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Heavy Metal Contamination in Shellfish with Emphasis on Zinc Contamination of the Pacific Oyster, *Crassostrea Gigas*.

Surveillance Report
EPS 5 - PR - 76 - 2

Pacific Region
January, 1976

el 7012974 F

HEAVY METAL CONTAMINATION IN SHELLFISH WITH EMPHASIS ON ZINC CONTAMINATION OF THE PACIFIC OYSTER, *CRASSOSTREA GIGAS*

by

H. Nelson and D. Goyette

Pollution Abatement Branch
Environmental Protection Service
Pacific Region

Report Number EPS 5-PR-76-2
January, 1976

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ABSTRACT

A shellfish heavy-metal monitoring program was conducted in 1973 in those coastal areas of British Columbia where the pulp and paper industry is involved in groundwood bleaching. A brightening agent in the bleaching process resulted in a considerable amount of zinc entering receiving waters and the biosphere. The bioaccumulation of zinc by the Pacific oyster prompted the industry to convert to a new bleaching compound which would largely eliminate zinc from the effluent discharges.

The monitoring program showed the degree of heavy-metal contamination in shellfish and sediments, and obtained background information for future use in determining heavy-metal depletion rates and recovery time of the marine system.

RÉSUMÉ

En 1973, on a entrepris un programme pour contrôler les effets des métaux lourds sur les crustacés dans les eaux côtières de la Colombie-Britannique où l'industrie des pâtes et papier fait le blanchiment de pâtes mécaniques. Par suite de l'emploi d'un agent de brillance dans le procédé de blanchiment, une quantité considérable de zinc pénétrait les eaux réceptrices et la biosphère. L'absorption à dose massive du zinc par les huîtres du Pacifique a incité la direction de l'industrie du papier à utiliser un nouveau composé de blanchiment qui éliminerait en grande partie la présence du zinc dans l'effluent de l'usine.

Le programme a révélé l'intensité de la contamination subie par les crustacés et les sédiments sous l'action des métaux lourds et a fourni des renseignements de base qui s'avéreront très utiles pour déterminer à quelle vitesse se dépeuplent les eaux de mer sous l'effet des métaux lourds et combien de temps elles prennent pour se régénérer.

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CONCLUSIONS

Elevated levels of zinc were found in the Pacific oyster, Crassostrea gigas, exposed to effluent from groundwood bleaching pulp mills in British Columbia. The zinc concentrations correspond to known or anticipated effluent flow patterns and can be used to determine the extent of pulp mill influence. In addition to high zinc levels, the oysters in the Crofton area showed a deterioration in physical condition with increasing proximity to the effluent discharge.

Mussels and clams analysed during the study did not show significant copper and zinc contamination.

Although the amount of zinc in the effluent discharge of groundwood mills in the Province has been greatly reduced, oysters may continue to accumulate above natural concentrations of metals from contaminated sediments. Continued monitoring is required to document the depletion rate of excessive amounts of zinc in sediments and shellfish, and would provide valuable information regarding ecological recovery times.

1 INTRODUCTION

In recent years the ability of the sea to adequately dissipate industrial discharges has been questioned. Certain constituents of industrial effluent are retained and concentrated in the biosphere, thus complicating the process of dilution and dispersion. Molluscan filter feeders, and in particular oysters, have the ability to accumulate potentially toxic heavy metals to levels greatly in excess of those occurring in their environment. Once introduced into the receiving water, the trace metals may be taken up by the shellfish directly from sea water or by ingestion of particles which may be suspended in the water or taken directly from the sediment. Work done in Tasmania, Australia, on the Pacific oyster, Crassostrea gigas, (Ayling, 1974) showed the latter process of accumulation to be the most important and suggests that accumulation factors based on the concentration of metals dissolved in sea water could be grossly misleading. Cadmium, lead, and zinc uptake was related to the amount of each metal available in the sediments rather than to body size as was previously thought. Copper appeared to be absorbed by a physiological process to a maximum concentration dependent on the size of the oyster.

The uptake and concentration of certain trace metals is a natural and obligatory function of shellfish. Zinc acts as an enzyme activator and therefore is necessary for normal biochemical functions. This element is also a constituent of important metallo-protein enzymes such as carbonic anhydrase (Keilin et al, 1940). Copper is an enzyme activator, a constituent of a flavo-protein, and has a role in the hemocyanins found in the hemolymphs of certain molluscs (Mahler, 1956). These essential elements may become toxic, when present at unnaturally high concentrations, by poisoning enzyme systems and consequently impairing the growth, reproduction, or metabolism of an organism (Pringle et al, 1968).

Shellfish are capable of concentrating trace metals to many times the natural levels without showing a deterioration in physical

condition. Some species are particularly adept at concentrating zinc, copper, and cadmium, all of which are potentially toxic to humans (Blacow, 1972). Vomiting and depression of blood count have been attributed to zinc contamination in mammals although the concentrations required to cause these conditions are not clearly known (Drinnan, 1966). Oysters collected from the Derwent River Estuary in Tasmania caused symptoms of nausea and vomiting when eaten (Ratkowsky et al, 1974). These oysters were found to contain zinc, copper, and cadmium at the very high levels of 10,000 μg/gm, 130 μg/gm, and 34 μg/gm, respectively, measured on a wet-weight basis. In comparison, background levels of zinc, copper, and cadmium for oysters grown in Tasmanian waters were 1,000 μg/gm, 30 μg/gm, and 2 μg/gm, respectively. The Derwent Estuary receives run-off of heavy metals associated with roof tops, sewage, and industrial effluent from an electrolytic zinc plant.

A significant source of zinc contamination in certain British Columbia coastal areas has been the pulp and paper industry. Until recently groundwood (mechanical) pulp used in the production of newsprint underwent a brightening process employing zinc hydrosulphite. A survey contracted by the British Columbia Forest Products Company, which operates a pulp mill at Crofton, B.C., revealed that effluent discharges had resulted in a significant build-up of zinc in the waters and shellfish of the area. Subsequently an alternative bleaching agent was considered.

In 1973, representatives of the pulp and paper industry indicated that four British Columbia pulp mills would be changing to a new bleaching compound, sodium hydrosulphite, for groundwood pulp. The new compound was to be produced by the Borol process with the by-product, sodium metaborate, being discharged into the pulp mill sewers. The conversions were completed at four coastal pulp mills by September, 1974. A fifth groundwood pulp mill, located at Ocean Falls approximately 300 miles north of Vancouver, has yet to initiate a conversion to sodium hydrosulphite.

Since the process change would largely eliminate zinc from the effluent discharge, the Environmental Protection Service initiated a program to determine the present zinc levels in shellfish found in the areas affected, and to monitor changes resulting from the change-over to the Boral process. This was part of a joint study with the Fisheries and Marine Service (Fisheries Operations and Fisheries Research and Development), Environment Canada; the Province of British Columbia, Pollution Control Branch; and the various companies involved. Other programs investigated the acute toxicity of boron to fish and oysters, the uptake of boron by fish and oysters, and the effect of boron on phytoplankton. The preliminary results of these parts of the study are reported elsewhere (Environment Canada Report, 1973).

The portion of the study carried out by the Environmental Protection Service included the following:

- An extensive field program for the collection of biological, sediment, and water samples from control areas and where groundwood bleaching was in progress.
- Analysis of the above-mentioned samples for heavy metal content with particular emphasis on zinc concentrations.
- Condition factor (CF) measurements on *C. gigas* to determine if a correlation exists between the heavy metal content of an oyster and its physical condition. CF is a measure of the plumpness or fatness of an oyster.

2 METHODS

2.1 Sampling Period and Location

The following four groundwood bleaching mills were sampled: the MacMillan Bloedel mills at Powell River and Port Alberni; the British Columbia Forest Products mill at Crofton; and the Crown Zellerbach mill near Campbell River (see Figure 1). Stations, as shown in Figures 2 to 4, were established to define the outer perimeter of any heavy metal contamination. These areas were sampled in May, 1973, for the initial background data. Supplementary samples of mussels and clams were collected from select areas in August and October, 1973 (see Appendix II). The pulp mill at Ocean Falls is situated in Cousins Inlet which does not support natural populations of oysters and, therefore, was not included in the monitoring program. In June, 1973, Gambier Island, Nanoose Harbour, Lasqueti Island, and Sooke Basin were added as control sites and/or for background data.

In order to record any seasonal fluctuation in heavy metal content of the Pacific oyster, this species was collected again in August, 1973, and November, 1973. During the November collection, stations A13 and A24 were added in the Powell River area and station D14, in the Crofton area, was relocated on Ruxton Island. To reduce the number of samples to be analysed for the original study, shellfish from certain stations have been frozen for future analysis. These stations have been deleted from the figures.

2.2 Field Procedures

2.2.1 Biological Samples. Oysters, mussels, and clams were collected from each station when available and put in frozen storage. The species collected were the Pacific oyster, *C. gigas*; the edible mussel, *Mytilus edulis*; the little-neck clam, *Protothaca staminea*; the soft-shelled clam, *Mya arenaria*; and the butter clam, *Saxidomus giganteus*. Oyster samples, consisting of two to five individuals each, were taken from five different locations along the middle intertidal zone at each station to account

for any local variations. Oysters of average size for each particular area were collected. The number of mussels and clams collected from each station was dependent on the organisms' size and hence the quantity of tissue available for analysis. The shucked meat was placed in plastic bags and frozen to await analysis. During handling, care was taken to avoid metal contamination; this included the wearing of plastic gloves and the use of porcelain tools when possible.

2.2.2 Condition Factor Determinations. The condition or fatness of oysters is usually determined by measuring the degree to which oyster meats fill the shell cavities. This is possible because of a regular relationship which exists between the total volume of whole oysters and the volume of the shell cavity (Quayle, 1969). Volumes are generally found by displacement or by weighing in air and water, the volume of the shell cavity being the difference between the whole oyster and the shells, after shucking.

In the present study, the method of weighing in air and water proved unsuitable because of the error introduced by bubbles trapped within the shells of whole, intact oysters. This was true of oysters freshly collected from an intertidal zone covered by the tide, as well as for oysters collected and frozen before weighing. Displacement measurements were not used because of time limitations. The method adopted was to weigh the whole oyster, remove the meat, and then weigh the empty shells. The shell weight subtracted from the whole oyster weight yields a value which closely approximates the volume measurement of the shell cavity.

Those specimens of *C. gigas* collected in August, 1973, for condition factor determinations were weighed on the day of collection to avoid moisture loss. The shucked oyster meat was frozen and held for dry weight measurements to be applied to the equation:

$$CF = \frac{\text{dry weight of meat}}{\text{weight of whole oyster - weight of shells}} \times 1000$$

2.2.3 Water Samples. Water was collected from several stations in each area at depths of 0 and 5 metres using a Van Dorn sample bottle. The sample was passed through a 0.45μ millipore filter to remove plankton and acidified with Transistar grade HNO_3 (10 mls/litre). The samples were stored in neoprene bottles.

2.2.4 Sediment Samples. Sediment samples were collected on the August, 1973, survey using a Ponar grab sampler. The samples were put in plastic containers and frozen to await analysis.

2.3 Analytical Procedures

2.3.1 Biological Samples. The analytical techniques used for the determination of heavy metal and boron content in the shellfish appear below. The analyses were performed on the whole body tissue of the organisms.

Zinc, Copper, Cadmium

- whole tissue samples were dried for 48 hours at 110°C then ground in a mortar and pestle.
- one-gram portions were then digested in 10 mls conc. nitric acid for approximately 6 hours.
- samples were made up to 100 mls with water and analysed with a Jarrell Ash Atomic Absorption (AA) unit.

Mercury

- whole tissue samples were digested in conc. sulfuric acid for approximately 12 hours and then heated to 85 - 90°C while adding hydrogen peroxide drop-wise to complete digestion.
- the sample was then reduced to its elemental state with stannous sulfate and purged with argon gas to carry the vaporized mercury into the measuring cell.
- the mercury was measured by flameless atomic absorption with the Jarrell AA unit.

Boron

- a simplified spectrophotometric curcumin method developed by R.E. Drew (1973) of the Fisheries and Marine Service was used to determine boron (B) concentrations in oysters. The method involves a sulphuric acid-hydrogen peroxide digestion at 100°C, followed by formation of the boron-curcumin complex (rosocyanin) utilizing a variation of the method devised by Uppstrom (1968).

2.3.2 Water Samples. These samples have not been analysed due to analytical problems associated with the analysis of heavy metals in sea water.

2.3.3 Sediment Samples. Sediments were dried at 103°C to a constant weight, digested with aqua regia and conc. hydrofluoric acid and then analysed for zinc, copper, and cadmium with a Jarrell AA unit.

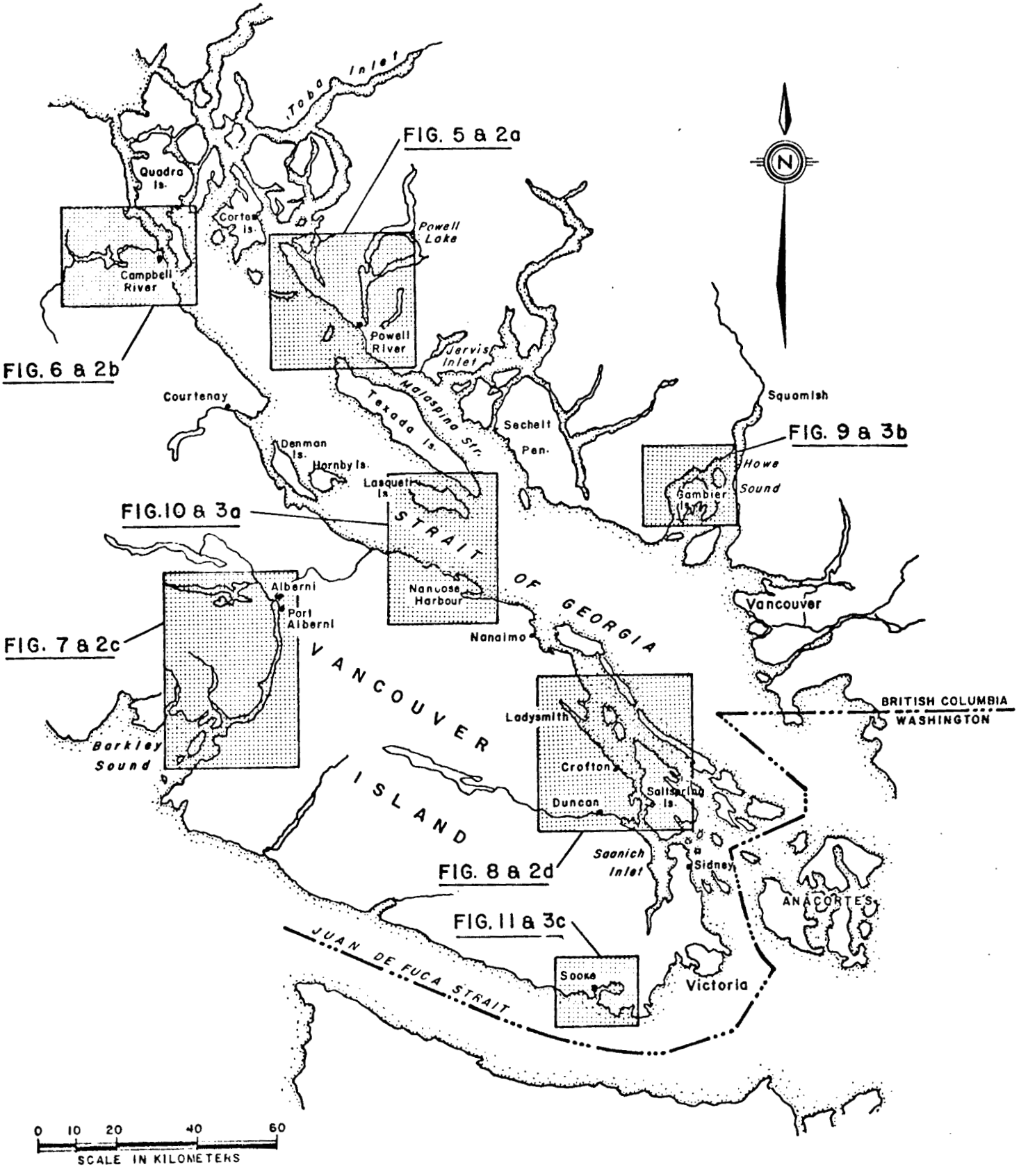

FIGURE I. GENERAL LOCATION OF STUDY AREA

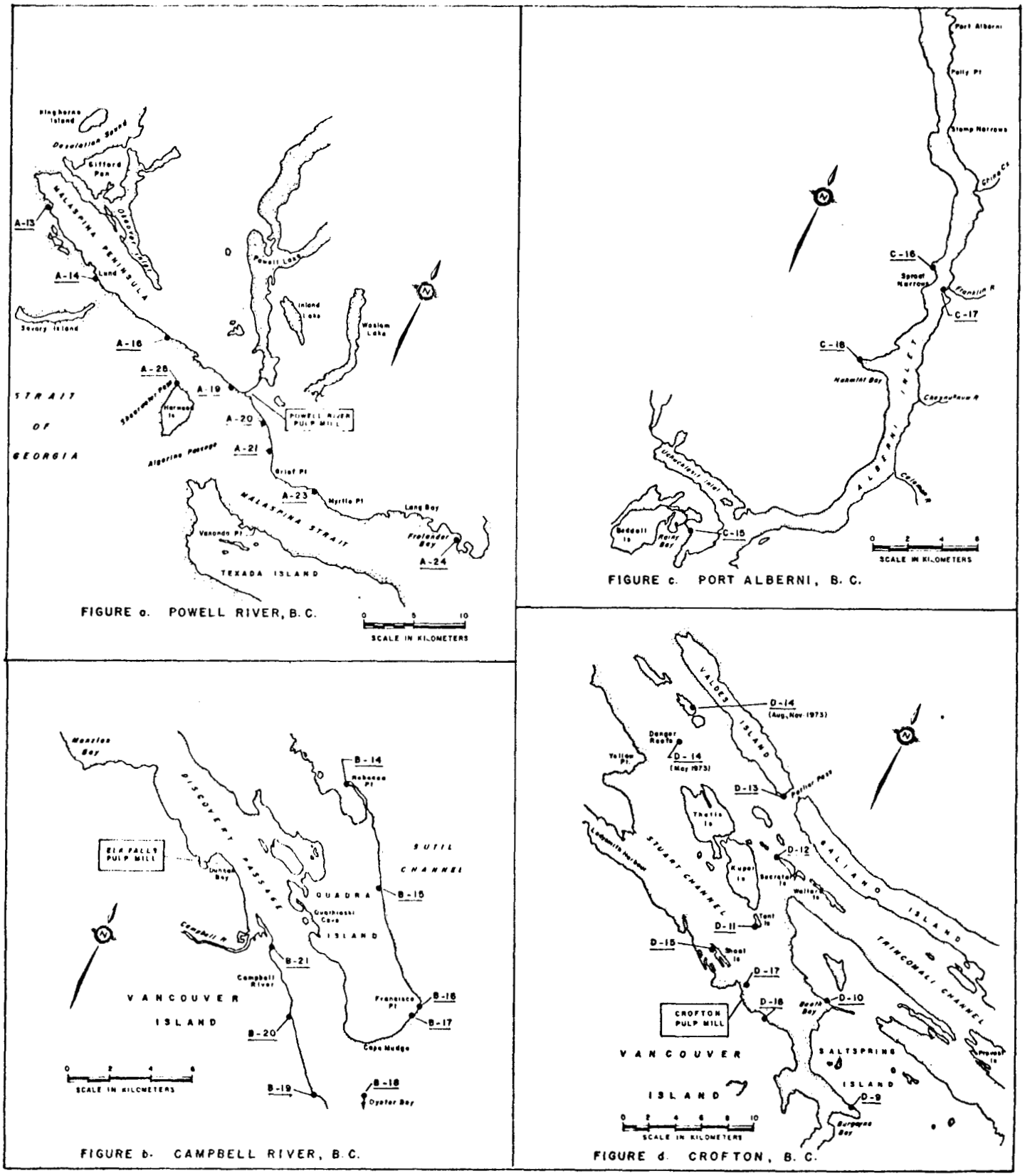

FIGURE 2 SHELLFISH STATION LOCATIONS

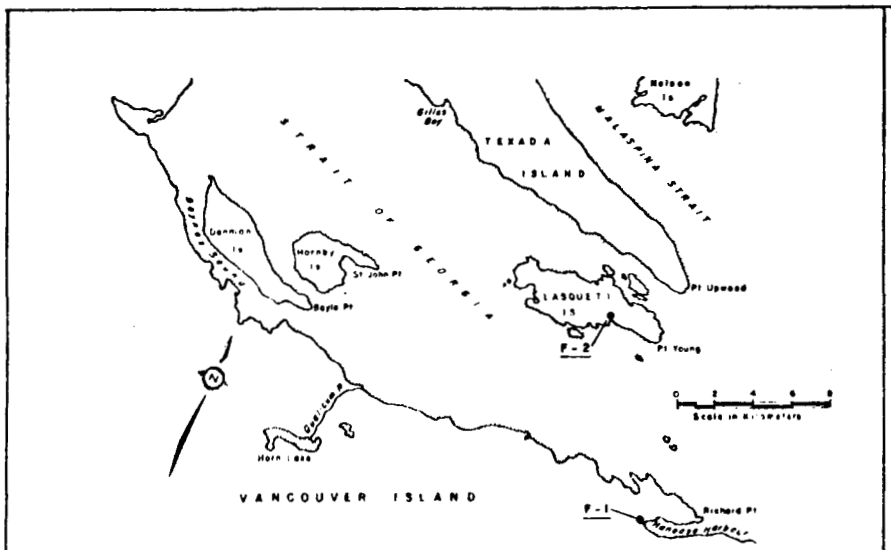

FIGURE a. LASQUETI ISLAND AND NANOOSE HARBOUR, B.C.

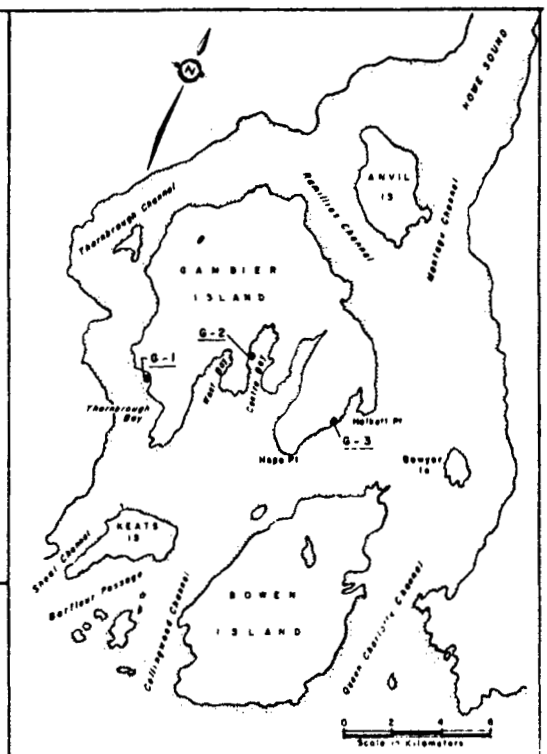

FIGURE b. GAMBIER ISLAND, B.C.

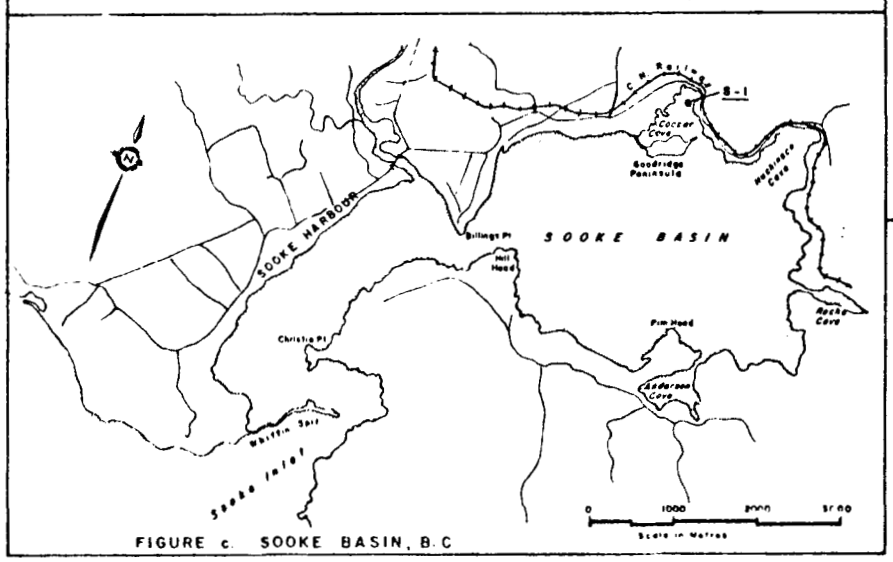

FIGURE c. SOOKE BASIN, B.C

FIGURE 3 SHELLFISH STATION LOCATIONS

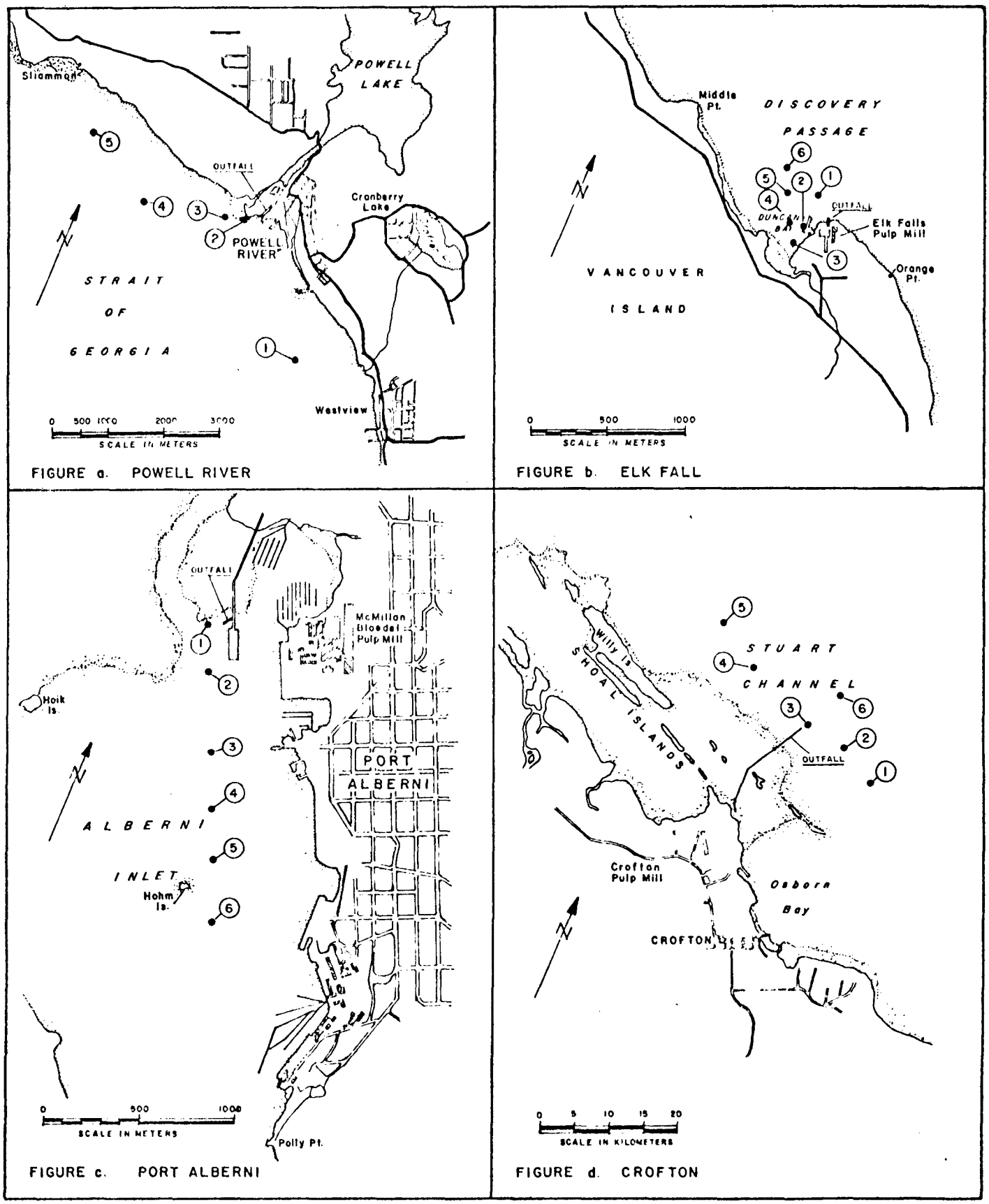

FIGURE 4 SEDIMENT STATION LOCATIONS

3 RESULTS

3.1 Zinc Concentrations in the Pacific Oyster

The mean zinc concentrations in whole oysters from the May and June, 1973, collections are shown in Figures 5 to 11. Table 1 gives the mean zinc concentrations in *C. gigas* for the three sampling periods, May, August, and November, respectively. Each value represents the mean of five samples taken from each station. For more detailed information on the zinc results, refer to Appendix I.

3.2 Other Heavy Metals and Boron in the Pacific Oyster

The concentrations of copper and cadmium found in *C. gigas* appear in Appendix I. Table 2 shows the mercury content of oysters collected in May, 1973; the results are mean values of 5 samples per station expressed on a wet-weight basis. In June, 1974, oysters were collected and analysed for boron to establish background levels before an appreciable amount of sodium metaborate had entered receiving waters as a result of the process change. These results are presented in Table 3 and represent mean values of 3 samples per station expressed on a wet-weight basis.

3.3 Zinc Concentrations in Mussels and Clams

Table 4 shows mean zinc concentrations in *P. staminea*, *S. giganteus*, *M. arenaria*, and *M. edulis*. Note that these values are considerably lower than those for the Pacific oyster and thus are not of major concern but are useful for comparative purposes. Clams and mussels were also analysed for copper; these results are shown in Appendix II along with more detailed data on the zinc analyses.

3.4 Condition Factor

Condition factor, as determined from shell cavity volume, gives a value ranging from about 40 (very thin oysters) to about 150 (very plump oysters) according to Quayle, 1969. The results of the present study appear in Table 5. The condition of oysters was related

to the distance away from the pulp mill outfall that the samples were taken. Although considerable variation was found between oysters from the same station, a trend can be seen in the Crofton area with the oysters' condition generally improving with increasing distance from the outfall.

3.5 Sediment Analysis

Table 6 shows the levels of zinc, copper, cadmium, and lead found in sediments collected from the four pulp mill areas. A definite trend was seen in zinc concentrations at stations located various distances from the pulp mill outfall at Port Alberni. The zinc level of 1,700 μg/gm close to this outfall was considerably greater than those found at the other pulp mills. The relatively high zinc concentration (630 μg/gm) from station 3 at Campbell River was believed to be the result of contamination after sampling.

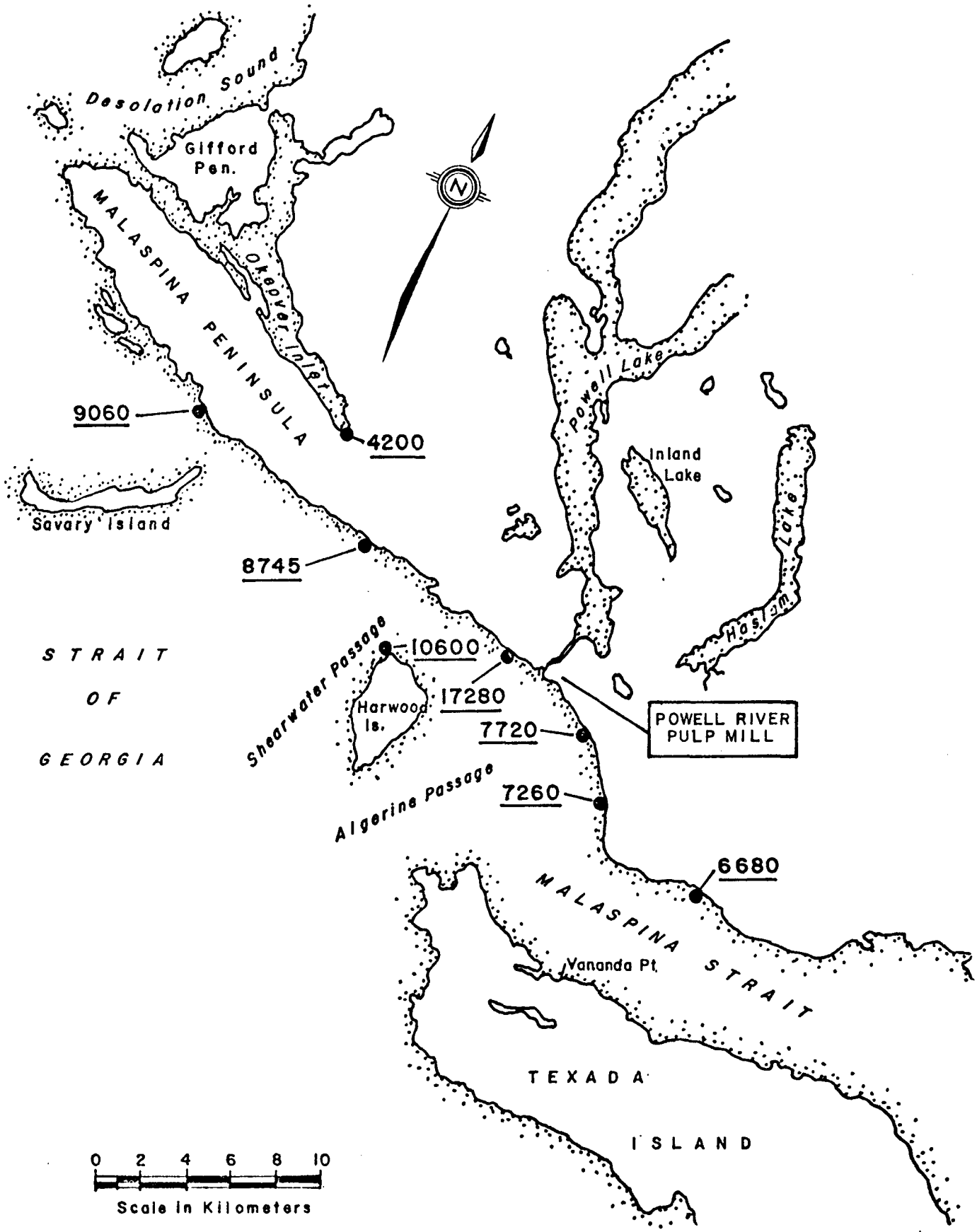

FIGURE 5. MEAN DRY WEIGHT ZINC CONCENTRATIONS IN *C. gigas* - POWELL RIVER, B.C. - MAY 1973

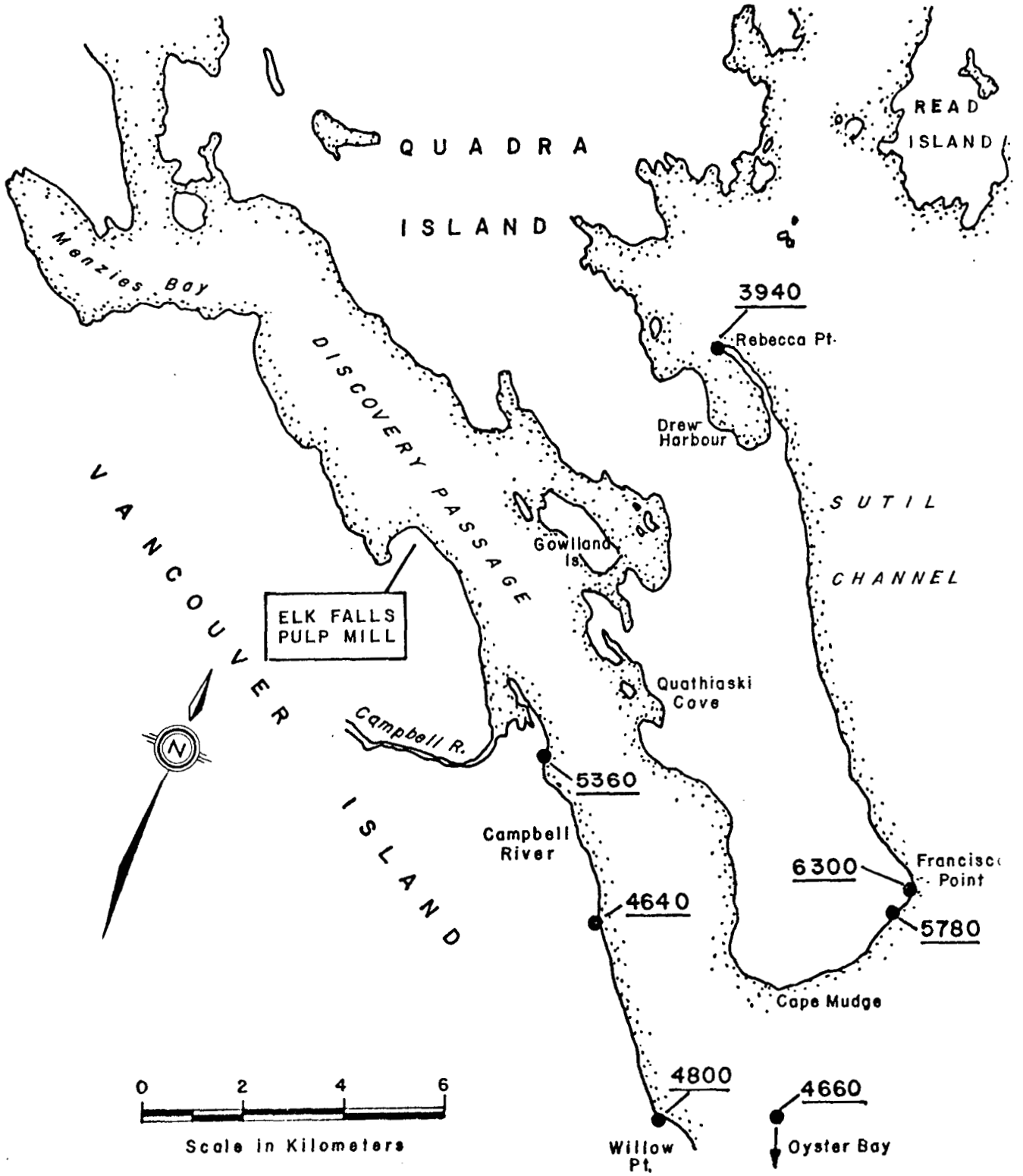

FIGURE 6. MEAN DRY WEIGHT ZINC CONCENTRATIONS IN *C. gigas* - CAMPBELL RIVER, B.C. - MAY 1973.

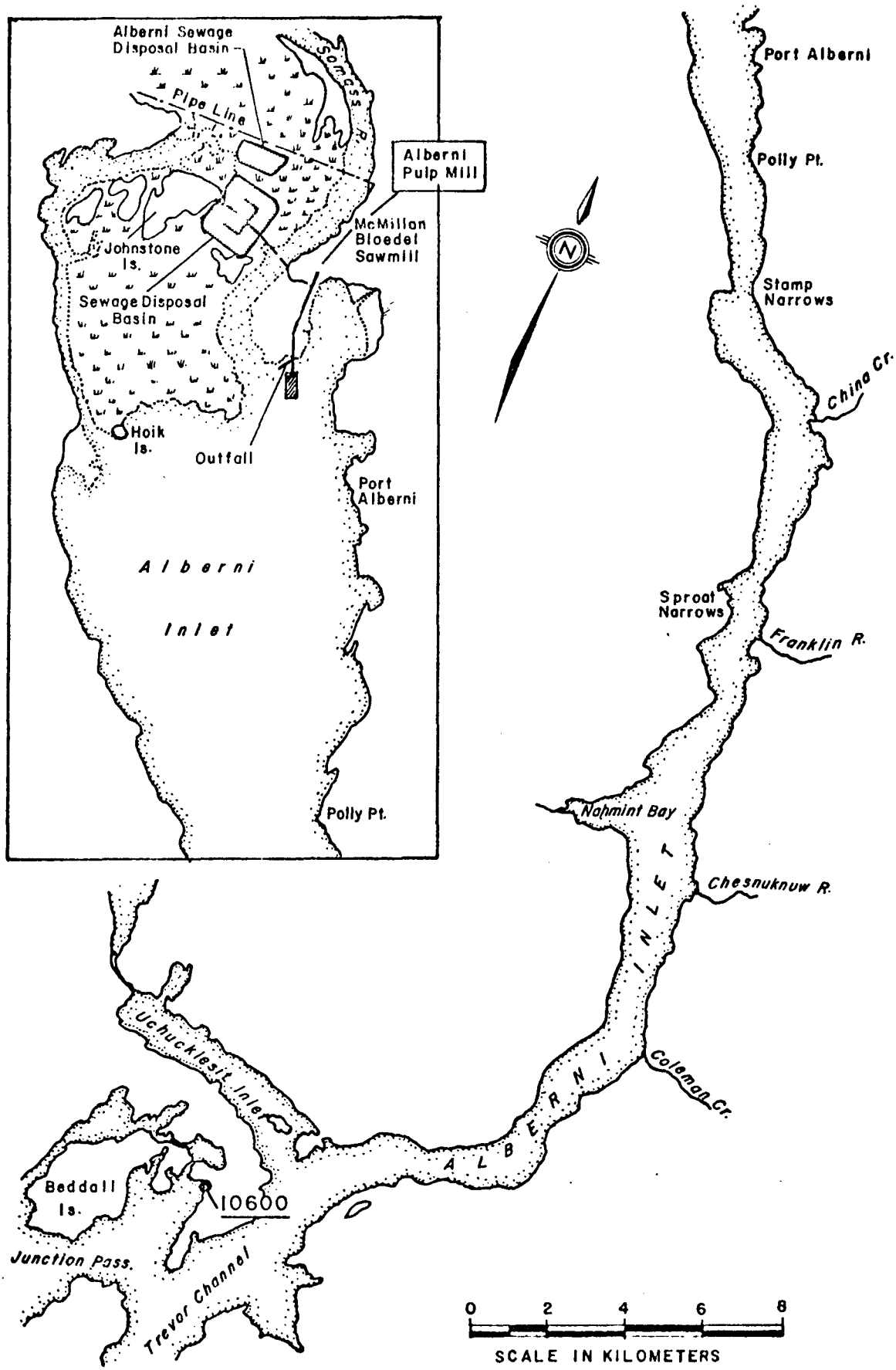

FIGURE 7. MEAN DRY WEIGHT ZINC CONCENTRATIONS IN *C. gigas* - PORT ALBERNI, B.C. MAY 1973

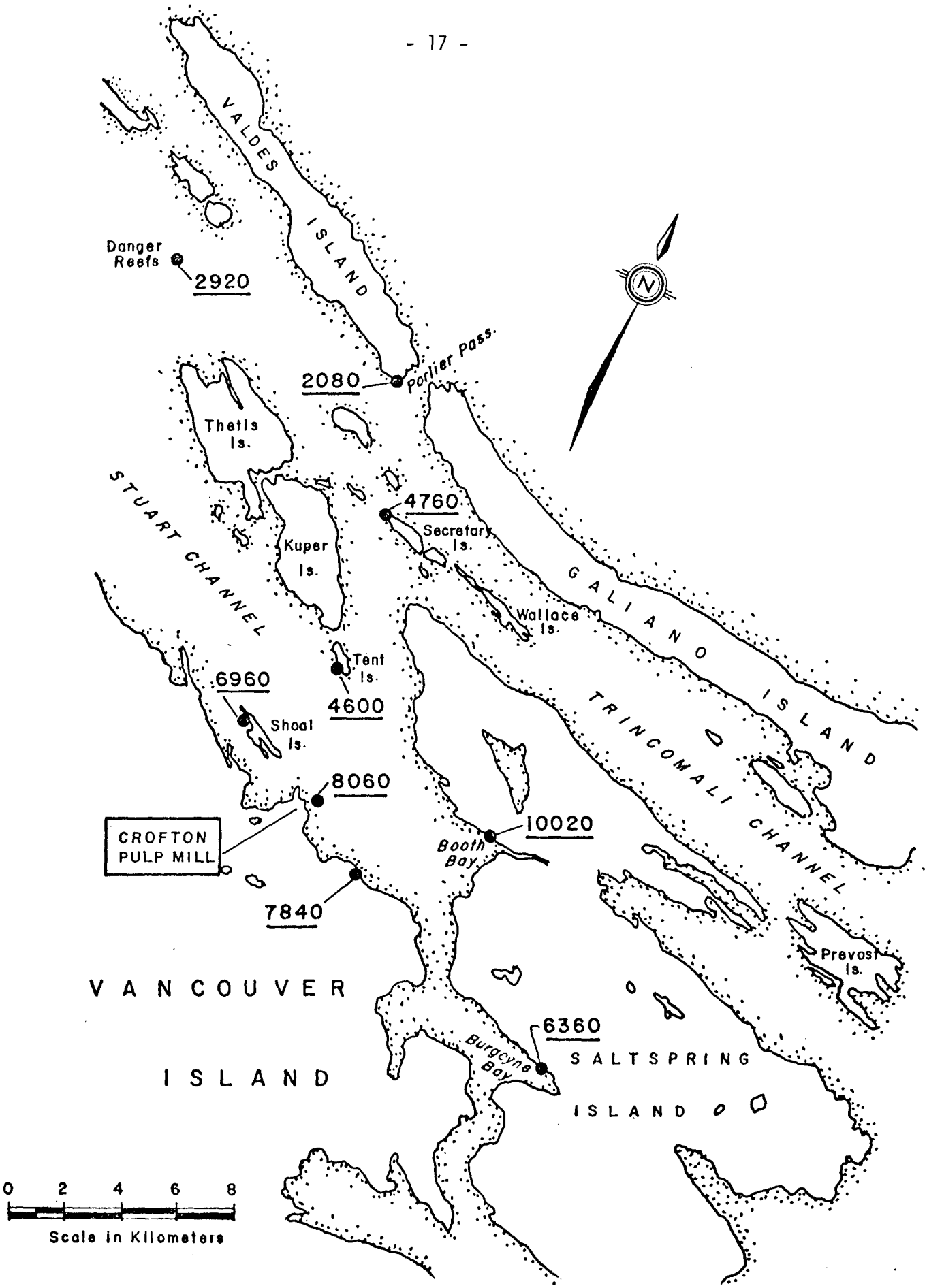

FIGURE 8. MEAN DRY WEIGHT ZINC CONCENTRATIONS IN *C. gigas* - CROFTON, B.C. - MAY 1973

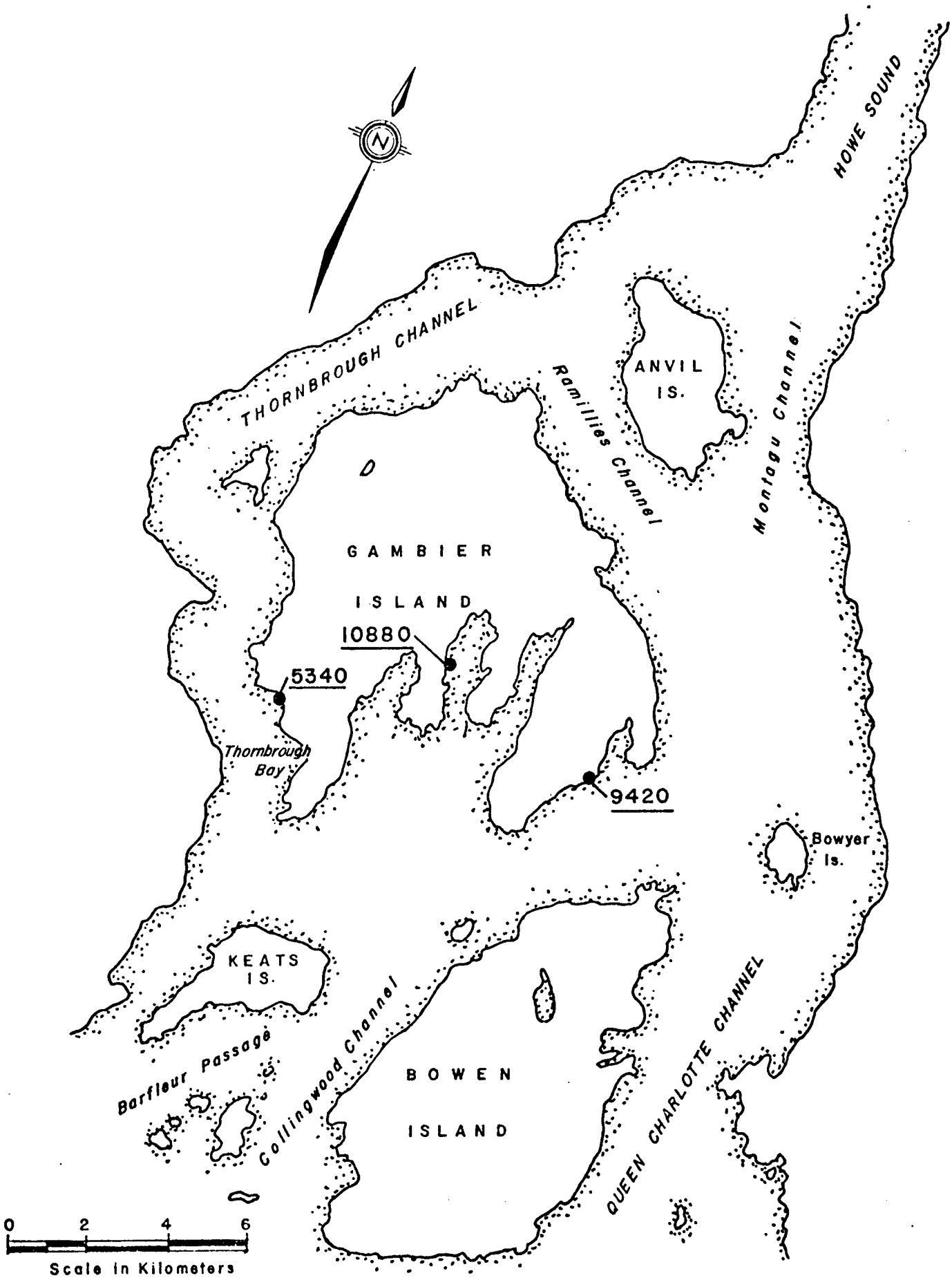

FIGURE 9. MEAN DRY WEIGHT ZINC CONCENTRATIONS IN C. gigas - GAMBIER ISLAND, B.C. - JUNE 1973

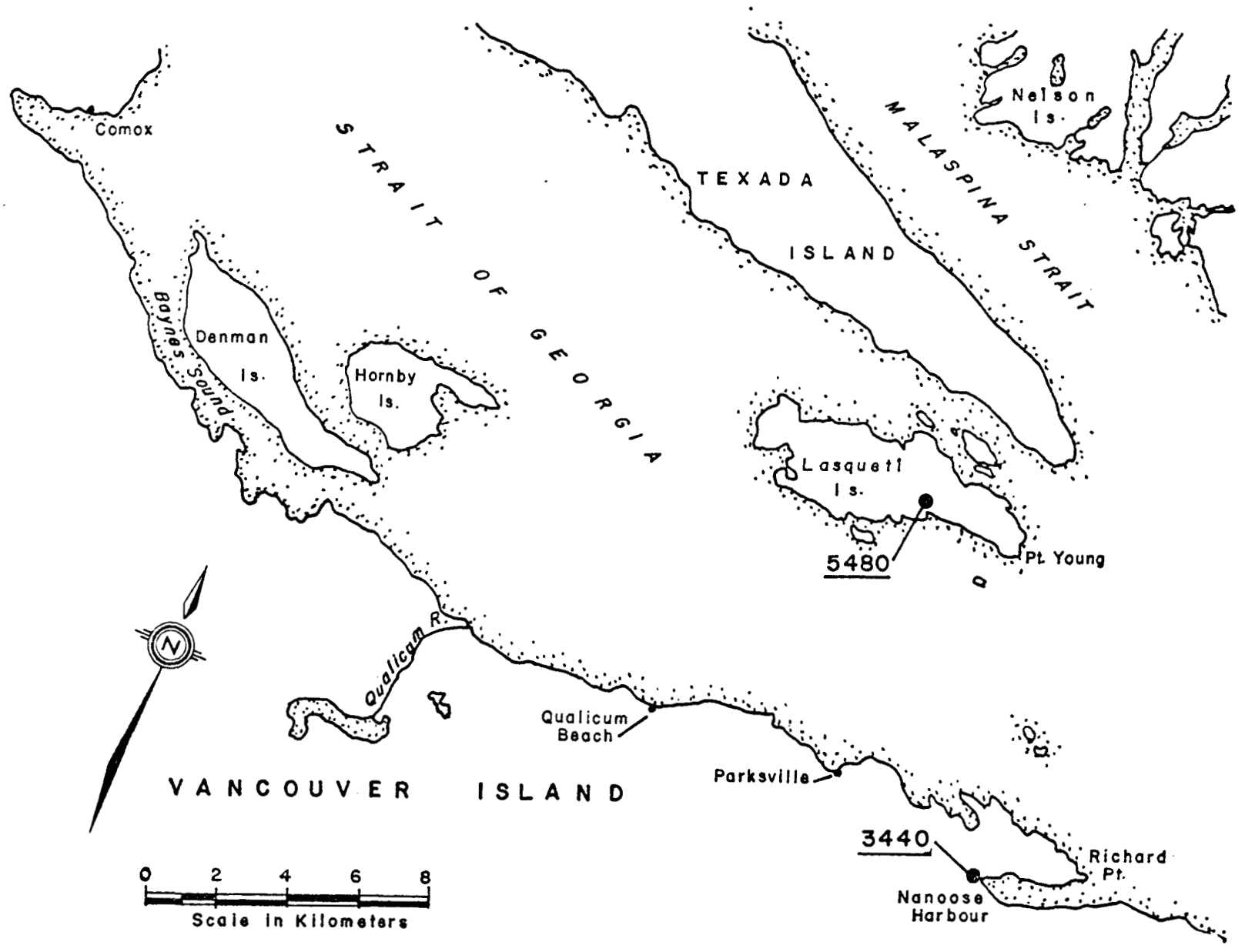

FIGURE 10. MEAN DRY WEIGHT ZINC CONCENTRATIONS IN *C. gigas* - LASQUETI ISLAND AND NANOOSE HARBOUR, B.C. - JUNE 1973.

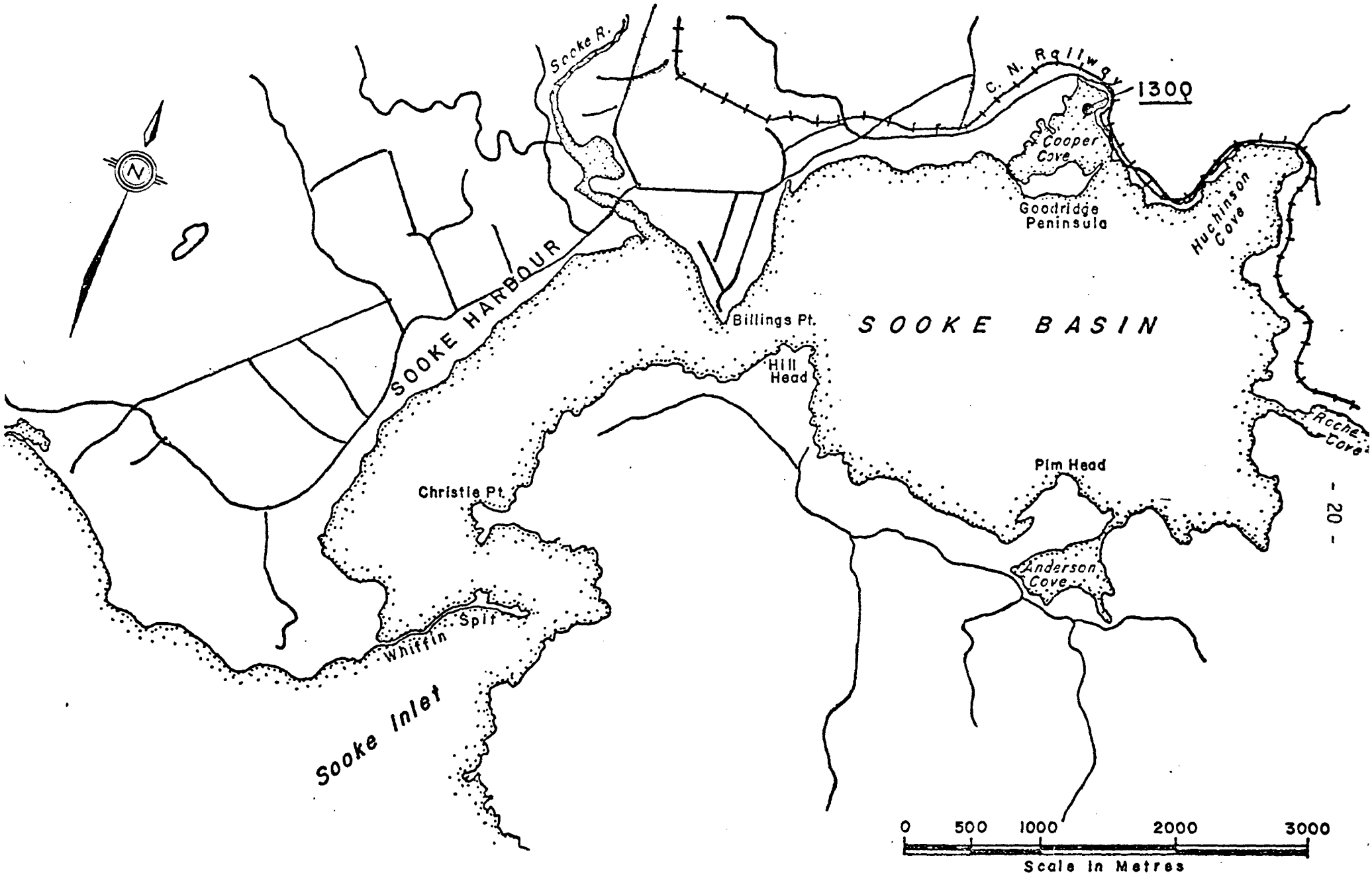

FIGURE 11. MEAN DRY WEIGHT ZINC CONCENTRATIONS IN C. gigas - SOOKE BASIN, B.C.
JUNE 1973

TABLE 1 MEAN SEASONAL ZINC CONCENTRATIONS IN CRASSOSTREA GIGAS

Station	Zinc µg/gm					
	May		August		November	
	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.
Powell River						
A-13	-	-	-	-	7,600	850
A-14	9,060	1,360	-	-	5,900	820
A-16	8,740	1,472	12,200	1,700	9,300	1,580
A-19	17,280	2,120	13,600	1,900	15,900	2,320
A-20	7,720	1,170	9,500	1,100	8,000	1,260
A-21	7,260	1,120	5,500	770	5,200	800
A-23	6,680	856	5,700	690	4,300	680
A-24	-	-	-	-	6,500	850
A-25	10,600	1,604	11,800	1,700	13,000	1,400
Campbell River						
B-14	3,940	650	3,000	560	4,000	900
B-16	-	-	2,900	520	3,300	600
B-17	5,780	656	4,900	730	-	-
B-18	4,660	742	4,600	780	3,400	610
B-19	4,800	644	4,000	620	-	-
B-20	4,640	824	5,400	1,080	-	-
B-21	5,360	1,024	6,800	1,170	-	-
Alberni Inlet						
C-15	10,600	2,180	10,700	2,180	-	-
Crofton						
D-9	6,360	1,066	4,300	900	4,500	840
D-10	10,020	1,420	8,000	1,040	11,300	1,150
D-11	4,600	768	4,100	730	5,800	1,130
D-12	4,760	896	3,000	620	-	-
D-13	2,080	320	2,300	480	-	-
D-14	2,920	520	-	-	2,100	460
D-15	6,960	1,300	5,000	980	6,200	790
D-16	7,840	-	9,300	1,270	6,400	760
D-17	8,060	1,150	16,900	1,700	12,700	1,270

TABLE 2 SHELLFISH TISSUE ANALYSIS - MEAN MERCURY CONTENT IN *CRASSOSTREA GIGAS*, MAY, 1973

Area	Station	Hg(μg/gm)
Powell River	A-14	0.067
	A-19	0.057
	A-20	0.048
	A-23	0.038
Campbell River	B-14	0.038
	B-17	0.034
	B-18	0.057
	B-19	0.036
	B-20	0.037
Alberni Inlet	C-15	0.182
Crofton	D-9	0.035
	D-10	0.028
	D-11	0.114
	D-14	0.219
	D-15	0.146
	D-16	0.141
Nanoose Bay	F-1	0.031
Lasqueti Island	F-2	0.101
Gambier Island	G-1	0.146
	G-2	0.200
	G-3	0.229

TABLE 3 SHELLFISH TISSUE ANALYSIS - MEAN BORON CONTENT IN *CRASSOSTREA GIGAS*, JUNE, 1974

Area	Station	Boron µg/gm wet wt.	
		Range	Mean
Powell River	A-13	3.3 - 3.4	3.3
	A-14	3.3 - 4.4	4.1
	A-16	3.1 - 3.3	3.3
	A-19	2.5 - 2.7	2.6
	A-20	4.9 - 5.2	5.1
	A-21	3.8 - 4.2	4.0
	A-22	3.4 - 3.6	3.5
	A-23	3.0 - 3.2	3.1
	A-24	2.9 - 3.3	3.1
	A-25	3.3 - 3.4	3.4
Campbell River	B-14	4.7 - 5.3	5.0
	B-16	2.9 - 3.3	3.1
	B-19	3.7 - 3.9	3.8
	B-20	3.7 - 4.4	4.1
Alberni Inlet	C-15	1.8 - 2.0	1.9

TABLE 4 SHELLFISH TISSUE ANALYSIS - MUSSELS AND CLAMS

Species	Area	Station	No. of Samples	Zinc µg/gm	
				Dry Wt.	Wet Wt.
Protothaca staminea	Powell River	A-16	3	180	24
	Campbell River	B-16	3	170	23
		B-17	5	220	31
		B-18	5	170	27
		B-19	5	140	18
		B-20	3	80	13
	Alberni Inlet	C-15	5	210	28
	Crofton	D-9	5	130	16
		D-11	1	190	28
		D-13	4	90	15
		D-15	5	80	12
Saxidomus giganteus	Powell River	A-16	5	210	32
		A-19	5	160	26
		A-25	2	110	20
	Campbell River	B-16	3	80	15
		B-17	5	120	17
		B-18	5	90	14
		B-19	5	110	17
		B-20	1	150	26
	Crofton	D-9	5	100	17
		D-11	1	120	19
		D-13	5	90	22
		D-15	2	90	14
Mya arenaria	Powell River	A-19	2	180	26
		A-20	5	300	41
		A-23	5	210	25
		A-25	3	500	36
	Alberni Inlet	C-15	5	230	26
		C-17	5	310	35
		C-18	5	260	29
	Crofton	D-11	5	89	12
		D-15	2	70	9

continued...

Species	Area	Station	No. of Samples	Zinc µg/gm	
				Dry Wt.	Wet Wt.
...continued					
Mytilus edulis	Powell River	A-14	3	270	33
		A-16	1	240	26
		A-21	3	340	49
		A-23	3	340	55
		A-25	1	390	47
	Campbell River	B-14	3	500	55
		B-16	3	380	47
		B-17	3	150	22
		B-18	3	260	35
		B-19	3	270	36
		B-20	3	180	27
	Alberni Inlet	C-15	5	320	37
		C-17	2	350	63
		C-18	2	270	44

TABLE 5 CONDITION FACTOR DETERMINATIONS, AUGUST, 1973

Area	Station	No. of Specimens	Condition Factor		Miles from Outfall
			Range	Mean	
Powell River	A-16	5	62-115	82	5.0
	A-19	5	66-177	108	1.5
	A-20	5	48- 59	53	1.0
	A-21	5	60-120	94	3.0
	A-23	5	51- 93	74	6.0
	A-25	5	59-114	87	4.0
Campbell River	B-14	5	85-148	117	16.5
	B-16	5	62-145	103	10.5
	B-17	5	68-115	99	10.0
	B-18	5	63-156	116	12.0
	B-19	5	82-136	117	6.5
	B-20	5	103-165	128	4.5
	B-21	5	47-100	85	3.0
Crofton	D-9	5	126-163	145	7.5
	D-10	5	42- 78	61	3.5
	D-11	5	120-195	161	2.0
	D-12	5	85-176	129	5.0
	D-13	5	156-221	183	7.5
	D-15	5	115-154	133	2.0
	D-16	5	73-124	93	2.0
	D-17	5	38-144	73	1.0
Nanoose Bay	F-1	5	98-149	119	
Lasqueti Island	F-2	5	39- 50	47	
Gambier Island	G-1	5	39- 95	57	
	G-2	5	46-137	77	
	G-3	5	44- 93	68	

Condition factor gives values ranging from about 40 (very thin oysters) to about 150 (very plump oysters) according to Quayle, 1969.

TABLE 6 HEAVY METAL CONCENTRATIONS IN SEDIMENTS, AUGUST, 1973 (RESULTS IN μg/gm)

Area	Station	Zinc ± 10	Copper ± 5	Cadmium	Lead
Powell River	1	130	-	<10	-
	2	140	50	<10	-
	3	130	20	<10	-
	4	40	20	<10	-
	5	85	30	<10	-
Campbell River	1	80	20	<10	-
	2	20	5	<10	-
	3	630*	10	<10	-
	4	44	10	<10	-
	5	50	10	<10	-
Crofton	1	160	50	<15	<150
	2	230	20	<15	<150
	3	210	40	<14	<140
	5	180	40	<14	<140
	6	190	40	<14	<140
Alberni Inlet	1	1700	90	<15	<140
	2	1720	90	<15	<147
	3	1060	70	<14	<144
	4	470	60	<14	<144
	5	690	60	<13	<131
	6	500	70	<13	<126

* possible contamination

4 DISCUSSION

The results of zinc analyses of whole oysters from the four pulp mills previously employing zinc hydrosulphite bleaching confirms reports that zinc accumulation has occurred in shellfish. In some instances the zinc levels are considerably above natural background levels. The lowest background levels were found in oysters collected at Sooke Basin (Figure 1) where the concentrations of zinc, copper, and cadmium were 1,300 μg/gm, 51 μg/gm, and 3 μg/gm, respectively. All values referred to in the discussion are dry weight determinations unless otherwise specified. The Sooke Basin levels are considerably lower than those obtained in Georgia Strait from Lasqueti Island and Nanoose Harbour, which are other areas removed from pulp mill influences. These areas had zinc concentrations of about 5,500 μg/gm and 3,400 μg/gm, respectively. The cause of the higher than anticipated zinc levels in oysters collected in Boat Cove on Lasqueti Island is unknown. Oysters taken from Gambier Island, another area more or less removed from pulp mill influences, showed significantly high levels of zinc (6,800 - 15,000 μg/gm) and copper (760 - 1,700 μg/gm). These levels, particularly the copper levels, suggest that the discharge from the Britannia Copper Mine near the head of Howe Sound may have affected the oysters in this area.

The highest zinc concentrations found during the May, 1973, survey were in the order of 19,000 μg/gm, in oysters from the Powell River area. This was about 16,000 μg/gm above the background level for that particular area. Although the very high zinc concentrations were confined to oysters from the immediate outfall areas (within 1 or 2 miles), elevated zinc levels could be detected for considerable distances from the respective effluent discharges.

The levels of copper, cadmium, and mercury in oysters do not seem to be influenced by proximity to pulp mill discharges. Concentrations of boron in oysters were found to be roughly equivalent to the

level of this element naturally present in sea water, i.e., 3.5 ppm, indicating no bioaccumulation.

Zinc and copper levels found in shellfish other than oysters do not indicate significant contamination from the pulp mills but suggest species differences in trace metal uptake as has been previously reported. M. arenaria and M. edulis contained concentrations of zinc consistently higher than P. staminea and S. giganteus, possibly indicating a species difference in the physiological role of this element.

Although the sediment analyses in the present study showed high zinc levels at only one of the pulp mills sampled, recent work has shown industrial sediments to be an important contributor of heavy metals to the biosphere. The work done by Ayling (1974) in Tasmania revealed high lead (1,400 ppm) and copper (220 ppm) levels from an abandoned tailing dump used during the goldrush era.

Quayle (1969) reports that oysters collected from near the former copper smelter in Ladysmith Harbour, B.C., which ended production around 1949, contained 36,000 ppm zinc and 20,000 ppm copper. At the time, average levels found in oysters from other nearby areas were 10,000 ppm zinc and 600 ppm copper. The recently-established copper and molybdenum mine in Rupert Inlet, B.C., has resulted in high levels of metals in sediments close to the tailing outfall. Levels of 28,000 ppm copper, 1,500 ppm zinc, and 1,000 ppm molybdenum were reported by Utah Mines Ltd. (March, 1974) in an environmental monitoring report.

The zinc concentrations found in oysters appear to correspond closely to known or anticipated effluent flow patterns and could be used to determine the extent of pulp mill influence, as discussed below.

4.1 Powell River

Analysis of oysters from the Powell River area revealed a much higher level of contamination than the other areas tested. The maximum average zinc concentration found in oysters was 17,280 μg/gm, (Table 1, Figure 5). These samples were obtained nearest to the mill discharge

while samples from the other stations ranged from 6,680 to 10,000 μg/gm. Zinc levels were noticeably higher on the northwestern side of the Powell River mill than those to the southeast. The average zinc concentration found at station A14 (approximately 10 miles to the northwest) was 9,070 μg/gm, compared to 6,680 μg/gm at station A23 (approximately 8 miles to the southeast).

The pattern of zinc concentrations indicates that the net effluent flow is in a northwesterly direction. This is supported in observations made by MacMillan Bloedel personnel and by known current movements in the area. The influence of the pulp mill extends outward to Harwood Island where oysters showed an average zinc concentration of 10,600 μg/gm. In comparison, oysters collected from the western tip of Texada Island in 1971 showed a zinc concentration of 5,600 μg/gm.

Control samples from Okeover Arm, which is located north of Powell River near the entrance to Toba Inlet, had an average zinc concentration of 4,200 μg/gm (range 3,200 to 4,800 μg/gm). These oysters were collected far enough from the mill influence to be considered representative of natural background zinc levels for that geographical area. Considering 4,200 μg/gm the average background level, the area of elevated zinc levels extends beyond the outer-most stations which were located at Myrtle Point and Lund in May, 1973. The two additional stations sampled in November, 1973, i.e., A13 and A24, also showed concentrations above background levels (Table 1).

4.2 Campbell River

Oyster samples collected around the Crown Zellerbach Elk Falls mill, located at Duncan Bay, indicated that some increase in zinc levels in whole oyster tissue had occurred. However, due to the tidal flushing in this area, levels of contamination were below the other mill areas. Figure 6 shows the geographical distribution of zinc in oyster tissue in the vicinity of the Elk Falls pulp mill. Unfortunately the closest point that oyster samples could be obtained was approximately 3 miles

southeast of the point of effluent discharge, and within the influence of the Campbell River. The average zinc concentration on oyster tissue in this area was 5,360 μg/gm (range 3,200 to 8,000 μg/gm).

Zinc concentrations in the oysters were slightly higher at Francisco Point than those nearer the mill. This may be the result of eddy currents which would tend to concentrate mill effluents in this area. Water containing mill effluent, displaced southward on a flood tide from Discovery Passage, would flow into both Sutil Channel and Discovery Passage on the ebb tide. This would tend to expose the shellfish beds in the Cape Mudge and Francisco Point areas to mill effluent more frequently than those areas along the Vancouver Island shoreline.

Samples from Rebecca Spit, which should be well beyond the influence of the mill effluent, showed an average zinc level of 3,940 μg/gm (range 3,600 - 4,500 μg/gm). If this value is taken to represent the natural background level for oysters in this area, oysters from Oyster Bay approximately 16 miles south of the mill may have been slightly affected by the discharge from the Elk Falls mill, although levels are not considered to be high.

4.3 Crofton

Oysters from the Crofton area showed a significant increase in zinc levels over background. In general, the concentrations were lower than those found in the Powell River area and high levels did not extend as far from the point of effluent discharge. The tidal currents and methods of discharge differ between these two mills and this would influence the behaviour of the effluent. The discharge at the Powell River mill is directly into the surface waters of Malaspina Strait, whereas at Crofton the effluent is diffused into Stuart Channel where tidal currents are greater. Consequently, shellfish beds in the Crofton area would be exposed to more dilute effluent.

Figure 8 shows the mean dry weight zinc concentrations found in whole oysters collected in the Crofton area in May, 1973. The area

affected appears to extend from between Chemainus Bay and the Shoal Islands (mean 6,960 µg/gm, range 4,600 to 9,000) on the northwestern side of the Crofton mill to beyond Burgoyne Bay (mean 6,360 µg/gm, range 5,400 - 7,800) to the southeast. To the north, elevated zinc concentrations were detected to the Secretary Islands in Trincomali Channel (mean 4,760 µg/gm, range 4,200 to 5,800 µg/gm).

The distribution of zinc concentrations in oysters from the Crofton area suggests a net southeasterly flow of effluent through Stuart Channel with a tendency for the effluent to concentrate in Booth Bay, directly across Stuart Channel from the two effluent diffusers. Booth Bay oysters showed a mean zinc level of 10,020 µg/gm and ranged from 8,700 to 11,000 µg/gm. These conclusions are supported by the condition factor measurements (Table 5) which indicate a deterioration in oyster condition to the south of the pulp mill and in Booth Bay. The influence of the pulp mill discharge on the local oyster population has been reported previously (Jackson, 1962; Dobrocky Seatech Ltd., 1973; Porter, 1969) and resulted in the end to commercial oyster production in the area in 1964-65.

4.4 Port Alberni

The only oysters found in the Port Alberni region were located in Barkley Sound many miles from the pulp mill. A mean level of 10,600 µg/gm zinc (range 8,200 to 14,000 µg/gm) was found in oysters taken from Rainy Bay, which is 24 miles from the Alberni pulp mill (Figure 2c). Zinc levels found in oysters from this area were unexpectedly high; however, there is known mineralization in the area and further analysis is required to confirm any relationship to mill discharge. Analysis of clams and mussels collected along Alberni Inlet indicated no trend in zinc concentration (Table 4). It was noted that the oysters collected in Rainy Bay were in excellent condition with remarkably large shells filled with meat. The numbers were not great and sampling was restricted.

4.5 Seasonal Fluctuation in Zinc Concentrations

The levels of zinc found in oysters collected during the three sampling periods, as shown in Table 1, do not differ significantly, although in most cases concentrations were greater in May and August than in November. May corresponds to a time when the oysters are feeding heavily on phytoplankton from the spring bloom of diatoms which usually occurs in March under optimal conditions of light, temperature, and nutrients. The oysters are at their peak condition with tissues filled with glycogen (animal starch) and, with increased water temperature, they begin to develop sperm. Eggs and sperm replace the glycogen-filled tissues and the oysters remain in this condition until spawning occurs, around August. Inconsistent results in the August heavy metal data, when compared to data from May and November, may be due to the spawning condition of the oysters from different areas. Since this activity is temperature dependent, the oysters in some areas sampled may have already spawned while others were awaiting a rise in water temperature.

An oyster could lose a considerable portion of zinc content during the spawn since gonadal tissue has been found to accumulate certain trace metals in higher concentrations than other anatomical areas (Pringle et al, 1968). After spawning the oyster is very thin and watery but by October or November much of its weight has been regained. Very little feeding occurs between November and March because of a lack of diatoms and decreased water temperature. During this period of inactivity, the ingestion of heavy metals will also be reduced. This cycle should be considered when sampling to determine levels of trace metals in an area.

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ACKNOWLEDGEMENTS

The assistance of the following people during the course of this study was greatly appreciated: Dr. J. Davis of the Fisheries and Marine Service; L. Martin of the Environmental Protection Service - Fisheries Service Laboratories, West Vancouver; R.E. Drew of the Fish Inspection Laboratory, Vancouver; and the Environmental Protection Service biological technicians, D. Sullivan, J. Landucci, D. Brothers, and D. DeMill.

APPENDIX I

HEAVY METAL DETERMINATIONS IN *C. GIGAS*
(Results in μg/gm)

a. MAY, 1973

b. JUNE, 1973

c. AUGUST, 1973

d. NOVEMBER, 1973

APPENDIX I HEAVY METAL DETERMINATIONS IN C. GIGAS (Results in μg/gm)

a. MAY, 1973

Station	Zinc		Copper		Cadmium	
	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
Powell River						
A-14	9,600	1,400	230	34	10	1
	8,600	1,400	250	42	7	1
	8,300	1,200	230	33	10	1.4
	8,800	1,300	210	31	13	2
	10,000	1,500	310	46	9	1.4
A-16	7,800	1,300	140	23	4	0.7
	10,000	1,800	130	24	8	1
	9,800	1,660	150	25	7	1
	7,900	1,300	100	17	4	0.7
	8,200	1,300	130	21	< 3	< 0.4
A-19	18,000	2,200	270	36	4.5	0.6
	15,000	1,900	180	23		
	16,000	1,900	220	26	4	0.5
	18,000	2,100	210	24	7	0.8
	19,400	2,500	210	25	3	0.4
A-20	7,000	950	180	25	8	1
	8,300	1,400	220	35	7	1
	7,800	1,100	230	34	10	1
	7,800	1,100	200	28	10	1
	7,700	1,300	210	35	8	1
A-21	7,400	1,100	240	35	13	2
	7,200	1,200	200	33	10	2
	6,900	1,100	200	31	8	1
	7,400	1,100	200	29	9	1
	7,400	1,100	220	33	13	2
A-23	5,900	720	230	28	14	2
	7,200	1,000	320	45	11	2
	7,700	950	240	29	19	2
	5,600	740	250	33	15	2
	7,000	870	270	34	14	2
A-25	11,000	1,720	160	25	6	0.9
	9,000	1,600	150	25	5	0.9
	14,000	1,800	240	32	8	1
	9,400	1,500	170	27	4	0.6
	9,600	1,400	170	26	3	0.5

continued...

Station	Zinc		Copper		Cadmium	
	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
Okeover Arm*						
	4,600	820	150	26	10	1.8
	3,200	540	93	15	11	1.8
	4,200	750	92	15	8.9	1.5
	4,800	860	120	22	15	2.7
Campbell River						
B-14	3,700	680	110	21	9	2
	4,500	750	160	26	11	2
	3,600	570	110	17	9.5	1.5
	4,300	650	130	20	9	1
	3,600	600	130	22	9.5	2
B-16	6,300	930	140	21	13	2
B-17	6,100	940	140	22	13	2
	6,000	1,100	180	31	12	2
	6,300	1,100	150	25	11	2
	5,100	800	120	18	13	2
	5,400	840	160	25	13	2
B-18	4,100	650	120	20	10	2
	4,800	810	180	30	15	2.5
	3,800	570	120	19	13	2
	5,200	820	130	20	15	2
	5,400	860	170	28	10	2
B-19	5,600	680	150	22	15	2.2
	3,400	540	89	14	9.9	1.5
	5,400	480	130	18	12	1.7
	5,000	740	170	25	12	1.8
	4,600	780	110	19	9.9	1.7
B-20	6,400	1,220	220	43	11	2.2
	4,600	860	170	31	9.7	1.8
	4,200	700	160	26	8.6	1.4
	4,600	820	170	30	11	1.9
	3,400	520	120	18	8.6	1.3

continued...

* Samples collected by L. Melville, biologist for MacMillan Bloedel Ltd., Powell River Division. Each value represents a sample containing 2 oysters.

Station	Zinc		Copper		Cadmium	
	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
B-21	5,200	800	250	38	17	2.5
	5,800	1,000	310	60	11	2.1
	4,600	1,000	180	38	8.8	1.9
	3,200	830	180	47	6.5	1.7
	8,000	1,500	190	36	11	1.3
Alberni Inlet						
C-15	12,000	2,200	58	11	4	0.75
	10,000	2,000	55	11	3	0.5
	8,200	1,700	67	14	< 3	< 0.5
	14,000	3,000	82	18	6	1
	8,800	2,000	51	12	4	0.9
Crofton						
D-9	5,400	870	92	15	10	2
	7,800	1,400	120	21	8	1.5
	6,400	1,000	100	16	7	1
	6,600	1,100	110	18	7	1
	5,600	960	93	16	10	2
D-10	10,000	1,600	190	30	9	1
	11,000	1,500	260	35	16	2
	11,000	1,400	250	32	11	1
	9,400	1,400	190	28	9	1
	8,700	1,200	210	28	6	0.8
D-11	3,500	600	78	13	4	0.7
	5,200	970	110	19	9	1.5
	5,100	820	93	15	7	1
	3,700	620	59	9.9	< 2.5	< 0.4
	5,500	830	79	12	8	1
D-12	4,400	800	84	15	4	0.8
	5,800	1,100	140	26	7	1
	4,200	840	90	18	4	0.8
	5,000	930	110	20	5	0.9
	4,400	810	84	15	5	0.85

continued...

Station	Zinc		Copper		Cadmium	
	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
D-13	2,800	440	83	13	6	1
	2,000	340	70	12	< 3	< 0.5
	1,900	370	65	12	3.5	0.7
	2,000	130	51	3.3	< 2.5	< 0.2
	1,700	320	34	6.3	3.5	0.7
D-14	2,500	410	46	7.5	< 3	< 0.5
	3,000	550	50	9.3	7	1
	3,700	640	99	17	4	0.7
	2,700	480	61	11	< 3	< 0.5
	2,700	520	140	27	9	2
D-15	7,800	1,400	240	44	7.5	1
	8,000	1,400	240	43	9	2
	4,600	800	200	35	5.5	1
	6,500	1,300	240	49	8	2
	7,900	1,600	250	50	5.5	1
D-16	7,600	1,000	80	10	4	0.5
	8,700	1,300	120	18	5.5	0.9
	7,500	1,600	130	26	< 3	< 0.7
	8,000	1,400	150	26	< 3	< 0.5
	7,400	1,300	130	22	5	0.8
D-17	11,200	1,400	120	15	11	1
	6,800	1,000	100	15	3.5	0.5
	10,400	1,400	100	14	< 3	< 0.4
	5,100	950	120	21	< 3	< 0.5
	6,800	1,000	120	19	5.2	0.8

APPENDIX I (continued)

b. JUNE, 1973

Station	Zinc		Copper		Cadmium	
	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
Gambier Island						
G-1	9,600	1,700	870	160	24	4.3
	11,000	1,500	1,200	160	25	3.3
	8,000	1,200	1,000	150		
	12,000	1,900	1,300	210	25	4
	6,800	920	760	100	34	4.7
G-2	9,400	1,740	880	160	16	2.9
	13,000	1,700	1,100	140	17	2.2
	8,200	1,100	770	100	20	2.6
	14,000	2,400	1,200	200	15	2.4
	9,800	1,400	830	120	15	2.1
G-3	15,000	2,200	1,700	260	19	2.9
	11,000	1,700	1,300	190		
	9,000	1,200	1,100	160	27	3.7
	11,000	1,400	1,300	170	24	3.1
	11,000	1,600	1,300	190	21	3
Nanoose Harbour						
F-1	3,600	540	190	28	20	2.8
	4,400	646	190	28	14	2.1
	3,600	600	200	34	11	1.8
	2,400	400	110	19	8.9	1.5
	3,200	540	160	28	11	1.9
Lasqueti Island						
F-2	6,600	1,200	380	68	19	3.4
	3,600	520	190	27	18	2.5
	5,400	820	280	43	15	2.3
	6,200	1,000	380	63	19	3.1
	5,600	680	280	48	18	3.1
F-2*	5,600	1,100	300	59	19	3.8
	5,800	1,000	310	60	15	2.8
	6,800	1,100	360	62	18	3
	5,000	1,100	240	53	20	4.4
	5,800	1,000	370	67	13	2.4

continued...

* One oyster per sample.

Station	Zinc		Copper		Cadmium	
	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
Sooke Basin						
S-1	1,300	260	52	10	4	0.8
	1,100	190	41	7	3	0.6
	1,800	330	65	12	4	0.7
	1,200	230	55	11	< 3	< 0.6
	1,100	210	43	9	3	0.6

APPENDIX I (continued)

c. AUGUST, 1973

Station	Zinc		Copper		Cadmium	
	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
Powell River						
A-16	11,000	1,600	98	15	5.4	0.8
	14,000	2,000	160	22	5.6	0.8
	10,000	1,800	110	18	4.4	0.8
	11,000	1,400	130	16	4.6	0.6
	15,000	1,900	130	16	5.8	0.7
A-19	14,000	1,900	130	17	5	0.7
	15,000	1,900	140	18	3.7	0.5
	14,000	2,200	130	19	4.7	0.7
	16,000	2,100	180	25	5.5	0.7
	9,000	1,200	79	9	2.8	< 0.3
A-20	8,300	1,000	160	19	9.8	1.2
	14,000	1,600	280	32	11	1.2
	10,000	1,200	270	32	11	1.3
	5,700	800	120	16	9.3	1.3
	9,300	1,100	190	22	9.8	1.1
A-21	4,000	510	71	9	5.4	0.7
	4,900	700	100	15	5.6	0.8
	6,300	890	94	13	8.6	1.2
	5,000	860	96	16	7	1.2
	7,400	890	120	14	8.2	1
A-23	4,500	570	160	20	9.9	1.2
	6,300	940	240	36	14	2
	7,600	820	230	25	16	1.7
	4,100	540	120	16	13	1.7
	5,900	560	150	14	15	1.5
A-25	11,000	1,800	160	25	5.9	0.9
	9,100	1,000	150	17	6.7	0.8
	12,000	1,800	150	23	< 2.9	< 0.4
	14,000	1,900	220	30	5.1	0.7
	13,000	1,900	190	28	4.9	0.7
Campbell River						
B-14	3,600	670	76	14	5.6	1
	1,900	370	39	8	6.4	1.3
	2,800	560	67	14	6.5	1.3
	3,200	620	61	12	8.4	1.7
	3,600	580	78	13	8.7	1.4

continued...

Station	Zinc		Copper		Cadmium	
	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
B-16	2,600	510	53	10	8.4	1.6
	4,500	890	89	18	9.2	1.8
	1,900	360	40	8	8.2	1.6
	2,400	320	50	7	8.5	1.1
	3,300	520	71	11	9.3	1.5
B-17	4,100	660	100	16	6.7	1.1
	6,700	870	180	23	11	1.4
	5,700	860	110	16	10	1.5
	4,700	820	87	15	11	1.9
	3,100	420	61	8	<2.3	<0.3
B-18	4,600	800	140	24	10	1.7
	4,000	640	120	19	8.9	1.4
	4,300	740	120	21	11	1.9
	5,600	1,000	140	25	12	2.1
	4,400	730	120	19	6.5	1.1
B-19	5,400	780	200	28	10	1.4
	4,500	510	100	12	11	1.3
	2,200	440	100	20	5.6	1.1
	3,600	660	120	22	9.9	1.8
	4,300	690	89	14	9.9	1.6
B-20	5,500	1,100	140	27	9.1	1.8
	7,300	1,500	170	33	10	2.1
	4,400	880	120	23	8.4	1.7
	4,700	960	120	25	7	1.4
	4,900	980	120	23	8	1.6
B-21	6,900	1,200	230	41	11	2
	4,000	620	140	22	6.1	1
	9,500	1,700	290	51	16	2.7
Alberni Inlet						
C-15	11,000	2,400	44	10	<2.6	<0.6
	16,000	2,900	110	20	<2.5	<0.5
	9,000	1,600	57	10	<2.7	<0.5
	10,000	2,300	50	11	<2.6	<0.6
	7,500	1,700	39	9	<2.7	<0.6

continued...

Station	Zinc		Copper		Cadmium	
	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
Crofton						
D-9	5,200	1,100	71	15	4.3	0.9
	4,200	900	71	15	< 3.5	< 0.8
	4,200	840	68	14	< 2.7	< 0.6
	3,600	760	57	12	4	0.8
D-10	9,600	1,000	160	17	7.2	0.8
	7,400	1,100	120	19	3.3	0.5
	11,000	900	220	17	11	0.8
	920	1,000	140	16	7.4	0.8
	11,000	1,200	250	27	7.7	0.8
D-11	5,000	860	81	14	4.2	0.7
	3,400	580	70	12	< 3	< 0.5
	3,000	620	57	12	< 3	< 0.7
	3,000	640	57	12	4	0.8
	6,200	960	110	17	7.5	1.2
D-12	4,000	760	93	18	7.4	1.4
	3,000	720	67	16	5.6	1.3
	2,600	500	65	13	3.8	0.8
	2,000	400	54	11	5.2	1.1
	3,400	700	78	16	8.7	1.8
D-13	2,300	510	55	12	2.8	0.6
	2,900	630	62	14	4.8	1.1
	2,000	470	54	13	3.4	0.8
	2,000	390	61	12	3.7	0.7
	2,200	410	61	11	4.8	0.9
D-15	4,300	990	83	19	3.7	1
	6,500	1,300	120	24	3.3	0.7
	4,500	970	65	14	4.1	0.9
	4,000	800	75	15	3.4	0.7
	5,900	840	120	17	6	0.9
D-16	12,000	1,700	200	28	4.4	0.6
	9,100	1,200	110	15	7.1	1
	7,900	950	130	15	7.8	0.9
	9,300	1,300	150	21	5.3	0.8
	8,000	1,200	130	20	5.9	0.9
D-17	8,400	660	45	4	7.5	0.6
	20,000	2,300	140	16	7.2	0.8
	8,200	1,200	68	10	3.1	0.4
	26,000	2,400	250	23	7.8	0.7
	22,000	2,000	140	13	10	0.9

APPENDIX I (continued)

d. NOVEMBER, 1973

Station	Zinc		Copper		Cadmium	
	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
Powell River						
A-13	6,100	670	140	15	9.3	1
	10,000	1,300	240	29	14	1.7
	5,300	570	91	10	7	0.8
	7,500	800	150	16	8.2	0.9
	9,000	890	230	22	13	1.3
A-21	7,800	1,200	240	35	9.3	1.4
	4,400	720	140	22	7.3	1.2
	5,400	860	150	24	6.7	1.1
	5,000	740	-	-	7.6	1.1
	3,600	460	420	54	14	1.9
A-23	3,600	620	160	27	8	1.4
	3,400	560	120	19	8.6	1.4
	5,000	760	150	23	14	2.1
	5,000	760	140	22	11	1.7
	4,400	700	120	20	12	1.9
A-24	9,200	1,200	410	53	23	3
	5,400	700	250	33	16	2.1
	7,000	860	330	40	21	2.6
	3,600	620	230	25	20	2.2
	7,400	860	310	37	17	2
A-25	12,000	1,300	180	18	7.1	0.7
	14,000	1,300	180	18	5.7	0.6
	12,000	1,500	160	21	5.2	0.7
	14,000	1,400	180	19	6.7	0.7
	14,000	1,500	150	17	5.2	0.6
Vananda Bay	7,000	940	320	43	14	1.9
	11,000	1,200	450	52	17	2
	8,000	1,000	280	37	8	1.1
	8,200	1,100	370	50	14	1.9
	8,800	1,200	330	45	14	1.9
Campbell River						
B-14	3,200	560	82	15	8.4	1.5
	3,600	1,600	72	31	9	3.8
	2,400	440	64	12	10	1.8
	7,000	1,100	190	30	14	2.2
	4,000	780	110	21	9.2	1.8

continued...

Station	Zinc		Copper		Cadmium	
	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
B-15	4,000	620	110	16	11	1.7
	2,800	480	84	15	6.6	1.2
	3,200	620	75	15	8.1	1.6
	4,200	660	92	15	7.8	1.2
	3,200	620	76	14	7.6	1.4
B-16	3,600	620	83	14	12	2
	3,200	600	70	14	9.1	1.8
	4,200	800	77	14	9.6	1.8
	3,200	540	55	9	8.4	1.4
	2,400	460	61	11	5.8	1.1
B-18	4,200	760	120	22	11	1.9
	2,600	460	69	12	11	1.9
Crofton						
D-9	3,000	580	76	14	3.4	0.6
	5,000	940	57	11	5.5	1
	5,600	1,000	74	14	5.5	1
D-10	10,000	940	120	12	6.7	0.6
	12,000	1,400	190	22	9.4	0.5
	12,000	1,100	160	15	9.1	0.9
D-11	7,300	1,500	81	16	5.7	1.2
	4,200	790	53	10	5.1	1
	6,000	1,100	78	14	7.4	1.3
D-14*	2,500	550	47	10	5.4	1.2
	1,600	360	43	10	3.6	0.8
	2,100	480	50	11	5.6	1.3
D-15	7,400	940	160	21	6.5	0.8
	4,600	600	110	15	5.8	0.8
	6,600	840	120	16	7.8	1
D-16	6,200	850	76	10	5.8	0.8
	11,000	1,100	87	9	7.1	0.7
	2,000	330	33	5	5.4	0.9
D-17	15,000	1,000	110	8	< 3	< 0.2
	10,000	1,000	81	8	3.4	0.3
	13,000	1,800	97	13	4.1	0.5

continued...

* new designation

Station	Zinc		Copper		Cadmium	
	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
Nanoose Harbour						
F-1	2,600	440	110	19	5.1	0.9
	2,800	580	72	15	7.6	1.5
	2,800	520	73	14	6.6	1.3
	2,400	460	94	17	8.3	1.5
	2,400	400	110	17	6.1	1
Lasqueti Island						
F-2	3,000	440	120	18	11	1.6
	7,400	1,100	.280	41	25	3.6
	3,000	480	110	18	28	4.5
	4,800	880	230	42	17	3
	7,700	820	420	44	23	2.5
Gambier Island						
G-1	10,000	1,400	1,200	170	24	3.2
	14,000	1,700	1,400	160	26	3
	15,000	2,100	1,300	170	36	4.8
	13,000	1,800	1,500	190	31	4
	17,000	1,900	1,600	170	35	3.8
G-2	17,000	1,800	1,500	150	23	2.3
	15,000	1,600	1,400	140	18	1.8
	10,000	960	-	-	18	1.6
	14,000	1,800	900	120	24	3.2
	16,000	1,800	1,400	150	18	2
G-3	8,000	960	690	84	23	2.8
	7,800	1,200	810	130	27	4.2
	4,400	340	490	37	32	2.5
	14,000	1,900	1,400	180	23	3
	16,000	1,700	1,300	130	33	3.5

APPENDIX II

HEAVY METAL DETERMINATIONS IN MUSSELS AND CLAMS
(Results in μg/gm)

a. SHELLFISH TISSUE ANALYSIS - *Protothaca staminea*

b. SHELLFISH TISSUE ANALYSIS - *Saxidomus giganteus*

c. SHELLFISH TISSUE ANALYSIS - *Mya arenaria*

d. SHELLFISH TISSUE ANALYSIS - *Mytilus edulis*

APPENDIX II HEAVY METAL DETERMINATIONS IN MUSSELS AND CLAMS
(Results in μg/gm)

a. SHELLFISH TISSUE ANALYSIS - *Protothaca staminea*

Area	Station	Number of Specimens	Zinc		Copper	
			Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
Powell River	A-16 (Aug./73)	2	200	26	11	1.4
		2	190	26	8	1
		2	150	21	7	1
Campbell River	B-16 (Aug./73)	2	170	21	11	1.4
		2	170	24	12	1.7
		2	170	25	10	1.4
	B-17	2	190	26	9	1.2
		2	170	28	8	1.3
		2	310	48	8	1.3
		2	180	26	9	1.4
		2	230	29	<0.5	<0.06
	B-18	2	160	27	10	1.7
		2	160	24	10	1.4
		2	94	16	14	2.3
		2	200	34	13	2.1
		2	220	33	8	1.2
	B-19	3	97	12	18	2.4
		3	160	19	23	2.7
		3	160	20	10	1.3
		3	170	23	11	1.4
		3	120	16	12	1.5
	B-20	1	50	10	23	4.4
		1	100	14	40	5.4
		1	88	15	30	5
Alberni Inlet	C-15 (Aug./73)	2	210	28	5	0.7
		2	390	53	7	0.9
		2	200	25	17	2.2
		2	150	20	9	1.2
		2	87	13	11	1.6
Crofton	D-9	2	130	16	7	0.9
		2	78	9	14	1.5
		2	89	11	19	2.3
		2	220	28	15	2
		2	130	17	8	1.1

continued...

Area	Station	Number of Specimens	Zinc		Copper	
			Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
	D-11	1	190	28	16	2.3
	D-13	1	87	14	13	2
		1	100	16	6	0.9
		1	75	13	< 0.61	< 0.1
		1	-	-	8	1.2
		1	97	16	7	1.1
	D-15	1	100	12	< 0.7	< 0.07
		1	89	14	15	2.3
		1	98	15	5	0.8
		1	61	11	8	1.5
		1	75	10	8	1.1

APPENDIX II (continued)

b. SHELLFISH TISSUE ANALYSIS - Saxidomus giganteus

Area	Station	Number of Specimens	Zinc		Copper	
			Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
Powell River	A-16	2	230	35	11	1.6
		2	230	38	10	1.7
		2	200	34	10	1.7
		2	150	22	9	1.3
		1	230	32	14	2
	A-19	2	170	29	10	1.7
		2	170	22	9	1.2
		2	140	26	12	2.1
		2	170	24	11	1.6
		2	170	28	14	2.3
	A-25	2	120	22	8	1.5
	(Aug./73)	2	98	18	15	2.8
Campbell River	B-16	1	71	12	21	3.6
	(Aug./73)	1	96	17	18	3.1
		1	87	15	11	1.9
	B-17	1	93	15	19	3
		1	120	18	19	2.8
		1	130	19	18	2.7
		1	130	18	33	4.8
		1	110	17	26	3.9
	B-18	1	96	15	21	3.4
		1	110	17	12	1.9
		1	78	13	13	2.2
		1	73	12	15	2.4
		1	84	15	23	4
	B-19	1	110	18	14	2.4
		1	120	17	35	5
		1	110	19	30	4.9
		1	130	20	14	2.3
		1	90	10	21	2.4
	B-20	1	150	26	110	19
Crofton	D-9	1	83	13	10	1.6
		1	170	28	7	1.2
		1	100	17	7	1.2
		1	92	15	7	1.1
		1	79	13	12	1.9

continued...

Area	Station	Number of Specimens	Zinc		Copper	
			Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
	D-11	1	120	19	18	2.8
	D-13	1	84	21	15	3.8
		1	110	29	24	6.2
		1	83	20	16	3.9
		1	78	18	13	2.9
		1	100	22	8	1.7
	D-15	1	92	14	8	1.2
		1	78	14	5	0.9

APPENDIX II (continued)

c. SHELLFISH TISSUE ANALYSIS - *Mya arenaria*

Area	Station	Number of Specimens	Zinc		Copper	
			Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
Powell River	A-19	1	160	26	18	1.5
		2	200	26	24	9.2
	A-20	2	250	28	19	2.2
		2	250	31	20	2.5
		2	410	69	13	2.1
		2	260	31	12	1.4
		2	320	48	39	5.8
	A-23	2	130	16	16	2
		2	230	22	15	4.6
		2	120	21	17	2.5
		2	160	20	15	1.9
		2	390	48	21	2.5
	A-25	3	400	33	26	4.1
		3	410	16	8	1.1
		3	690	60	25	2.1
Alberni Inlet	C-15 (Oct./73)	1	210	25	8	0.9
		1	430	46	6	0.7
		2	160	20	10	1.2
		2	200	20	9	0.8
		2	160	21	9	1.2
	C-17 (Oct./73)	1	390	39	-	-
		1	200	-	21	-
		2	360	36	17	1.7
		3	270	25	20	1.9
		4	310	38	21	2.5
	C-18	3	280	31	20	2.2
		3	300	31	16	1.7
		3	230	27	23	2.8
		3	150	21	24	3.3
		3	340	37	31	3.4
Crofton	D-11	1	80	10	14	1.6
		1	71	13	13	2.3
		1	170	20	12	1.4
		1	59	6	13	1.3
		1	66	9	14	2
	D-15	1	73	10	33	4.5
		2	67	8	20	2.6

APPENDIX II (continued)

d. SHELLFISH TISSUE ANALYSIS - *Mytilus edulis*

Area	Station	Number of Specimens	Zinc		Copper	
			Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
Powell River	A-14	5	220	33	12	1.7
		5	290	35	10	1.2
		5	290	31	10	1.1
	A-16 (Aug./73)	10	240	26	27	3
	A-21	5	370	49	14	1.9
		5	330	48	13	1.9
		5	320	49	13	1.9
	A-23	5	370	60	43	7
		5	240	40	20	3.4
		5	400	66	28	4.7
	A-25 (Aug./73)	10	390	47	34	4
Campbell River	B-14 (Aug./73)	5	350	42	51	6.1
		5	700	72	24	2.5
		5	460	50	44	4.7
	B-16 (Aug./73)	5	320	41	23	2.9
		5	500	62	10	1.3
		5	330	38	10	1.2
	B-17	5	87	13	< 3	< 0.4
		5	200	31	17	2.7
		5	160	22	12	1.6
	B-18	5	260	36	12	1.6
		5	250	34	16	2.1
		5	280	36	18	2.4
	B-19	5	360	47	19	2.5
		5	180	24	14	1.8
		5	260	36	28	3.8
	B-20	5	150	26	11	1.8
		5	170	27	17	2.5
		5	210	-	23	-

continued...

Area	Station	Number of Specimens	Zinc		Copper	
			Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
Alberni Inlet	C-15 (Aug./73)	5	300	34	70	7.9
		5	290	32	9	1
		5	340	41	25	3
		5	200	26	28	3.7
		5	450	54	10	1.2
	C-17 (Oct./73)	7	340	54	13	2.1
		9	350	71	15	2.4
	C-18 (Oct./73)	10	270	44	14	2.3
		12	270	44	16	2.6