadmium, copper, lead, iron, manganese, nickel and cobalt. Ten millilitres of a buffered solution of sodium diethyldithiocarbamate were added immediately to this sample which was then shaken for 5 min.

Approximately 500 g of a composite surface sediment was collected using an aluminium scoop. These samples were air dried between filter-paper sheets, disaggregated in a porcelain mortar and sieved through a 210 μm nylon screen. The fraction which passed through the screen was reserved for analysis.

Sediment cores were collected by hammering PVC tubes directly into the sediment. Good penetration with very little compaction of the sediment was achieved using this method. The tube was then sealed at the top using a rubber stopper and withdrawn from the sediment. Both ends of the tube containing the sediment core were sealed using polythene-covered corks and the whole sample frozen to −20°C. Frozen cores had to be stored for eight weeks but no deterioration of the sediment was observed during this period.

Molluscs were collected from the rocky shore and at a number of sites within the estuary. Living specimens were suspended in clean seawater for up to five days to allow them to purge their intestinal contents. The wet tissues were then removed from the shells and frozen in glass vials.

Detailed descriptions of the further preparation of these samples and the determination of their metal contents have been explained elsewhere (Watling and Watling, 1982).

Results and Discussion

Metals in Water

Surface and bottom water samples were collected from up to twenty-five sites at low tide during May 1977 (Fig. 2). The concentrations of nine elements in these samples are listed in Table 1.

In general, metal levels in surface waters are higher in the river, gradually decreasing towards the national road bridge, after which concentrations remain relatively constant in the rest of the estuary. However, the distributions of cobalt and mercury do not follow this pattern. Cobalt levels in the river are low, <0,3 μg/ℓ, but immediately below the national road bridge these levels increase sharply and, with few exceptions, remain approximately five times higher than the concentrations found

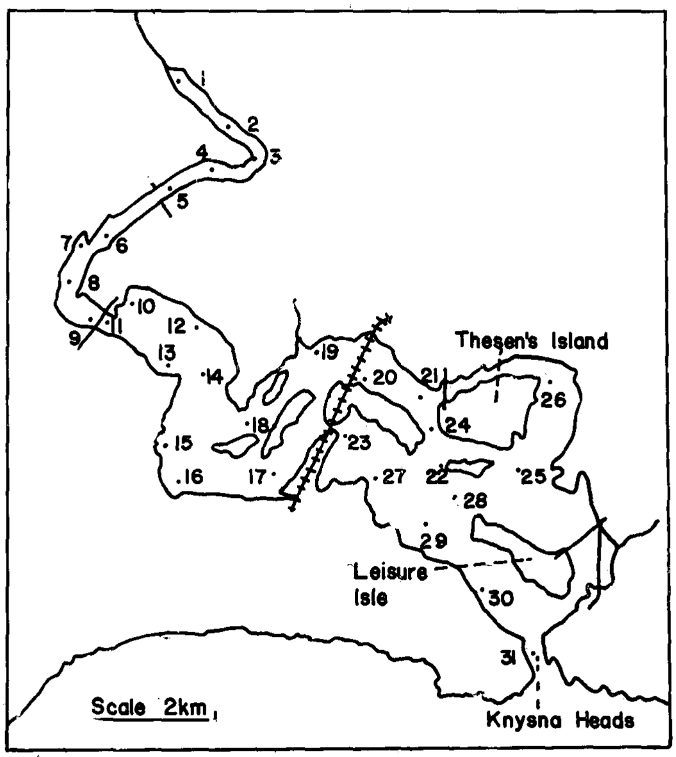

Figure 2
Map showing sampling sites for waters, surface sediments and sediment cores

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

Sample (refer Fig. 2)	Element Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Hg
1	1,9	8,1	37,0	510	39,8	0,3	0,4	0,6	0,046
2	2,4	5,1	8,5	76	10,1	0,1	0,1	3,0	0,151
3	4,7	2,1	8,3	62	11,0	0,1	0,1	0,9	0,095
4	1,7	1,5	3,3	128	16,2	0,1	0,3	1,8	0,055
5	1,8	1,1	2,1	89	13,9	0,2	0,3	1,7	0,028
6	1,5	0,9	3,1	99	13,1	0,2	0,1	0,8	0,086
8	2,5	2,4	26,0	110	16,3	0,2	1,5	10,1	0,600
9	1,5	1,1	1,4	122	3,5	0,3	0,3	4,1	0,032
10S	<0,1	2,3	0,9	164	8,4	3,7	<0,1	0,3	0,100
10B	1,9	2,1	2,2	239	7,5	2,1	0,5	0,4	0,136
12S	0,6	1,2	0,3	113	7,8	2,8	<0,1	0,1	0,041
12B	0,8	2,3	1,6	226	3,3	1,3	0,2	0,7	0,100
14S	0,2	1,7	0,3	102	6,4	1,2	<0,1	<0,1	0,100
14B	0,4	1,7	1,6	219	4,2	1,2	0,3	0,5	0,127
15S	0,2	0,2	<0,1	77	6,7	1,2	<0,1	<0,1	0,170
15B	0,4	2,3	1,3	185	4,2	0,6	0,3	0,1	0,051
16S	<0,1	0,2	0,4	94	6,3	2,2	<0,1	<0,1	0,163
16B	0,4	<0,1	1,8	219	3,6	0,5	0,1	0,4	0,061
17S	0,1	<0,1	0,1	57	5,4	1,2	<0,1	<0,1	0,125
18S	<0,1	0,6	0,3	100	5,2	0,2	<0,1	<0,1	0,131
18B	0,2	1,0	1,3	178	2,7	0,4	0,3	0,1	0,028
19S	<0,1	<0,1	0,1	74	4,7	1,6	<0,1	<0,1	0,191
19B	0,4	2,0	1,4	212	3,6	0,4	0,3	0,7	0,017
20S	0,2	0,8	0,1	51	3,9	0,6	<0,1	<0,1	0,100
20B	0,4	1,2	1,4	205	3,5	0,4	0,2	0,3	0,009
21S	0,2	0,3	<0,1	49	3,5	0,9	<0,1	0,1	0,196
21B	1,6	2,3	1,3	205	2,2	0,2	0,2	0,4	0,062
24S	0,2	0,6	<0,1	61	2,6	0,9	<0,1	<0,1	0,087
24B	4,3	1,1	1,1	178	2,0	0,1	0,6	0,2	0,010
25S	0,2	1,1	0,8	49	4,3	1,6	<0,1	<0,1	0,135
26S	0,1	0,6	0,8	150	5,4	1,2	<0,1	0,2	0,021
27S	0,2	0,3	<0,1	80	3,2	1,2	<0,1	<0,1	0,086
29S	<0,1	1,1	0,1	40	2,1	1,2	<0,1	0,1	0,125
29B	0,8	<0,1	1,7	141	1,1	0,1	0,2	0,2	0,024
30S	<0,1	1,1	0,3	56	1,9	1,6	<0,1	<0,1	0,410
30B	1,6	<0,1	1,2	160	1,2	0,2	0,2	0,1	0,038
31S	<0,1	1,1	1,0	30	2,1	0,9	<0,1	0,4	0,140
31B	1,6	1,1	1,5	129	1,1	0,1	0,5	0,5	0,021

S = Surface water sample B = Bottom water sample

in the river water. The highest levels occur below the railway bridge in that area of the Lagoon which may be said to be the most exploited commercially. It seems that these relatively high levels are indicative of an unnatural build-up of this metal but, as yet, the source has not been identified.

Mercury varies considerably over the length of the river and estuary, concentrations of up to 600 ng/ℓ being determined. The area below the railway bridge has higher mercury levels, the highest being found near Leisure Isle. It is interesting to note that mercury levels in the Swartkops estuary are consistently lower than 5 ng/ℓ (Watling and Watling, 1982), while the mean of the values obtained for Knysna water samples is 136 ng/ℓ.

In the case of the bottom waters, the results show a systematic decrease in metal concentrations towards the sea, although there are insignificant increases in lead, zinc, nickel and cadmium concentrations in the area immediately adjacent to the Heads. Specific values show very little relation to the concentrations found in the equivalent surface water. This discrepancy between concentrations in surface and bottom waters is puzzling, especially near the Heads where the strong currents should have mixed the water column totally.

In general metal levels with the exception of mercury, are low and are of the same order of magnitude as those determined for the Swartkops River (Watling and Watling, 1982).

Metals in Surface Sediments

An initial survey of the distribution of metals in the surface sediments of the Knysna estuary was undertaken in 1975 (Watling and Watling, 1977). From these data it was established that the estuary is relatively unpolluted with respect to trace metals. Isolated samples appear to have anomalously high concentrations but in many cases these can be related to specific nearby sources and are not serious.

One area which is interesting is that adjacent to Leisure

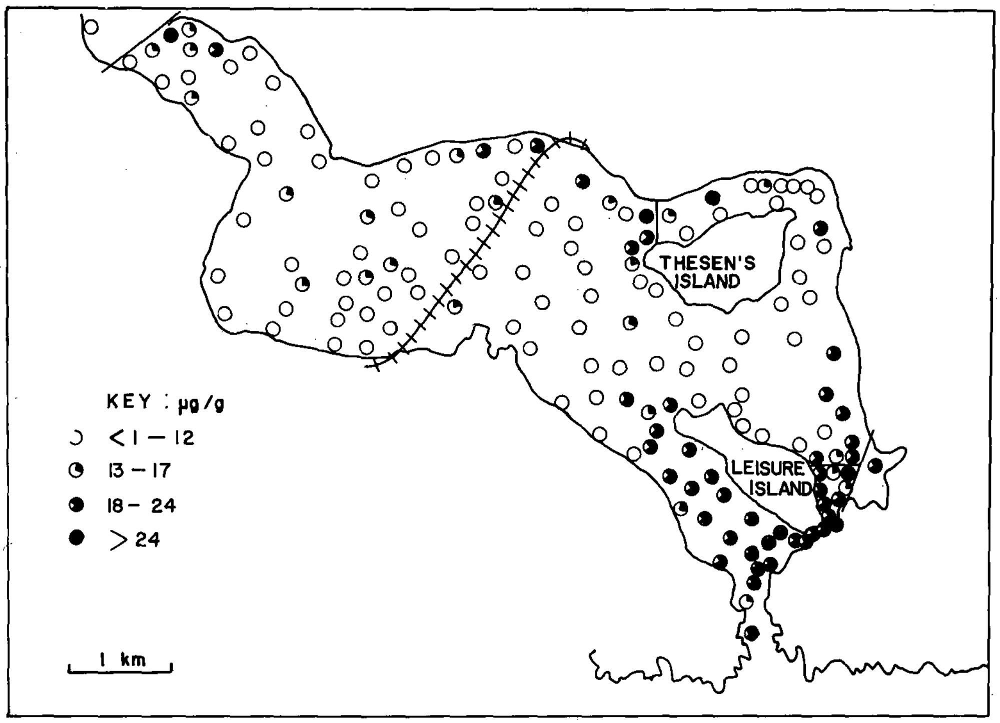

Figure 3
Lead concentrations in surface sediment samples

Isle and near the causeway where relatively high concentrations of a number of elements including lead (Fig. 3), cadmium, copper, nickel, cobalt and chromium were found in surface sediments. This is not surprising as this is an area subject to siltation and the salt marsh which has developed extends for a considerable distance. The anoxic sediments of salt marshes act as sinks for lead and other metals which are probably present in sulphide form (Chow *et al.*, 1973; Swanson *et al.*, 1972).

The most interesting study element was mercury. In the initial survey two sediment samples collected near the Point (Fig. 1) had very high mercury concentrations (Fig. 4). As this area has a large boat mooring and utilization zone it was felt that the anomaly could be the result of mercury-containing anti-fouling paints being leached from these boats. A follow-up survey was carried out one year later in which more than one hundred samples were collected and analysed for mercury and

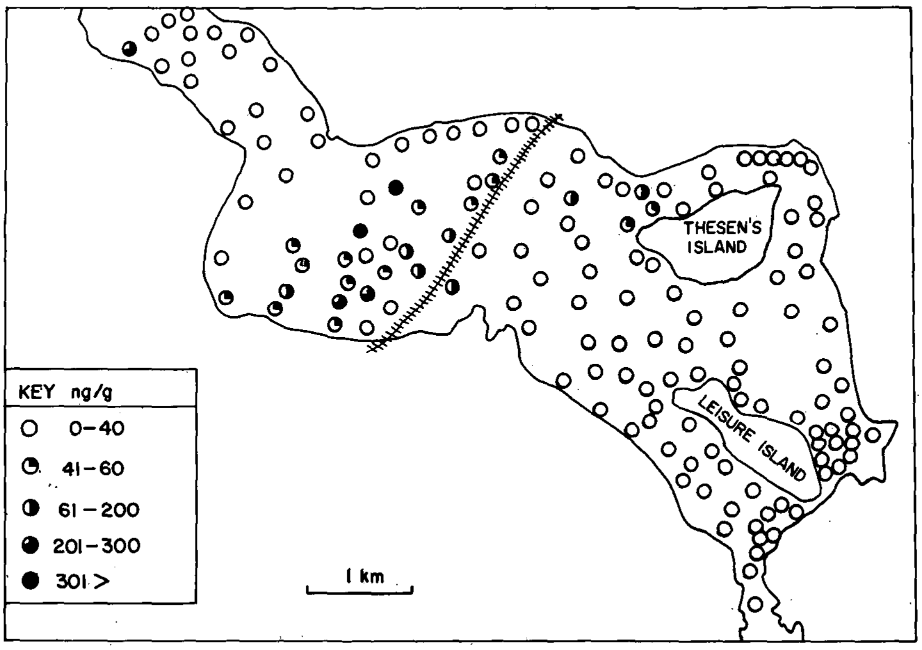

Figure 4
Mercury concentrations in surface sediment samples

TABLE 2
METAL CONCENTRATIONS (μg/g) IN DRAINAGE DITCH AND SEEPAGE SEDIMENTS

Sample (refer Fig. 5)	Zn	Cd	Cu	Pb	Ni	Co	Hg
				Element			
D1	8	0,2	2	6	3	1,2	0,005
D2	10	0,3	2	10	6	1,0	0,004
D3	9	0,1	2	6	5	0,2	0,002
D4	650	0,2	15	102	14	3,4	0,024
D5	90	0,3	10	74	13	3,0	0,128
D6	10	0,3	2	10	6	0,6	0,004
D7	12	0,1	3	8	6	0,8	0,002
D8	24	0,1	3	18	11	2,6	0,001
D9	31	0,1	5	26	23	3,2	0,005
D10	13	0,1	3	12	6	1,0	0,003
D11	20	0,6	3	10	6	1,4	0,003
D12	8	0,1	3	4	4	0,2	0,001
D13	133	0,5	60	120	12	1,8	0,020
D14	39	0,1	7	254	6	1,6	0,012
D15	19	0,1	4	20	7	1,8	0,004
D16	118	0,3	22	92	7	2,0	0,024
D17	72	0,4	10	64	6	1,2	0,039
D18	104	0,5	22	76	6	0,5	0,064
D19	11	0,3	3	7	4	2,1	0,028

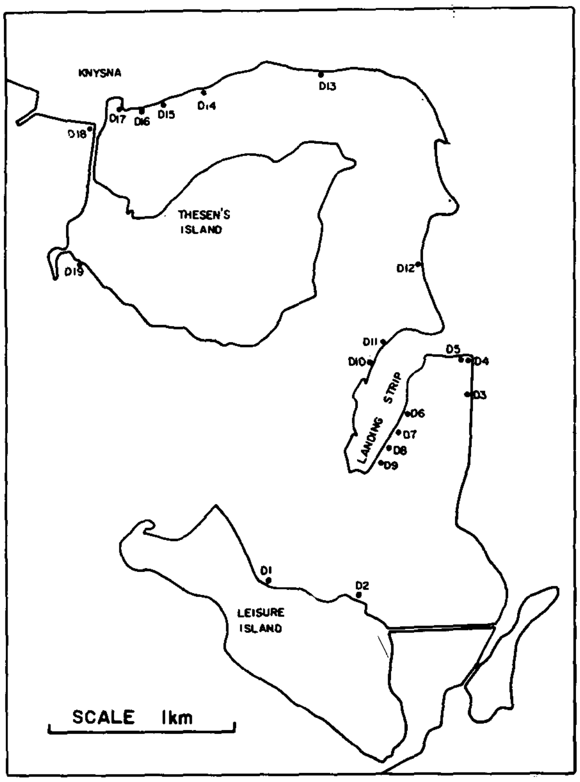

Figure 5
Map showing the locations of drains

four other elements. Metal concentrations in these samples have been reported by Watling and Watling (1980). No coherent anomaly is apparent from the results for any of the elements. Apparently the mercury anomaly was transient and its source, although not determined, does not represent a long-term pollution threat.

The results of the 1975 surface sediment survey also indicated that there was a significant input of metals to the area associated with the town of Knysna, Thesen's Island and Leisure Isle. Drainage ditch and seepage sediments were collected from the sites shown in Figure 5 and were analysed for seven elements. Metal concentrations in these samples are listed in Table 2.

The sediments from drains 4 and 5 contain elevated levels of several metals. These are probably the result of drainage and seepage from both an urban and an industrial area which are situated on the upland region to the east of Knysna Lagoon. Drain 13 is in the immediate vicinity of a caravan park but surface runoff from the outside of Knysna town contributes to the flow. Drains 14—18 are fed directly by urban runoff. Drain 14 runs through a motor repair yard and it is likely that the excessively high lead concentration in the sediment from this drain is derived directly from the old car batteries which are lying in the yard.

In general, metal levels in the drain sediments are considerably higher than those in the "normal" estuarine sediments, which is to be expected. However, the anomalous areas associated with each drain are not extensive so that, although these drains must introduce metals to the estuary, the effects of these metals are not significant to the estuary as a whole.

Metals in Sediment Cores

Twelve sediment cores were collected in 1978 from the river and estuary (Fig. 2). Metal concentrations in every core sample, together with a scale drawing and sedimentological description of the core and an interelement correlation matrix have been detailed elsewhere (Watling and Watling, 1980).

A general correlation matrix for metal concentrations in these core samples is shown in Table 3. The predominant interelement relationships are based on the clay facies elements potassium, magnesium, aluminium and chromium, while the carbonate facies elements are developed as a separate subfacies. Iron and nickel appear to be strongly attached to the clay web and it may be presumed that they coprecipitate with the clay minerals.

Geometric means for the concentrations of each element in these cores have been calculated and are listed in Table 4. These results do not provide evidence of metal build-up in the estuary and elevated metal levels are generally localised.

Four sites of metal accumulation of a relatively long-lived nature have been identified. These include Thesen's Island point (Fig. 2, site 28), very close to the Leisure Isle resort, where cadmium levels are consistently the highest found in the estuary during this survey and Thesen's Island jetty (Fig. 2, site 24), where the sedimentary sequence is one of extremely reducing grey/black silty sand which contains elevated amounts of copper, zinc, cobalt, nickel, cadmium and chromium. Lead concentrations are consistently high in the core collected from the southern land abutment of the railway bridge (Fig. 2, site 23). Increased levels of nine elements occur in the bottom half of the core collected near the national road bridge (Fig. 2, site 11) (Table 5). This suggests that there was a localised source of metals which is no longer present, perhaps related to the period

TABLE 3
CORRELATION MATRIX FOR KNYSNA SEDIMENT CORES

	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Na	K	Ca	Mg	Sr	Al	Cr
Cu	—	0,152	0,725	0,759	0,233	0,565	0,808	0,423	0,203	0,315	0,087	0,196	0,020	0,444	0,754
Pb		—	0,167	0,217	0,072	0,089	0,103	0,029	0,049	0,172	0,095	0,105	0,068	0,002	0,192
Zn			—	0,756	0,110	0,625	0,748	0,570	0,323	0,473	0,060	0,282	−0,088	0,594	0,713
Fe				—	0,234	0,751	0,893	0,463	0,347	0,485	−0,009	0,264	−0,145	0,623	0,906
Mn					—	0,336	0,218	0,212	0,158	0,238	0,326	0,485	0,028	0,273	0,288
Co						—	0,687	0,324	0,466	0,484	−0,103	0,240	−0,149	0,682	0,670
Ni							—	0,452	0,177	0,287	−0,042	0,141	−0,092	0,511	0,824
Cd								—	0,228	0,446	0,475	0,564	0,056	0,501	0,579
Na									—	0,784	0,221	0,572	0,010	0,718	0,467
K										—	0,404	0,715	0,088	0,821	0,638
Ca											—	0,796	0,568	0,195	0,242
Mg												—	0,113	0,558	0,484
Sr													—	0,016	−0,010
Al														—	0,710
Cr															—

TABLE 4
GEOMETRIC MEANS FOR METAL CONCENTRATIONS (μg/g) IN KNYSNA SEDIMENT CORES

Sample	Element														Hg
(refer Fig. 2)	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Na	K	Ca	Mg	Sr	Al	Cr (ng/g)
1	0,5	1,6	2,2	939	14	0,2	0,6	0,002	1 520	364	144	435	8	1 010	1,5	9
3	0,4	1,8	2,0	1 010	26	0,3	0,5	0,007	1 200	323	157	382	7	1 010	1,3	3
4	2,2	5,5	9,4	3 860	19	1,0	2,3	0,044	4 860	1 060	743	1 570	32	5 090	6,8	45
5	1,2	4,0	4,4	2 160	20	0,5	1,4	0,007	3 250	768	383	929	17	3 080	4,2	30
7	1,4	3,2	5,6	2 760	12	0,4	1,6	0,009	3 800	884	389	1 080	14	3 090	5,0	20
11	3,9	11,0	13,9	5 810	13	0,9	4,4	0,101	1 320	525	155	608	7	3 740	9,3	55
13	1,8	3,6	7,5	2 640	8	0,4	1,9	0,047	3 150	856	1 290	1 030	24	3 070	6,2	33
18	1,7	5,1	7,1	3 690	18	0,7	2,2	0,061	3 060	943	2 720	1 100	55	2 750	8,8	40
22	2,4	6,8	6,6	2 330	22	0,4	1,6	0,082	3 140	1 060	66 900	1 930	1 190	3 650	6,4	10
23	1,8	23,3	7,6	3 820	19	0,5	1,6	0,004	2 420	981	7 350	1 190	79	1 960	6,9	42
24	4,1	8,3	10,8	5 490	21	0,9	3,6	0,074	4 260	1 270	78	1 460	6	6 900	11,4	23
28	3,1	12,1	9,6	3 730	37	0,6	2,2	0,153	4 890	1 510	132 000	5 600	560	5 390	10,1	35

TABLE 5
METAL CONCENTRATIONS (μg/g) IN CORE 6 TAKEN NEAR THE NATIONAL ROAD BRIDGE

Sample	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Na	K	Ca	Mg	Sr	Al	Cr
1	4,0	65,6	11,8	5 280	47	1,0	2,9	0,073	9 970	892	301	2 070	18	629	8,9
2	2,6	18,8	10,2	5 470	37	1,1	2,7	0,089	11 430	1 430	485	2 200	22	6 040	9,4
3	2,2	11,3	9,4	4 500	12	0,8	2,4	0,071	6 340	937	375	1 410	17	4 750	7,2
4	1,7	6,1	6,8	4 810	5	0,6	2,2	0,058	2 270	514	154	560	8	3 270	6,5
5	1,3	5,6	4,2	360	4	0,5	1,8	0,035	1 880	376	72	470	3	3 180	4,5
6	1,8	5,8	7,1	3 830	5	0,6	2,0	0,054	2 250	549	112	631	4	4 400	5,8
7	1,5	5,4	4,3	4 600	4	0,5	1,4	0,043	1 740	537	56	460	4	3 790	4,9
8	4,1	7,6	9,8	5 880	10	0,9	2,4	0,056	2 070	672	128	868	7	6 470	6,7
9	2,9	7,2	13,7	6 570	10	1,0	3,3	0,101	1 850	656	202	925	17	5 250	7,2
10	2,1	6,6	18,0	5 800	9	0,9	9,7	0,110	773	480	104	580	8	4 860	7,7
11	3,0	14,1	13,8	7 800	15	1,0	5,2	0,096	892	624	133	631	7	5 430	10,4
12	3,2	14,8	16,2	6 340	13	1,0	3,5	0,161	985	584	211	669	12	4 750	10,2
13	2,6	8,4	27,5	6 700	12	1,2	3,7	0,211	1 010	614	147	872	13	5 640	7,4
14	8,2	11,1	44,6	4 780	8	0,8	7,0	0,337	573	566	207	509	7	5 190	7,0
15	2,8	7,3	23,6	5 500	6	0,7	4,7	0,237	314	259	56	176	3	2 240	5,7
16	17,4	11,8	22,3	16 100	42	1,5	15,6	0,158	357	270	113	290	5	2 570	26,8
17	16,3	12,7	25,8	11 800	31	1,3	13,1	0,156	364	291	188	321	5	2 810	19,3
18	18,9	26,2	25,1	15 000	40	1,8	16,2	0,100	557	415	242	389	5	3 930	30,6
19	16,8	19,4	21,8	14 900	41	1,7	13,7	0,151	503	316	167	287	4	3 090	26,4

TABLE 6
METAL CONCENTRATIONS IN MOLLUSCS FROM KNYSNA

Species: sample location and date		No		Wet mass (g)	Dry mass (g)	Zn	Cd	Cu	µg metal/g wet tissue Pb	Fe	Mn	Ni	Co	Cr
Crassostrea margaritacea														
Featherbed	1975	20	x̄	4,46	0,85	95	1,73	1,10		22	0,97			0,34
			s			27	0,37	0,20		10	0,59			0,24
Beacon Point	1975	10	x̄	2,70	0,38	322	1,34	2,5		47	0,74		0,06	
			s			228	0,35	1,6		20	0,37		0,03	
East Head	1975	5	x̄	3,55	0,52	329	2,39	3,7	0,08	42	0,92	0,32	0,06	0,43
			s											
Belvedere	1977	20	x̄	5,61	0,63	107	1,02	2,1	0,07	7	0,50	0,07	<0,02	0,26
Perna perna														
West Head	1978	40	x̄	4,70	0,69	1[illegible],6	0,70	0,90	0,05	77	0,80	1,13	0,10	0,74
			s	1,54	0,24	2,5	0,18	0,31	0,02	19	0,3[illegible]	0,49	0,03	0,20
Featherbed	1976	30	x̄	4,06		13,1	0,52	1,15	0,13	99	0,78	0,98	0,08	0,69
			s			2,7	0,18	0,30	0,10	55	0,32	0,87	0,05	0,37
Beacon Point	1978	11	x̄	3,49	0,58	15,5	0,99	1,20	0,09	66	1,05	1,51	0,12	0,63
			s	0,92	0,16	3,0	0,23	0,25	0,03	11	0,37	0,50	0,02	0,21
East Head	1978	30	x̄	4,48	0,67	12,8	0,55	0,94	0,04	64	0,73	1,21	0,07	0,76
			s	0,91	0,09	2,0	0,16	0,23	0,02	19	0,23	0,57	0,03	0,16
Venus verrucosa														
Leisure Isle sand	1978	16	x̄	5,68	1,31	3,9	0,79	1,81	0,20	123	0,98	0,66	0,34	0,84
			s	0,91	0,59	0,9	0,44	0,26	0,08	24	0,34	0,08	0,07	0,39
Mactra glabrata														
Leisure Isle sand	1975	20	x̄	10,37		12,0	1,27	1,07	0,34	111	1,10			
Solen capensis														
Thesen's Island point	1978	13	x̄	11,58	2,47	10,1	0,46	0,80	0,10	260	1,50	0,14	0,09	0,84
			s	4,26	0,93	0,9	0,09	0,15	0,05	52	0,39	0,04	0,02	0,50
Atrina squamifera														
Leisure Isle sand	1978	20	x̄	41,9	12,7	206	3,8	1,48	0,12	131	0,85	0,66	0,2[illegible]	0,97
			s	12,7	6,2	77	1,3	0,47	0,08	28	0,21	0,21	0,08	0,26
Patella granularis														
Beacon Point	1978	40	x̄	0,83	0,20	11,9	3,3	1,1	0,14	377	1,3	0,74	0,05	0,39
			s	0,24	0,05	1,7	1,0	0,2	0,08	67	0,3	0,13	0,03	0,19
Patella oculus														
Beacon Point	1978	16	x̄	5,63	1,23	10,8	2,4	0,71	0,15	379	1,07	0,56	0,09	0,62
			s	1,55	0,29	1,8	0,70	0,12	0,04	97	0,24	0,32	0,01	0,14
East Head	1978	20	x̄	6,34	1,26	8,8	3,8	0,61	0,05	177	0,71	0,23	0,03	0,83
			s	1,07	0,25	2,0	1,8	0,14	0,02	40	0,15	0,07	0,02	0,13
West Head	1978	20	x̄	11,72	2,67	8,6	4,5	0,47	0,07	143	0,80	0,18	0,10	0,73
			s	1,56	0,39	0,9	1,3	0,09	0,02	14	0,17	0,04	0,03	0,11
Patella longicosta														
Beacon Point	1978	20	x̄	4,04	0,98	11,2	7,1	0,65	0,15	121	1,07	0,54	0,09	0,74
			s	1,61	0,38	1,9	3,7	0,14	0,06	37	0,29	0,10	0,03	0,28
East Head	1978	20	x̄	5,92	1,16	12,1	11,1	0,61	0,09	89	0,83	0,25	0,06	1,01
			s	3,55	0,61	4,5	6,2	0,13	0,05	36	0,36	0,09	0,05	0,44
West Head	1978	12	x̄	4,51	0,85	10,7	11,9	0,50	0,06	53	0,57	0,15	0,08	1,07
			s	1,59	0,31	1,8	3,6	0,12	0,02	14	0,12	0,03	0,02	0,32
Patella barbara														
Beacon Point	1978	22	x̄	7,60	1,75	17,9	3,7	0,82	0,19	258	1,10	0,68	0,13	0,59
			s	2,25	0,57	3,8	0,8	0,18	0,09	53	0,25	0,18	0,04	0,12
East Head	1978	20	x̄	10,38	2,58	13,1	1,2	0,94	0,31	247	1,88	0,44	0,06	1,26
			s	9,60	2,26	3,9	0,9	0,26	0,15	91	0,89	0,17	0,02	0,44
Patella miniata														
Beacon Point	1978	14	x̄	8,76	1,88	9,9	4,0	0,93	0,12	334	8,5	0,38	0,06	0,69
			s	2,51	0,56	1,2	1,4	0,16	0,03	53	5,9	0,06	0,01	0,23
East Head	1978	6	x̄	5,30	1,09	9,0	5,1	0,72	0,04	230	1,21	0,30	0,02	1,04
			s	1,55	0,24	0,9	1,7	0,11	0,05	65	0,27	0,04	0,01	0,31
West Head	1978	4	x̄	10,68	1,83	7,9	9,8	0,61	0,04	87	0,60	0,26	0,03	0,82
Patella argenvillei														
East Head	1978	8	x̄	9,27	1,95	10,3	5,8	0,70	0,02	68	0,84	0,33	0,04	0,56
			s	2,88	0,74	2,4	1,7	0,20	0,01	9	0,33	0,11	0,01	0,14
West Head	1978	2	x̄	8,13	1,95	10,5	10,8	0,95	0,04	86	1,53	0,35	0,12	0,28
Patella cochlear														
Beacon Point	1978	4	x̄	3,84	0,99	7,1	3,9	0,88	0,09	123	1,66	1,01	0,09	0,71
East Head	1978	10	x̄	3,14	0,72	10,0	7,2	0,75	0,05	106	1,05	0,41	0,07	1,40
			s	1,29	0,32	1,7	1,9	0,09	0,03	12	0,23	0,05	0,04	0,27
West Head	1978	10	x̄	3,00	0,57	8,1	7,5	0,52	0,03	91	0,56	0,28	0,06	1,29
			s	0,35	0,05	0,9	2,1	0,12	0,02	11	0,21	0,11	0,04	0,08

x̄ mean s standard deviation

during which the bridge was under construction. In addition, lead concentrations increase dramatically in the top few samples from this core. This may be due to the proximity of the national road, the lead being derived from motor exhausts containing organo-lead fuel additives.

On the whole there do not appear to be any significant areas of mercury build-up although one or more sources of this element must exist for the concentrations determined for Knysna sediment samples to be well above background over such a wide area. The mercury source need not, however, be a direct result of contamination by man.

Metals in Biological Samples

Concentrations of nine elements in the wet tissues of molluscs collected in the Knysna estuary are given in Table 6.

Metal concentrations in *Crassostrea gigas* and *Ostrea edulis* grown at Belvedere are low (Watling and Watling, 1976). Therefore it may be assumed that concentrations in *Crassostrea margaritacea* from the same site will also represent background levels. Metal concentrations in *Perna perna* collected from a number of sites in the estuary are average when compared with levels determined for this species growing at other sites on the South African coast (Watling and Watling, 1979). The accumulation of metals by *C. margaritacea* and *P. perna* has been demonstrated in laboratory experiments (Watling, 1978). As metal concentrations in specimens collected during the present survey are low, we may assume that the Knysna estuary is unpolluted with respect to metals.

Several other bivalves and gastropods were also collected. The metal concentrations in these vary greatly between species and some apparently high values are observed. Few published data are available for comparison with these values. However, in view of the relatively low levels already determined for the oysters and mussels, it is expected that, with the possible exception of cadmium, the values obtained for these molluscs growing in and near the Knysna estuary represent near background levels.

Potential biological monitors for metals in 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). Metal concentrations in selected species of molluscs occurring along the coastline are being determined in several laboratories as part of the National Marine Pollution Monitoring Programme. The use of certain biological species 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 pollutant input, even if this is intermittent, as they provide an integrated measure of the trace metal load of a water mass. The data obtained during the present survey will serve as a baseline for the future monitoring of the Knysna estuary.

Conclusions

On the basis of metal levels in water, surface sediment and sediment cores, the Knysna Lagoon is as yet relatively unpolluted. There are indications that transitory anomalies do occur and may represent point sources of input. However, it should be noted that not all transitory anomalies are of man-made origin and natural fluctuations in background concentrations of trace metals do occur. Such natural fluctuations could be particularly noticeable in the unpolluted environment of the Knysna River. Man is however, responsible for the input of certain heavy metals into the area and of particular interest in this respect is the mercury anomaly near the Point which has been discussed. In addition, certain of the town drains are sources of zinc, copper, lead, nickel, cobalt and mercury. The anomalous areas associated with these drains are small, however, so that their im pact on the ecology of the estuary is of minimal significance.

Four sites of metal accumulation in the sediments of a more permanent nature have been located from the results. These are Thesen's Island point, Thesen's Island jetty, the railway bridge and the national road bridge. However, metal concentrations at these sites are only slightly elevated above background and do not represent significant metal inputs.

Metal concentrations in *C. gigas* and *O. edulis* from the Knysna estuary are much lower than many of the reported values for these species which indicates that Knysna estuary is unpolluted with respect to zinc, cadmium, copper, iron, manganese and nickel. Metal concentrations in other molluscs growing in or near the Knysna estuary are generally low and it is assumed that these values represent near natural levels for the indigenous species.

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References

CHOW, T.J., BRULAND, K.W., BERTINE, K., SOUTAR, A., KOIDE, M. and GOLDBERG, E.D. (1973) Lead pollution, records in southern California coastal sediments. *Science* **181** 551.

DARRACOTT, A. and WATLING, H. (1975) The use of molluscs to monitor cadmium levels in estuaries and coastal marine environments. *Trans R. Soc. S. Afr.* 41 325.

DAY, J.H., MILLARD, N.A.H. and HARRISON, A.D. (1952) The ecology of South African estuaries. Part III. Knysna: a clear open estuary. *Trans R. Soc. S. Afr.* 33 367.

DAY, J.H. (1967) The biology of Knysna estuary, South Africa. In: *Estuaries* edited by G.H. Lauff, Washington, American Association for the Advancement of Science, p.397.

SWANSON, V.E., LOVE, A.H., FROST, I.C. (1972) Geochemistry and diagenesis of tidal-marsh sediment, Northeastern Gulf of Mexico. *U.S. Geol. Survey Bull.* 1360.

WATLING, H.R. (1978) Selected molluscs as monitors of metal pollution in coastal marine environments. Unpublished PhD thesis, University of Cape Town.

WATLING, H.R. and WATLING, R.J. (1976) Trace metals in oysters from Knysna estuary. *Mar. Pollut. Bull.* 3 45.

WATLING, H.R. and WATLING, R.J. (1979) Metal concentrations in *Perna perna* from the southern African coast. *S. Afr. J. Sci.* **75** 371.

WATLING, R.J. and WATLING, H.R. (1977) Metal concentrations in surface sediments from Knysna estuary. CSIR Special Report FIS 122, Pretoria, National Physical Research Laboratory, CSIR.

WATLING, R.J. and WATLING, H.R. (1980) Metal surveys in South African estuaries II. Knysna estuary. CSIR Special Report FIS 203, Pretoria, National Physical Research Laboratory, CSIR.

WATLING, R.J. and WATLING, H.R. (1982) Metal surveys in South African estuaries. I. Swartkops River. *Water SA* 8(1)