TRACE ELEMENT CONCENTRATIONS IN TROPICAL MARINE FISH AT BOUGAINVILLE ISLAND, PAPUA NEW GUINEA

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Abstract. Baseline trace element concentrations have been measured in eight species of marine fish from Bougainville Island, Papua New Guinea. This is the first stage in an assessment of environmental impact associated with mining operations.

In general, concentrations of Cu, Pb, Zn, Cd, Hg, and As in edible portions of the fish comply with Australian National Health and Medical Research Council public health standards. Two species of shark contained As concentrations in muscle tissue in excess of prescribed standards. Increased concentrations of Cu, Zn, and Cd were recorded in liver and kidney, but Hg and Pb were not preferentially accumulated in these organs.

The relationship between the size of fish and metal assay was investigated. Mercury content and weight of fish were always positively correlated but concentrations of other metals were variably correlated with size.

1. Introduction

Although several baseline studies have been conducted to assess levels of heavy metals in marine fish, most of these investigations report information from cool temperate (Bloom and Ayling, 1977; Eustace, 1974), Mediterranean (Gilmartin and Revelante, 1975; Bernhard, 1978), and warm temperate areas (Bebbington *et al.*, 1977; Brooks and Rumsey, 1974). Only limited data are available for the high Arctic (Bohn and Fallis, 1978) and tropical maritime regions (Taylor and Bright, 1973). Records of Hg concentrations in marine fish are available for the tropical Indian Ocean (Mensaveta and Siriyong, 1977) and Papua New Guinea (Sorentino, 1979). However there are few, if any, records of other heavy metals in fish from Pacific equatorial regions.

Because of the increasing awareness of the dangers of heavy metals in the marine environment (Krenkel, 1975; Ruivo, 1972), there is a growing need for such information as industrial development proceeds in tropical third world countries. Environmental disturbances associated with mineral extraction ventures are of particular importance.

This investigation is part of an extensive study of an open cast prophyry copper mining operations situated 6° S, 155° E on Bougainville Island, Papua New Guinea where, by agreement with the Government, marine tailings disposal is conducted.

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The purpose of the present study is to obtain information about natural background concentrations of heavy metals in marine fish as a first stage in evaluating mining influences. The data also satisfy a requirement for information regarding heavy metal levels in marine teleosts from the tropical Pacific Ocean.

2. Methods and Materials

Fish were collected from three sites on the east coast of the Island (Figure 1) using 10 cm mesh surface gill nets. Four sampling days were spent at each site and on each day, nets were set at 1200 h and fished at 1800 h, 2400 h, and 0600 h the following day. Captured fish were placed immediately on ice, transported to the laboratory each morning, identified to species and the standard length and weight of individual fish recorded. A sample of edible muscle tissue was dissected from the dorso-lateral musculature beneath the dorsal fin or each fish (Brooks and Rumsey, 1974) skinned, washed in distilled water, wrapped in aluminum foil and frozen prior to analysis. The liver, kidney, reproductive organs and second branch of the right hand gill arch were also removed and similarly preserved.

To determine concentrations of Cu, Pb, Zn, and Cd in muscle tissue and organs, a known weight of thawed tissue was digested in a 250 ml conical flask with a mixture of analytical grade nitric and perchloric acids. The digestion was assisted by fitting an air condenser which provided refluxing conditions. For varying sample weight, the acid proportions and final volumes are tabulated below:

Sample weight	ml $HClO_4$ added	ml HNO_3 added	Vol. remaining after evap. ml	ml water added	Final volume
20 g ± 0.5	10	25	5	95	100
10 g ± 0.2	5	12	2	48	50
5 g ± 0.1	5	12	2	23	25
< 5 g	5	12	2	23	25

The aqueous digest was analyzed directly using a Perkin-Elmer 603 flame atomic absorption spectrophotometer with background correction. Small organs were analyzed whole while larger ones were homogenized and a representative sample weighed and digested for analysis.

For the determination of total Hg, samples were dissolved in nitric acid at room temperature to prevent loss of methyl Hg. When the digestion was complete, organic matter together with organic Hg compounds were decomposed by addition of potassium permanganate solution. Excess permanganate and manganese oxide were reduced by the addition of hydroxylamine hydrochloride. The Hg^{2+} was reduced to metallic Hg with stannous chloride prior to determination of total Hg by flameless atomic absorption spectrophotometry.

Arsenic concentrations were determined by digesting samples in a mixture of nitric,

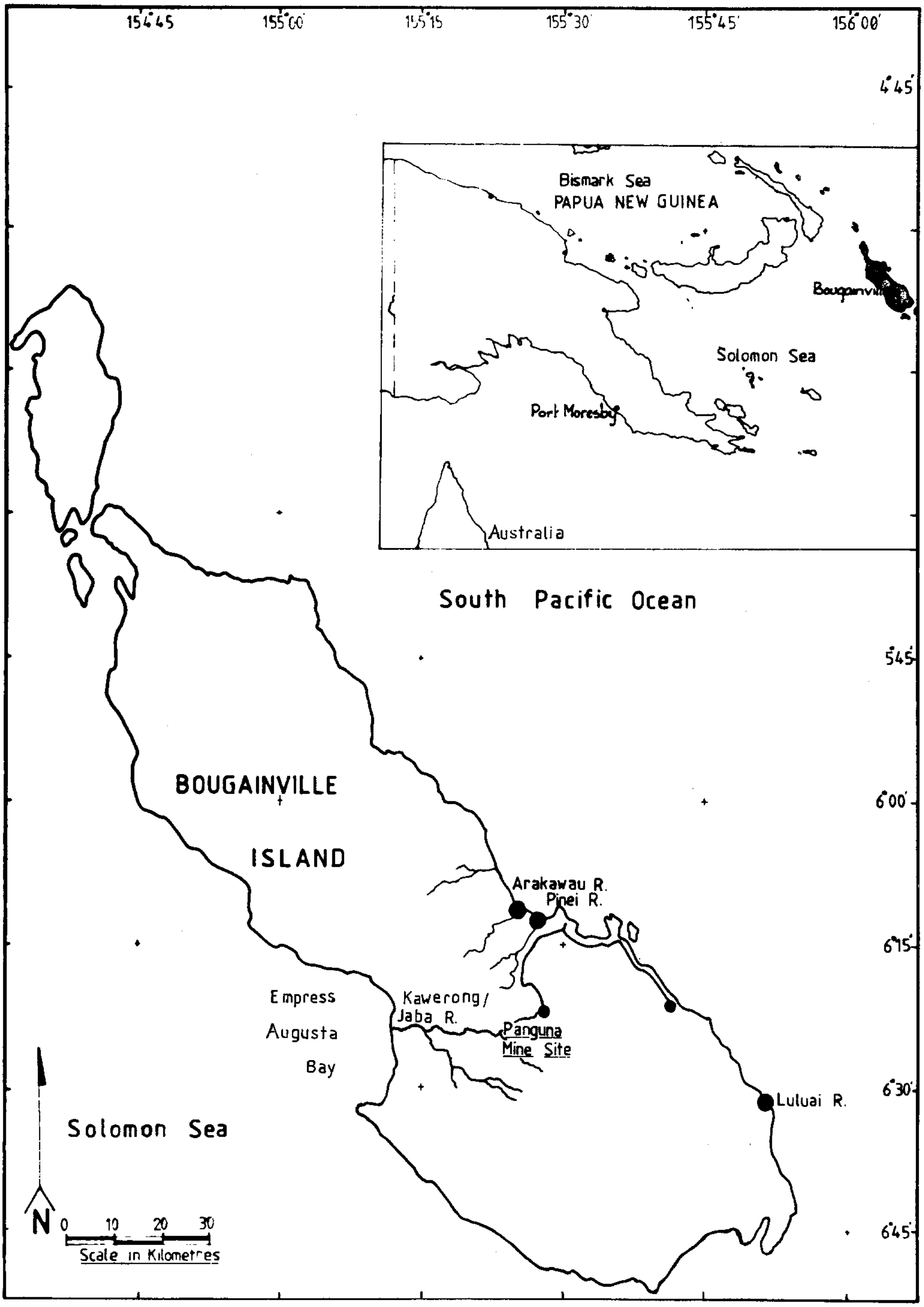

Fig. 1. Fish collection sites for trace element analysis.

perchloric and sulphuric acids. Nitric and perchloric acids were then removed by fuming and, after dilution, As was reduced to the trivalent state by addition of potassium iodide and stannous chloride solution. Zinc was added to the solution liberating arsine and hydrogen. These gases were passed through a hydrogen sulphide scrubber and then bubbled through a solution of silver diethyl-dithiocarbamate dissolved in pyridine. Here the arsine formed a soluble red complex having an absorption maximum of 540 nm. The plot of absorbance versus (μg) As is linear in the range 0 to 25 μg As. Determinations were conducted on a Bausch and Lomb Spectronic 70 spectrophotometer.

Detection limits for the various elements are tabulated below:

Element	Detection limit ($mg\ kg^{-1}$)	Standard deviation ($mg\ kg^{-1}$)
As	0.1	0.4 at 2 $mg\ kg^{-1}$
Hg	0.02	0.04 at 3 $mg\ kg^{-1}$
Zn	0.2	0.2 at 5 $mg\ kg^{-1}$
Cu	0.01	0.06 at 0.3 $mg\ kg^{-1}$
Pb	0.1	0.06 at 0.07 $mg\ kg^{-1}$
Cd	0.01	0.01 at 0.02 $mg\ kg^{-1}$

The accuracy of the methods was verified by analyzing the National Bureau of Standards Bovine Liver sample, No. 1577 for Cu, Pb, Zn, and Cd. Four replicate determinations were conducted for each of Cu and Zn while two determinations were conducted for each of the metals Cd and Pb. Two reagent blanks were included with each determination. The results are summarized below:

	Cu	Pb	Zn	Cd
NBS listed value ($mg\ kg^{-1}$)	193 ± 10	0.34 ± 0.08	130 ± 10	0.27 ± 0.04
Bougainville Copper Ltd. Analytical Laboratory ($mg\ kg^{-1}$)	183	0.4	127	0.24

3. Results and Discussion

Results of muscle tissue analyses are summarized in Table I while concentrations of heavy metals in selected organs are shown in Table II.

Various measures of central tendency have been previously quoted to express this kind of data; for example, arithmetic mean (Bohn and Fallis, 1978), geometric mean (Brooks and Rumsey, 1974) and median (Eustace, 1974). In the present survey, the Kolomogorov-Smirnoff Statistic (D max) and the moment statistics (g_1) and (g_2) were computed to test whether the 295 data sets deviated significantly from normality.

Results showed that 191 sets were normally distributed and the arithmetic mean is tabulated in these instances as a measure of central tendency. Transformation of the non-normal sets showed that 25 were log-normally distributed and the geometric mean is appropriately quoted for these cases. For the remaining 79 sets, the median is tabulated.

The degree of association between weight and metal assay was measured by computing Spearman Rank correlations for the 108 muscle data sets and the 196 organ data sets. Results are summarized in Tables III and IV, respectively.

3.1. Heavy metals in muscle tissue

Examination of Table I shows that for muscle tissue, concentration differences among sites and species with respect to each metal are numerically quite small. In the case of Cu, concentrations are generally higher at the Pinei River site compared with other sites but no attempt has been made in this paper to statistically compare sites or species. This will be done subsequently as part of an assessment of the effect of mining operations on metal concentrations in fish.

Eustace (1974) showed that the muscle tissue of bony fish (Teleostomi) contained higher concentrations of Cu and Zn than the muscle tissue of sharks (Elasmobranchii). A similar pattern was found for Cu in the present survey. The bony fish *Chorinemus tala, Caranx ignobilis* and *Chorinemus toloparah* contained higher levels of Cu than the sharks *Carcharhinus limbatus, Rhizoprionodon acutus* and *Sphyrna lewini*. However concentrations of Zn were similar for all species as were concentrations of Pb and Cd.

The sharks *C. limbatus* and *S. lewini* contained the highest levels of Hg while the sharks *R. acutus* and *S. lewini* were highest in As. The Hg levels recorded for *C. limbatus* in the present study (0.20 to 0.27 mg kg^{-1}) are slightly less than the mean concentration recorded for the same genus from the west coast of Bougainville Island (0.33 mg kg^{-1}; Sorentino, 1979) where mine tailings are discharged.

For each metal, the ranges in central tendency measures for all species are shown in Table V and compared with results of previous studies together with Australian National Health and Medical Research Council Standards for edible seafoods.

It is interesting to note that results of the present survey are similar to those from other geographical areas and compare favorably with health standards.

Clearly As is the exception, and levels recorded for the milk shark *R. acutus* exceed the standard by a factor of three. However, the range in central tendency measures for the bony fish is 0.4 to 1.5 mg kg^{-1} which complies with the public health standard.

High levels of As in fish have been recorded by Bebbington *et al.* (1977) for marine fish off the N.S.W. coast of Australia and by Bohn and Fallis (1978) in high Arctic regions. Arsenic is commonly associated with pyritic mineralization (Portmann, 1972a) and in the present survey, elevated levels in fish resulting from leaching of metal anomalies on the island are to be expected.

However, Cannon *et al.* (1977) have shown that As occurs as arsenobetaine in the Australian dusky shark *Carcharhinus obscurus*. The stability of this form and the fact that it is excreted unchanged by humans reduces its toxicological importance.

TABLE I

Concentrations of trace elements in muscle tissue of eight species of marine fissh from Bougainville Island (mg kg^{-1} wet weight)

Species	Site	Cu			Pb			Zn		
		Mean	Absolute range	*n*	Mean	Absolute range	*n*	Mean	Absolute range	*n*
Chorinemus tala	P	0.67	0.20–1.20	40	0.1**	0.1–0.5	40	3.9	2.2–5.6	39
	A	0.45*	0.14–2.65	37	0.2**	0.1–0.5	37	3.5	2.4–4.6	37
	L	0.59	0.35–0.92	9	0.2	0.1–0.3	9	3.4	2.6–4.4	9
Polydactylus indicus	P	0.39	0.20–0.85	8	0.3	0.1–0.6	8	3.8	2.5–4.8	8
	A	0.28	0.18–0.65	8	0.1	0.1–0.3	8	3.0	2.1–4.1	8
	L	0.27	0.09–0.78	54	0.2**	0.1–0.5	54	3.0**	2.4–7.6	54
Trachinotus bailloni	P	0.46	0.18–1.00	35	0.1**	0.1–0.8	35	3.7	2.3–5.9	36
	A	0.35	0.09–0.95	57	0.1**	0.1–0.5	59	3.5*	1.9–6.0	59
Caranx ignobilis	P	0.52	0.13–1.30	36	0.1**	0.1–0.6	36	3.6	2.8–6.4	36
	A	0.41	0.20–0.80	17	0.2	0.1–0.4	17	3.4	2.1–6.0	17
Chorinemus tolooparah	P	0.57	0.35–0.89	5	0.1	0.1–0.1	5	4.5	3.9–5.1	5
	A	0.45	0.34–0.60	9	0.1	0.1–0.2	9	3.7	3.0–4.2	9
Carcharhinus limbatus	P	0.39*	0.13–1.60	34	0.1**	0.1–0.6	35	3.4	2.3–6.7	40
	A	0.31*	0.06–1.55	70	0.2**	0.1–0.8	70	3.3	2.5–5.4	70
	L	0.32*	0.15–1.25	88	0.2**	0.1–0.6	88	3.2**	2.6–5.9	88
Rhizoprionodon acutus	A	0.35	0.11–1.10	21	0.1**	0.1–0.5	21	3.3	2.5–3.8	21
	L	0.33*	0.12–2.55	44	0.2**	0.1–0.8	45	3.3**	2.6–7.0	45
Sphyrna lewini	A	0.32	0.18–0.63	11	0.2	0.1–0.6	11	3.7	3.1–5.7	11
	L	0.47	0.24–1.20	11	0.2	0.1–0.3	10	3.9	3.4–4.9	10

Key to Species: C. tala – Queen Fish; P. indicus – Threadfin Salmon; T. bailloni – Trevally; C. ignobilis – Turrum or Trevally; C. tolooparah – Trevally; C. limbatus – Spinner Shark; R. acutus – Milk Shark; S. lewini – Hammerhead Shark.

TABLE II

Concentration of trace elements in selected organs of five species of marine fish from Bougainville Island (mg kg^{-1} wet weight)

Organ	Species	Site	Cu			Pb		
			Mean	Absolute range	*n*	Mean	Absolute range	*n*
Liver	C. tala	P	11.7	3.8–44.0	36	1.0**	1.0–4.0	36
		A	9.8	1.2–23.0	35	1.0**	1.0–7.0	35
		L	9.1	4.4–14.6	10	1.0**	1.0–2.0	10
	P. indicus	P	9.5	4.8–15.0	7	1.0	1.0–1.0	7
		A	10.4	4.7–22.0	7	1.0**	1.0–4.4	7
		L	7.2	1.5–30.0	50	1.0**	1.0–4.0	50

Cd			Hg			As			Size range weight (g)
Mean	Absolute range	*n*	Mean	Absolute range	*n*	Mean	Absolute range	*n*	
0.01**	0.01–0.23	40	0.11	0.03–0.47	27	0.6	0.2–0.9	14	210–1312
0.01**	0.01–0.04	38	0.16	0.04–0.36	37	0.7	0.1–1.3	33	193–743
0.01	0.01–0.01	9	0.17	0.08–0.27	8	0.7	0.5–1.0	4	264–492
0.02*	0.01–0.46	8	0.10	0.02–0.24	7	0.7	0.2–1.8	7	510–4280
0.01**	0.01–0.03	8	0.09	0.05–0.21	8	0.7	0.3–1.8	8	526–1762
0.01	0.01–0.03	53	0.15	0.04–0.40	54	0.4*	0.1–2.1	53	345–3660
0.02**	0.01–0.12	35	0.04*	0.02–0.50	32	1.5	0.5–5.2	21	182–363
0.01**	0.01–0.11	59	0.04**	0.02–1.10	59	1.4	0.2–4.3	56	185–481
0.01**	0.01–0.32	36	0.03*	0.01–0.92	26	0.7	0.4–1.2	13	237–2155
0.01**	0.01–0.02	17	0.04	0.01–0.11	17	0.7	0.2–1.8	15	312–2480
0.10	0.01–0.42	5	0.03	0.02–0.04	3	0.6	0.4–0.7	3	476–1576
0.01	0.01–0.01	9	0.06	0.03–0.09	9	0.7	0.5–0.9	9	456–880
0.02**	0.01–0.05	41	0.24	0.01–0.83	40	1.8	0.8–4.0	24	652–6000
0.01**	0.01–0.04	38	0.27*	0.02–2.10	69	1.8	0.2–4.1	68	510–35550
0.01**	0.01–0.01	9	0.20*	0.02–1.30	86	1.8*	0.9–5.3	82	904–43230
0.01**	0.01–0.05	21	0.10*	0.02–1.70	21	3.4	0.9–6.1	15	210–2676
0.01**	0.01–0.33	44	0.07**	0.02–2.00	43	3.5	0.8–7.5	39	193–2723
0.01	0.01–0.01	11	0.39	0.06–1.70	11	2.6	0.9–4.0	10	468–27490
0.01**	0.01–0.03	10	0.44	0.03–1.40	9	2.5	0.7–5.4	8	490–31750

Key to Sites: P – Pinei River; A – Arakawau River; L – Luluai River.
* geometric mean quoted
** median
Elsewhere the arithmetic mean is tabulated.

Zn			Cd			Hg			Size range weight (g)
Mean	Absolute range	*n*	Mean	Absolute range	*n*	Mean	Absolute range	*n*	
39.7*	27–102	38	3.1*	0.2–34.0	36	0.09	0.02–0.20	5	210–1312
39.7	9–69	35	4.3	0.2–10.0	35	—	—	—	193–743
30.1	18–38	10	3.7	1.6–6.1	10	—	—	—	264–492
36.3	27–46	7	5.9	2.6–9.0	7	0.20	0.07–0.50	5	510–4280
38.6	28–50	7	5.4	1.1–8.2	7	—	—	—	526–1762
40.8	17–74	50	6.1	0.1–19.0	50	0.25	0.02–0.53	34	345–3660

TABLE II (cont.)

Concentration of trace elements in selected organs of five species of marine fish from Bougainville Island (mg kg^{-1} wet weight)

Organ	Species	Site	Cu			Pb		
			Mean	Absolute range	*n*	Mean	Absolute range	*n*
	T. bailloni	P	15.2	0.9–72.0	34	1.0**	1.0–5.5	34
		A	12.3	2.1–55.0	56	1.0**	0.9–23.4	54
	C. ignobilis	P	9.2	1.3–21.0	32	1.0**	1.0–3.0	32
		A	9.2	3.7–18.0	15	1.0**	1.0–2.0	15
	C. tolooparah	P	3.4	1.9–4.8	3	1.0	1.0–1.0	3
		A	8.8	4.4–14.0	9	1.0	1.0–1.0	9
Kidney	C. tala	P	3.4	1.3–7.4	21	1.0**	1.0–7.0	21
		A	3.7	0.8–7.7	31	1.0**	1.0–9.0	31
		L	3.7	1.4–5.8	8	1.9	1.0–5.0	8
	P. indicus	P	2.8	0.4–7.5	6	1.3	1.0–2.0	6
		A	3.4	2.3–5.2	8	1.0	1.0–1.0	8
		L	3.4	1.0–7.3	45	1.0**	1.0–4.0	45
	T. bailloni	P	3.7	1.0–9.2	9	2.1	1.0–4.0	9
		A	3.8	0.8–11.0	24	1.2**	1.0–22.0	24
	C. ignobilis	P	2.7	0.7–5.0	12	1.0**	1.0–4.0	12
		A	3.5	2.6–5.2	10	1.0**	1.0–6.0	10
	C. tolooparah	P	4.7	3.3–6.6	4	2.8	1.0–5.0	4
		A	4.6	1.9–7.9	6	1.0**	1.0–1.0	6
Gills	C. tala	P	1.7	0.5–6.3	35	1.0**	1.0–6.0	35
		A	1.3	0.4–2.3	29	1.0**	1.0–9.0	30
		L	1.6	0.4–3.0	10	1.4	1.0–3.0	10
	P. indicus	P	1.3	0.2–2.2	6	1.3	1.0–2.0	6
		A	0.8	0.2–2.1	8	3.0	2.0–5.0	8
		L	1.1	0.2–2.5	35	1.0**	1.0–3.8	35
	T. bailloni	P	1.8	0.5–5.0	32	1.0**	1.0–10.0	32
		A	1.9	0.3–8.3	56	2.0**	1.0–10.0	56
	C. ignobilis	P	1.2	0.2–3.2	39	1.0**	0.5–5.0	39
		A	1.3	0.2–3.1	13	1.6	1.0–5.0	11
	C. tolooparah	P	1.8	1.3–2.4	3	2.0	1.0–3.0	4
		A	1.5	0.3–4.0	9	1.0**	1.0–2.0	9
Reproductive organ	C. tala	P	1.7*	0.8–6.3	34	1.0**	1.0–5.0	35
		A	1.4**	0.1–26.0	31	1.0**	1.0–14.0	32
		L	1.6	0.8–3.6	10	1.0**	1.0–2.0	10
	P. indicus	P	1.9	0.1–3.0	6	1.0	1.0–1.0	6
		A	1.6	0.8–3.4	8	1.5	1.0–4.0	8
		L	1.2	0.2–2.5	44	1.0**	1.0–4.0	44

Zn			Cd			Hg			Size range weight (g)
Mean	Absolute range	n	Mean	Absolute range	n	Mean	Absolute range	n	
59.9*	25–490	34	9.8	0.4–47.0	34	0.04	0.02–0.06	3	182–363
47.4*	17–320	55	7.0	0.2–34.0	55	—	—	—	185–481
44.9	23–97	32	1.2	0.5–4.6	32	0.04	0.02–0.10	13	237–2155
43.1	25–66	15	0.9	0.4–2.2	15	0.09	0.02–0.18	5	312–2480
30.0	21–40	3	—	—	—	—	—	—	476–1576
46.8	36–67	9	5.5	1.9–7.6	9	—	—	—	456–880
133.3	47–330	21	2.1	0.4–6.0	21	—	—	—	293–813
116.4	23–460	31	1.8	0.2–6.3	29	—	—	—	215–743
86.4	53–115	8	1.6	0.1–2.8	9	—	—	—	264–492
39.7	27–68	6	1.8	0.1–3.4	6	—	—	—	697–4280
41.9	20–170	8	1.2	0.5–4.3	8	—	—	—	526–1762
33.4	12–88	45	1.1*	0.1–8.3	45	0.21	0.09–0.33	15	345–3660
3884.3	74–13400	9	4.6	0.3–8.3	9	—	—	—	200–356
3838.7	14–14100	24	9.5	0.8–26.0	24	—	—	—	229–330
210.3	62–1050	12	1.4	0.4–4.3	12	—	—	—	368–2155
126.0	71–200	10	0.9	0.1–2.5	8	—	—	—	366–651
1190.0	550–2000	4	5.3	0.5–17.0	4	—	—	—	600–1576
655.3	42–1100	7	1.0	0.2–2.2	6	—	—	—	456–880
25.0	16–37	35	0.1**	0.1–16.0	30	0.02	0.01–0.07	8	210–1312
23.7	14–33	30	0.1**	0.1–0.7	30	0.01	0.01–0.02	3	193–743
25.7*	18–88	10	0.1**	0.1–0.2	11	—	—	—	264–492
29.0	27–32	6	0.1	0.1–0.1	6	0.03	0.02–0.04	4	510–4280
35.1	22–44	8	0.1**	0.1–0.3	8	0.04	0.02–0.06	6	526–1762
33.9	17–45	35	0.1**	0.1–0.5	35	0.03*	0.01–0.18	34	345–3660
26.2	10–51	32	0.1**	0.1–1.3	30	—	—	—	182–363
28.6	8–66	56	0.1**	0.1–4.4	56	—	—	—	185–481
21.8*	14–42	39	0.1**	0.1–0.9	39	0.01**	0.01–0.06	23	237–2155
19.1	15–25	13	0.1**	0.1–1.0	13	0.04	0.02–0.05	3	312–2480
32.8	23–47	4	0.2	0.1–0.6	4	0.14	0.01–0.37	3	476–1576
23.4	19–30	9	0.1**	0.1–0.4	9	—	—	—	456–880
42.0*	9–305	34	0.1**	0.1–0.4	34	0.03	0.01–0.10	12	210–813
83.9	7–206	31	0.1**	0.1–3.6	28	0.02	0.01–0.03	10	193–743
59.2	11–96	10	0.1	0.1–0.1	10	0.02	0.02–0.02	5	264–492
56.5	5–120	6	0.1	0.1–0.2	6	—	—	—	510–4280
27.6	12–106	8	0.1	0.1–0.3	8	—	—	—	526–1762
39.0**	11–178	44	0.1**	0.1–0.2	44	0.04	0.01–0.10	34	345–3660

TABLE II (cont.)

Concentration of trace elements in selected organs of five species of marine fish from Bougainville Island (mg kg^{-1} wet weight

Organ	Species	Site	Cu			Pb		
			Mean	Absolute range	*n*	Mean	Absolute range	*n*
	T. bailloni	P	1.7	0.1–4.0	25	1.0**	1.0–3.0	26
		A	1.4*	0.1–6.1	47	1.0**	1.0–9.0	47
	C. ignobilis	P	2.5	1.0–4.7	10	1.0**	1.0–4.0	11
	C. tolooparah	P	0.7	0.4–1.1	3	1.0	1.0–1.0	3
		A	1.6	0.9–3.1	8	1.0**	1.0–6.0	8

Key to Species: C. tala–Queen Fish; P. indicus – Threadfin Salmon; T. bailloni – Trevally; C. ignobilis – Turrum or Trevally; C. tolooparah – Trevally; C. limbatus – Spinner Shark; R. acutus – Milk Shark; S. lewini – Hammerhead Shark.
Key to Sites: P – Pinei R.; A – Arakawau R.; L – Luluai R.

TABLE III

Spearman Rank correlation coefficients (r_s) relating weight of fish and metal assay of muscle tissue in 8 species of marine fish from Bougainville Island

Species	Site	Cu	Pb	Zn	Cd	Hg	As
C. tala	P	—	—	−0.34*	—	—	—
	A	—	—	−0.38*	—	—	—
	L	—	—	—	—	—	—
P. indicus	P	—	—	—	—	—	—
	A	—	—	—	−0.85*	—	—
	L	—	—	—	—	—	—
T. bailloni	P	—	—	—	—	—	—
	A	—	—	—	—	—	—
C. ignobilis	P	—	+0.37*	—	—	—	—
	A	—	—	—	—	—	—
C. tolooparah	P	−0.90*	—	—	—	—	—
	A	—	—	—	—	—	—
C. limbatus	P	—	—	—	—	+0.68*	—
	A	+0.25*	−0.29*	+0.25*	—	+0.48*	—
	L	—	—	+0.22*	—	+0.54*	+0.26*
R. acutus	A	—	—	—	—	—	—
	L	—	—	−0.33*	—	—	—
S. lewini	A	—	—	—	—	+0.81*	—
	L	—	—	—	—	—	—

* Significant ($\alpha \leqslant 0.05$). (+) Positive Correlation. (−) Negative Correlation.

Zn			Cd			Hg			Size range weight (g)
Mean	Absolute range	*n*	Mean	Absolute range	*n*	Mean	Absolute range	*n*	
113.8	9–245	25	0.1**	0.1–0.5	25	0.02	0.02–0.03	5	182–363
22.0**	9–213	47	0.1**	0.1–1.1	47	0.03	0.01–0.05	6	200–481
85.5	19–190	10	0.3	0.1–0.7	10	—	—	—	237–2155
94.0	18–242	3	0.2	0.1–0.2	3	—	—	—	476–1576
237.9	18–615	8	0.1**	0.1–0.3	8	—	—	—	456–880

* geometric mean quoted
** median
Elsewhere the arithmetic mean is tabulated.

TABLE IV

Spearman Rank Correlation coefficients relating weight of fish and metal assay of selected organs in 5 species of marine fish from Bougainville Island

Organ	Species	Site	Cu	Pb	Zn	Cd	Hg
Liver	C. tala	P	—	—	—	+0.36*	—
		A	—	—	—	—	—
		L	—	—	+0.73*	+0.70*	—
	P. indicus	P	—	—	—	—	—
		A	—	—	—	—	—
		L	−0.37*	—	—	−0.38*	—
	T. bailloni	P	—	—	—	—	—
		A	—	—	—	—	—
	C. ignobilis	P	+0.46*	—	+0.50*	—	—
		A	—	—	—	—	—
	C. tolooparah	P	—	—	—	—	—
		A	+0.72*	—	—	—	—
Kidney	C. tala	P	—	—	—	—	—
		A	—	—	—	+0.42*	—
		L	—	—	—	—	—
	P. indicus	P	−0.83*	+0.90*	—	+0.83*	—
		A	—	—	—	—	—
		L	−0.54*	—	−0.49*	—	+0.54*
	T. bailloni	P	—	—	+0.85*	—	—

TABLE IV (Cont.)

Spearman Rank Correlation coefficients relating weight of fish and metal assay of selected organs in 5 species of marine fish from Bougainville Island

Organ	Species	Site	Cu	Pb	Zn	Cd	Hg
		A	—	+0.49*	—	+0.48*	—
	C. ignobilis	P	—	—	+0.73*	—	—
		A	—	−0.81*	—	—	—
	C. toloopara h	P	—	—	—	—	—
		A	—	—	—	—	—
Gills	C. tala	P	—	—	−0.40*	—	—
		A	—	—	—	—	—
		L	—	—	—	—	—
	P. indicus	P	—	—	—	—	—
		A	—	—	—	—	—
		L	—	—	—	—	—
	T. bailloni	P	—	—	—	—	—
		A	−0.34*	—	—	+0.31*	—
	C. ignobilis	P	—	—	−0.41*	−0.40*	—
		A	—	—	—	—	—
	C. toloopara h	P	—	—	—	—	—
		A	—	—	—	—	—
Reproductive organs	C. tala	P	−0.38*	—	—	—	—
		A	—	—	—	—	—
		L	—	—	—	—	—
	P. indicus	P	—	—	—	—	—
		A	—	—	—	—	—
		L	—	—	—	—	—
	T. bailloni	P	—	—	—	+0.44*	—
		A	—	—	—	—	—
	C. ignobilis	P	—	—	—	—	—
		A	—	—	—	—	—
	C. toloopara h	P	—	—	—	—	—
		A	—	—	+0.74*	—	—

* Significant ($\alpha \leqslant 0.05$).
(+) Positive Correlation.
(−) Negative Correlation.

It is also important to note that there is no commercial fishery on Bougainville Island. Only subsistence fishing is conducted to provide a dietary protein supplement and sharks of various sizes are caught and consumed.

Concentrations of Cd and Hg, the metals of greatest environmental significance, are also quite low and it is concluded from these data that none of the species tested represents a danger to public health.

TABLE V

Trace element concentrations (mg kg^{-1} wet weight) in muscle tissue of various species of fish from different areas of the world

Source reference	Area	Cd	Pb	Cu	Zn	Hg	As	Species
Holden and Topping (1972)	U.K. (Firth of Forth and Firth of Clyde)	0.06–0.12	< 0.5–1.0	0.32–1.6	1.7–14.7	—	—	Mackerel, Plaice, Haddock, Herring, Whiting, Dog-fish
Taylor and Bright (1973)	Gulf of Mexico and Bahama Islands	0.01–0.09	0.05–0.73	0.23–1.15	3.17–4.0	0.05–1.09	—	4 species of Grouper
Eustace (1974)	Australia, Tasmania	< 0.05–0.06	—	< 0.25–2.1	4.6–13.5	—	—	17 species including Sharks, Cod, Flounder, Whiting, Perch, Leather-Jackets
Gilmartin and Revelante (1975)	Adriatic Sea	< 0.1	ND–1.2	0.06–1.2	—	0.04–0.21	—	Anchovy and Sardines
Brooks and Rumsey (1974)	New Zealand, East Coast, North Island	0.002–0.016	0.16–0.87	0.11–0.59	2.8–21.0	—	—	8 species including Snapper, Kingfish, Trevally, Gurnard etc.
Portmann (1972)	U.K., England and Wales	< 0.05–0.18	< 0.5–0.99	< 0.5–1.80	4.35–6.60	0.05–0.49	—	Cod, Whiting, Plaice, Herring, Mackerel
Bebbington *et al.* (1977)	Australia, N.S.W.	0.04	0.45–0.71	0.04–0.87	4.24–9.56	0.03–0.38	0.2–2.2	Commercial species including Flathead, Mullet, Snapper and Tailor
Present Survey	Papua New Guinea, Bougainville Is. East Coast	< 0.01–0.10	< 0.1–0.3	0.27–0.67	3.0–4.5	0.03–0.44	0.4–3.5	8 species including Sharks, Trevally, Threadfin
Australian National Health and Medical, Research Council Standards (1975)		2.0	2.0	30	40	0.5	1.5 (As_2O_3) 1.14 (As.)	

3.2. Heavy metals in selected organs

Examination of Table II shows that Cu concentrations in liver (3.4 to 15.2 mg kg^{-1}) exceed those in kidney (2.7 to 4.6 mg kg^{-1}) but both of these organs concentrated Cu to a greater extent than gills (0.8 to 1.9 mg kg^{-1}) and reproductive organs (0.7 to 2.5 mg kg^{-1}).

This confirms the findings of Holden and Topping (1972) with respect to Cu but not Zn or Cd.

In the present survey, as in the study conducted by Brooks and Rumsey (1974), there is evidence for preferential accumulation of Zn in the kidneys rather than the liver with concentrations ranging from 33 to 3,884 mg kg^{-1}. The highest concentrations were recorded in the trevallies *Trachinotus bailloni* (3839 to 3884 mg kg^{-1}) and *C. toloparah* (665 to 1190 mg kg^{-1}). These species also contained elevated levels of Zn in reproductive organs (*T. bailloni* (22 to 114 mg kg^{-1}) and *C. tolooparah* (94 to 240 mg kg^{-1})).

Cadmium accumulates equally in the liver (0.9 to 9.8 mg kg^{-1}) and kidneys (0.9 to 9.5 mg kg^{-1}) while concentrations in the gills and reproductive organs ranged from 0.2 to 0.3 mg kg^{-1}.

Concentrations of Pb and Hg vary only slightly; the range of central tendency among organs for all species at all sites being 1.0 to 3.0 mg kg^{-1} for Pb and 0.01 to 0.25 mg kg^{-1} for Hg.

In general, the results illustrated two broad patterns of metal distribution among the various organs. The soft organs, liver and kidney accumulated Cu, Zn and Cd while Hg and Pb were equally distributed among all organs and showed little interspecific differences. This confirms the work of other authors (e.g., Brooks and Rumsey, 1974) although Gilmartin and Revelante (1975) report marked interspecific differences with respect to Hg.

Compared to other species, the liver and kidney of the trevally *T. bailloni* contained much higher levels of Cu, Zn and Cd. The levels of Zn in the kidneys of this species (3884 mg kg^{-1}) are among the highest reported and are $\times 10$ greater than levels recorded for grouper in the Gulf of Mexico and the Caribbean (Taylor and Bright, 1973) and for various species from New Zealand (Brooks and Rumsey, 1974). This may be due to the feeding habits of the fish. On the other hand, concentrations of Cu in liver are less than those reported by the latter authors.

There are no health standards for organs but, because the liver is seldom, if ever consumed or used for oil production, these concentrations are unlikely to be a health hazard.

3.3. Metal assay and weight relationships

Examination of Table III shows that of the 108 correlations relating weight and metal assay in muscle tissue, 15 were significant ($\propto \leqslant 0.05$); 6 negatively, showing increased content in smaller fish and 9 positively, indicating higher levels in larger fish. The incidence of significant correlations in the elasmobranchs was twice that of teleosts.

One species of shark *C. limbatus* accounted for more than half of these instances with 8 significant correlations, 7 of which were positive.

Mercury was the only metal for which all correlations were positive and these occurred in the sharks *C. limbatus* and *S. lewini* confirming the work of other authors. Because the capacity of marine fish to excrete Hg is limited (Miettinen *et al.*, 1972) concentrations in the tissues increase with size or age (Menasveta and Siriyong, 1977).

Among the teleosts, inverse relationships were apparent for *Polydactylus indicus*, *C. tala*, and *C. tolooparah* for Cd, Zn, and Cu respectively. Similar results have been recorded for Cu (Brooks and Rumsey, 1974; Bohn and Fallis, 1978) and for Zn (Brooks and Rumsey, 1974).

Increased lead uptake with size was apparent for the trevally *C. ignobilis*. This result differs slightly from the work of Taylor and Bright (1973) who found very little correlation between size or age of grouper and concentrations of Cu, Pb, Cd, and As. Also unlike the result of Bohn and Fallis (1978), As content and size were unrelated in these teleosts.

Examination of Table IV shows that for selected organs, metal assay and weight relationships are significant in 28 of the 196 cases ($\alpha \leqslant 0.05$); 17 of these were positive and 11 were negative. More than half of these instances are accounted for by Cu, Zn, and Cd in the liver and kidney reflecting the general tendency for the soft organs to accumulate these metals.

These relationships will be important when comparing fish species from natural areas with those from areas influenced by mining activities.

4. Conclusions

The present baseline survey indicated that the body loads of heavy metals in marine fish taken from the East Coast of Bougainville Island do not represent a health hazard.

It is also apparent that levels of heavy metals reported in this survey are comparable with concentrations reported in the literature from widely varying geographical locations.

The liver and kidney of teleosts contained the highest concentrations of Cu, Cd, and Zn. Levels of Zn in the kidney tissue of *T. balloni* exceeded 3800 mg kg^{-1} and are among the highest concentrations recorded. Mercury and Pb were not preferentially accumulated which is consistent with previous reports.

The variables, metal content and size of fish were significantly associated in 14% of cases. Only in the case of Hg were all associations positive with larger fish containing higher concentrations of Hg.

Because coastal Papua New Guinea nationals depend on fish as a dietary supplement, it is proposed to extend this survey to assess the impact of mining operations on concentrations of heavy metals in fish.

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