MARINE TAILINGS DISPOSAL - CASE STUDIES

by

D.E. Goyette

Environmental Protection Service

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Introduction

The purpose of this paper is to describe some of the basic environmental problems associated with underwater tailings disposal and more specifically, marine disposal. Several case studies conducted by the Environmental Protection Service, Pacific Region, are presented to illustrate the extent and significance of the ecological damage that can occur.

Some form of ecological damage is unavoidable with any method of mine waste disposal, either on land or underwater. The selection of an appropriate waste treatment system to minimize this ecological damage often presents difficult and costly problems for the mining industry. At most inland mining operations in British Columbia, the common practice is land disposal, utilizing large tailings impoundments where the tailings solids are allowed to settle before discharge. The supernatant is then normally discharged directly into the receiving water, but can in many cases be recycled back to the mill. The latter is generally undertaken in areas with a limited water supply, such as the Highland Valley near Kamloops, B.C. Where tailings impoundments are used, the ecological damage is complete—either with the removal of all vegetation during the initial construction or burial by the tailings themselves. With proper construction of tailings impoundments and effluent control, the extent of the ecological impact can be controlled within a confined and pre-determined area. Upon abandonment the area affected can, for the most part, be repaired by reclamation with indigenous or new flora introduced.

At coastal mining operations, particularly in British Columbia, the normal practice has been to discharge tailings directly into the marine environment, often without any form of treatment. From the industry's point of view, economic, engineering, and aesthetic considerations make this the most desirable method of disposal. This approach continues to be popular as new mines are developed in B.C. and northern Canada. To date, approximately nine mines in B.C. have or are presently discharging tailings directly into marine waters. These are listed in Table 1. Tailings have been either deposited directly on the intertidal zone or discharged via a submerged outfall, with or without prior mixing with seawater. With this method of disposal, the potential for unconfined movement and re-suspension of tailings solids is very great. Consequently, the ecological impact can be much more extensive and occur over large areas of the receiving environment.

Ecological Effects of Marine Tailings Disposal

Physical Effects

B.C. Research Council (1970) in their review of underwater tailings disposal, point out that the major physical problems are turbidity and sedimentation. Turbidity is an alteration of the optical property of water, resulting from the presence of suspended particles and dissolved materials. This can occur naturally from such sources as stream run-off, re-suspension of bottom sediments, organic suspended matter, or originate from man's activities as in the case of mine tailings discharge. Turbidity, since it occurs naturally, does not necessarily imply a detrimental effect. However, if excessive and prolonged, particularly in areas or depths of the receiving waters which are accustomed to low, natural levels, increases in turbidity can cause significant ecological changes. Under these circumstances, the biological community which has evolved is dependent upon low sediment inputs.

The reduction in light penetration into the water column by increased turbidity can lead to a decrease in the range or population density of those organisms which are directly dependent upon sunlight for growth. This in turn will affect other organisms in the food chain which depend upon these aquatic plants as a source of food. This can ultimately lead to a reduction in the overall biological productivity of the receiving waters. Increased concentrations of suspended particles can cause clogging of the feeding apparatuses or abrasion in many of the sessile, filter-feeding animals, as well as free-swimming forms.

Irritation of the tissues by abrasion often results in increased mucus secretion, impairment of oxygen transport, and metabolism.

Increases in the suspended solids concentration have been shown to lower the pumping rates in many bivalves. Loosanoff and Tommers (1948) found that as little as 0.1 g/ℓ of silt reduced the average pumping rate of adult oysters by 57 percent. At a concentration of 1.0 g/ℓ, the reduction in average pumping rate was more than 80 percent and reached 94 percent at concentrations from 3.0 to 4.0 g/ℓ.

Prey-predator relationships can also be affected by increased turbidity. The reduction in visibility lowers the efficiency of capture, while the increased protection afforded to the prey can result in an imbalance in the normal community structure.

A more dramatic and perhaps the most significant effect of marine tailings disposal is the alteration of the habitat and burial of aquatic organisms caused by excessive deposition of tailings solids.

The benthic community is comprised of: (a) epifauna, those animals living either attached or free-living on or associated with the substrate, e.g., crabs, (b) infauna, those animals living in the substrate, usually sand or mud, e.g., clams, and (c) pelagic organisms, which are frequently associated with the bottom for such activities as feeding, egg-laying, etc., e.g., rockfish.

Lacking the mobility, epifaunal and infaunal organisms are the most seriously affected by tailings disposition. For those living on hard surfaces, this may mean actual burial or effects on settling rates, growth and availability of food or shelter. For those inhabiting particulate substrates, this may mean limitations on species distribution or possibly elimination by altering the grain-size composition of the sediments. The majority of the tailings particles are extremely fine and fall within a relatively narrow size-range. Consequently, tailings deposits, after a period of time, form a compact layer over the natural sediments which can alter the permeability and movement of water through the sediments.

Ellis (1936) found that fresh-water mussels were unable to survive in sand and gravel if the overlying silt layer was greater than 1/4 to 1 inch in thickness.

Pelagic organisms may also be forced to move to other areas as tailings deposits affect feeding or spawning grounds.

Heavy Metal Contamination

Another critical aspect of marine tailings disposal concerns the bio-accumulation or bio-magnification of heavy metals. This represents both a hazard to the organism itself, as well as the loss of fishery resources due to potential hazards to human health. Many marine organisms, in particular the bivalves, have been shown to concentrate heavy metals many times that found in their environment. Earlier estimates for oysters indicated concentration factors of 100,000 times that of sea water for zinc, 300,000 times for cadmium, and 14,000 times for copper (Brooks and Rumsby, 1965). It was originally thought that the major source for heavy metal uptake was metals in solution. However, recent studies indicate that the most important source of contamination in shellfish is directly from the sediments (Ayling, 1973). Tissue analysis of oysters found along the Tamar River, Tasmania, showed heavy metal concentrations 10 to 40 times that found in the sediment. Heavy metal uptake undoubtedly occurs from both dissolved metals and the sediments. Contamination from the sediments can occur either through direct ingestion of particulate matter containing heavy metals or possibly through a process of sediment diagenesis.

Elderfield and Hepworth (1975) were unable to explain the heavy metal concentrations in the sediment pore water on the basis of metal-sulphide solubility and postulated a process of sediment diagenesis. Their studies indicated heavy metal concentrations were many orders of magnitude higher than predicted on the basis of sulphide solubility. These concentrations set new limits of solubility and established concentration gradients which allowed heavy metals to diffuse upward into the sediment surface and overlying water column. This could substantially increase the heavy metal concentrations available to marine organisms. Consequently, the concentration factor of marine organisms and movements of heavy metals through the ecosystem makes any heavy metal input into marine waters, no matter how small, extremely significant and potentially hazardous to human health.

Case Studies

Without venturing into the specific details of each situation, the foregoing is a brief outline of various case studies conducted in British Columbia to illustrate some of the problems encountered as a result of marine tailings disposal.

Island Copper Mine - Rupert Inlet

The Island Copper Mine is a large copper-molybdenum mine located on the shore of Rupert Inlet, northern Vancouver Island. The mine began production in October, 1971, and currently processes approximately 33,000 tons of low-grade ore (0.52% copper, 0.025% molybdenum) per day. The tailings effluent is piped directly to Rupert Inlet and discharged at a depth of 50 metres. Before discharge, the tailings are mixed with sea water from Rupert Inlet, drawn from a depth of 15 metres. The daily volume of effluent is approximately 9.3 million Imperial gallons. During the initial 3-1/2 years of operation, approximately 35 million tons of tailings solids have been discharged into Rupert Inlet.

As a result of the discharge of raw tailings, extensive turbidity has developed over a large portion of Rupert Inlet and adjacent waters. On several occasions, surface turbidity has been observed over a distance of approximately 9 miles from the outfall. The area of turbidity is shown in Figure 1. The presence of large "turbidity clouds" in an area influenced by extreme tidal activity suggests a direct relationship with tidal currents. Current measurements taken in this region (Farmer, 1975, personal communication) showed current velocities which are capable of maintaining a major portion, if not all, of the tailings effluent in suspension. Near the floor of Rupert Inlet, maximum current velocities up to 3.5 knots were recorded well within the range capable of re-suspending most benthic deposits.

A latent period of approximately 1 year for turbidity to appear at the surface indicated that the major portion of the surface turbidity is associated with the movement of benthic deposits into the zone of large tidal activity.

Submersible observations in Rupert Inlet revealed that highly turbid conditions were present throughout the entire water column. Visibility near the surface of Rupert Inlet was limited to approximately 2.0 metres. This was reduced to 0.5 metres at a depth of 60 metres and continued to the floor of the inlet.

Poor visibility was caused by extremely fine tailings particles suspended throughout the water column. This gave the water the appearance of what is best described as a "dense grey fog". There was no evidence of flocculation of the suspended particles except near the floor of the inlet. In comparison, visibility in Quatsino Sound, beyond the area of turbidity, was estimated at times to be greater than 10 metres.

The presence of turbidity in the water column and the appearance of "turbidity clouds" in Rupert Inlet following a period of 12 days when no wastes were discharged, suggests that the problem will continue for some time after the mine ceases production.

As a result of the re-suspension and tidal dispersion of tailings solids, deposits have spread rapidly over the bottom of Rupert Inlet and adjacent areas. Figures 2 to 5 show the progression of tailings deposits from 1971 to 1974 as defined by visual evaluation of grab samples. Submersible observations in 1975 indicated that tailings deposits have now moved further towards the head of Holberg Inlet.

SCUBA diving observations further show that tailings deposits in many regions extend up to and include the intertidal zone. Deposits greater than 1/4 to 1/2 inch in thickness have resulted in the burial of many marine organisms and their source of food. These observations show that the continued deposition of tailings solids, particularly in the shallow, highly productive zones will result in substantial and long-term ecological changes throughout a major portion of Rupert Inlet and adjacent areas.

Britannia Mine - Howe Sound

The Anaconda Britannia Mine is located in Howe Sound, north of the City of Vancouver (Figure 6). The mine was in operation from 1899 to 1975, processing about 3,000 tons of ore per day. During this time, tailings were discharged directly into Howe Sound through two effluent pipelines located within the intertidal zone. In addition to the tailings effluent, acid mine water, following copper cementation, has been discharged to Britannia Creek which flows into Howe Sound.

Tailings from the mine form an extensive plume over the bottom of Howe Sound. From submersible observations, the northern extent of the tailings plume lies within 2 miles of the head of Howe Sound. Along the eastern slope of Howe Sound, adjacent to the mine, large terraces, 30 to 40 feet in height, indicated that considerable slumping and tidal scouring has occurred at the surface of the tailings bed. The long history of tailings deposition in Howe Sound has resulted in complete coverage of the natural sediments over most of Howe Sound. Wherever tailings deposits were present, both on the floor of Howe Sound or along the rocky shoreline, invertebrate macrofauna was sparse or absent. Near the mine site, intertidal macro-invertebrates are completely absent (McDaniel, 1973). The solid rock habitat around the mine site has been substantially disrupted by tailings deposition.

Copper and zinc analysis of shellfish tissue indicate widespread heavy metal contamination has occurred in Howe Sound. Figures 7 and 8 and Tables 2 and 3 show the mean dry weight concentration of copper and zinc found in oysters (*C. gigas*) and mussels (*Mytilus edulis*). Maximum average copper and zinc concentrations in oyster tissue were

2,550 and 14,000 μg/g, respectively. The mean dry weight copper and zinc concentrations in control oysters were 380 and 3,500 μg/g, respectively. The tissues of oysters contaminated with copper were green in colour and generally undesirable for human consumption. It is anticipated that in this case the major source of shellfish heavy metal contamination originates from acid mine water, although it has been shown that significant copper and zinc concentrations are present in the tailings sediment in Howe Sound (Thompson and McComas, 1974). Copper and zinc concentrations in the sediments ranged from 83 to 1,394 μg/g and 97 to 1,324 μg/g, respectively. This could also provide a significant source of heavy metals to marine organisms.

Other Marine Disposal Sites

Shellfish heavy metal contamination has been shown at other marine tailings disposal sites. At Texada Mines, dissolved copper concentrations of 1.3 to 2.5 μg/ℓ (ppb) and total copper concentration in the tailings solids of 1,000 mg/ℓ (ppm) indicate that the heavy metal contamination in shellfish was coming largely from ingestion of tailings solids. Copper concentrations found in oysters collected within the tailings plume averaged 3,700 mg/ℓ (ppm). The number of species of marine invertebrates also dropped from 40 species in control areas to 2 species within the area of tailings deposition.

In cases where raw tailings are discharged into exposed waters, the most significant environmental impact lies in the alteration of natural habitats. Wave action, mixing of tailings solids with natural sediments, and tailings dispersion reduce the possibility of developing compact tailings deposits. In the case of Jordan River mines, the periodic discharge of raw tailings into Juan de Fuca Strait created a fine sandy habitat compared to the original coarse sand and cobble substrate. Shifting tailings appears to preclude many of the original benthic organisms. However, these are replaced by new forms which are adjusted to sandy substrates. Increases in copper and zinc concentrations in shellfish around the point of discharge, however, have been observed.

Abandoned Disposal Sites

Underwater observations carried out at abandoned disposal sites indicate that the creation of either highly unstable or compact tailings deposits substantially restrict biological rehabilitation. Observation of tailings deposits after abandonment for 10 years showed only minimal recolonization by a select number of marine macro-invertebrates. These were predominantly epifaunal species with little evidence of any infaunal species.

If tailings deposition occurs over a hard, rocky substrate, the alteration of this habitat and the elimination of many benthic organisms which inhabit these areas appeared to be permanent.

Closing Comments

Studies carried out at various coastal mining operations in B.C. demonstrate that the unconfined disposal of mine tailings into marine waters usually results in significant and wide-spread ecological damage. The extent and long-term nature of this damage, plus the potential hazards to human health through bio-accumulation of heavy metals, indicate that the disposal of raw tailings into the marine environment should be considered only as the last resort, after all land disposal alternatives have been exhausted. Final decision on marine tailings disposal should not be made without a detailed evaluation of the physical, chemical, and biological characteristics of the receiving waters. This evaluation should, above all, include studies of the physical oceanography, natural heavy metal concentrations of the biota, and fishery resources of the receiving waters. An environmental monitoring program of a minimum of 3 years' duration should be undertaken before any site preparation and effluent discharges take place.

TABLE 1 B.C. MINES DISCHARGING TO MARINE WATERS

Name of Mine	Discharging to	T.P.D.	Mineral	Operating
Island Copper	Rupert Inlet	33,000	Cu, Mo	Yes
Westfrob	Tasu Sound	8,000	Fe, Cu	Yes
Texada	Georgia Strait	3,600	Fe, Cu	Yes
Britannia	Howe Sound	3,000	Cu, Zn	No
Jordan River	Juan de Fuca Strait	1,500	Cu	No
Brynnor	Toquart Bay, Barclay Sound	?	Fe	No
Yreka	Neroutsos Inlet	?	Cu	No
Jedway	Hecate Straits	?	Fe	No
B.C. Molybdenum*	Alice Arm	6,000	Mo	No

* To be re-activated.

TABLE 2 MEAN COPPER, ZINC, AND IRON CONCENTRATIONS (μg/g) IN THE PACIFIC OYSTER, *Crassostrea gigas*, HOWE SOUND, B.C., JUNE, 1975

Station	Zinc		Copper		Iron	
	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
5	10,200	1,650	2,550	420	230	37
6	11,000	1,700	1,500	220	112	17
7	10,000	6,400	2,100	880	142	26
9	12,000	2,050	1,300	340	96	15
10	7,900	1,500	1,200	240	69	13
11	14,000	1,600	1,800	210	91	11
12	6,800	1,100	890	130	83	13
13	7,100	1,400	770	160	64	13
15	3,500	750	380	80	70	16

TABLE 3 MEAN COPPER, ZINC, AND IRON CONCENTRATIONS (μg/g) IN MUSSELS, *Mytilus edulis*, HOWE SOUND, B.C., JUNE, 1975

Station	Zinc		Copper		Iron	
	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.	Dry Wt.	Wet Wt.
1	400	44	77	8	440	47
2	350	45	86	11	390	51
3	350	41	330	39	470	55
4	550	65	390	45	690	52
5	460	64	280	39	310	44
6	590	75	140	18	270	34
7	230	37	73	12	180	29
8	630	90	100	15	310	45
9	340	49	47	7	170	25
10	570	72	42	6	210	28
11	450	46	35	4	190	20
12	340	38	27	3	510	56
13	330	44	21	3	135	19
14	390	44	30	3	200	23
15	510	58	23	3	230	26

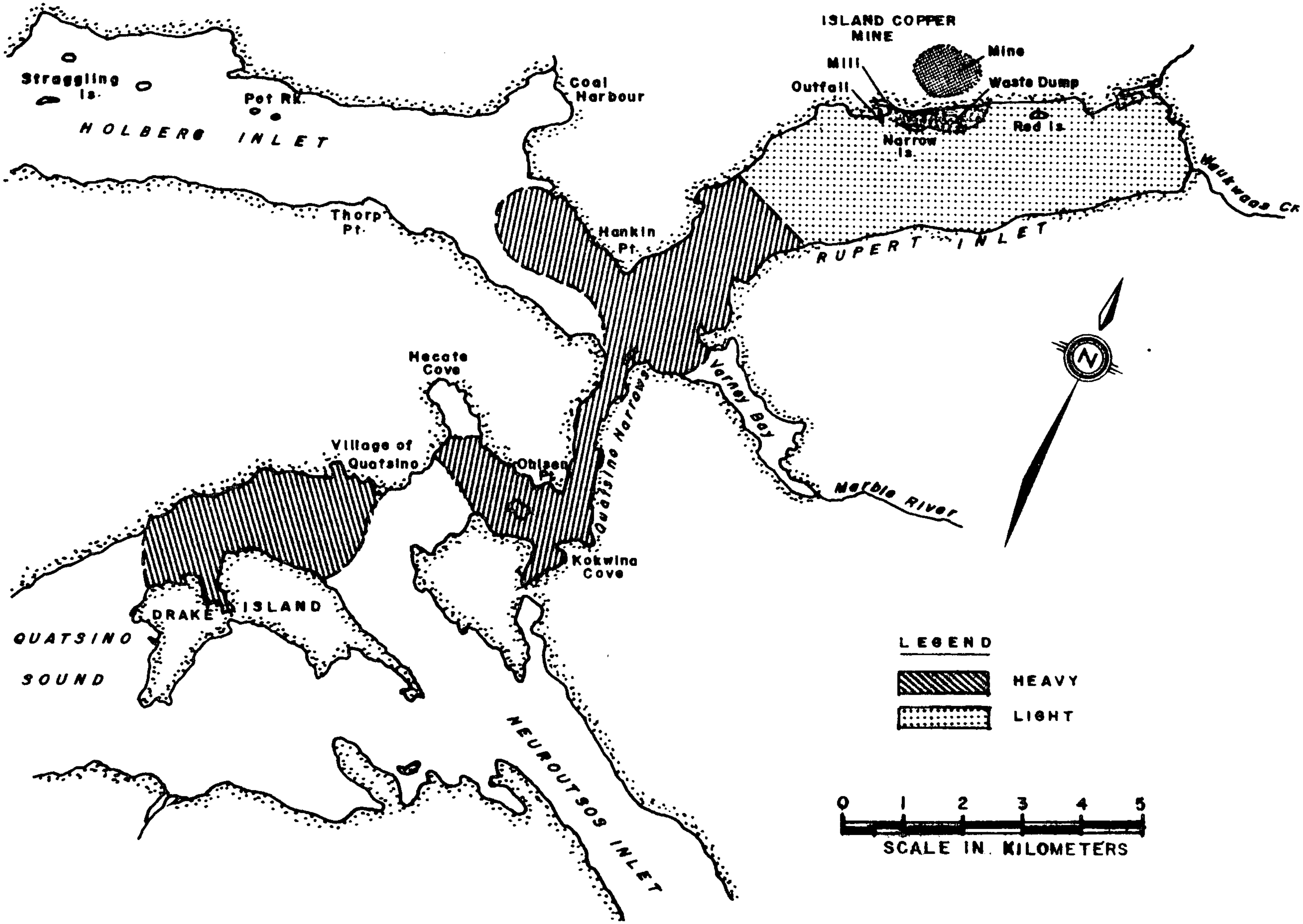

FIGURE 1 MAP SHOWING THE AREA OF SURFACE TURBIDITY - AUG. 3, 1973

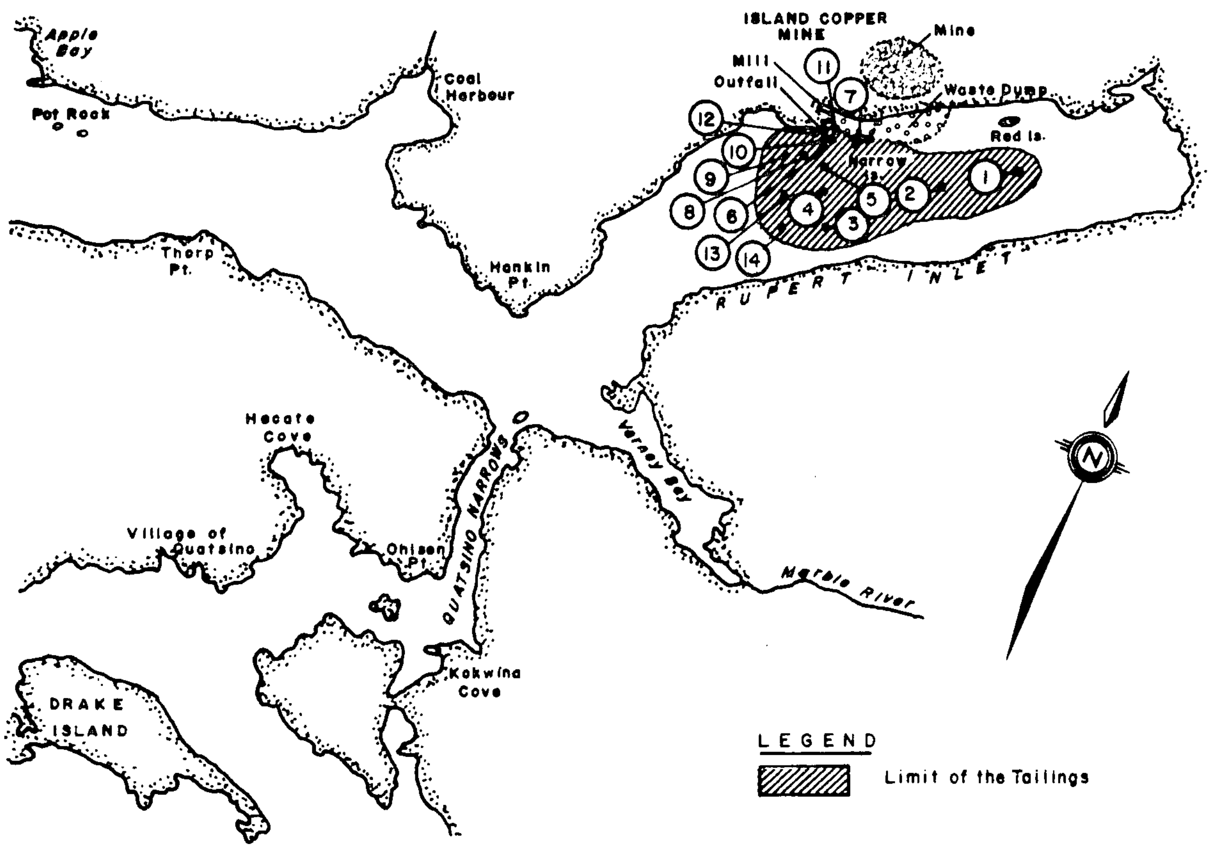

FIGURE 2 TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - NOVEMBER 3, 1971

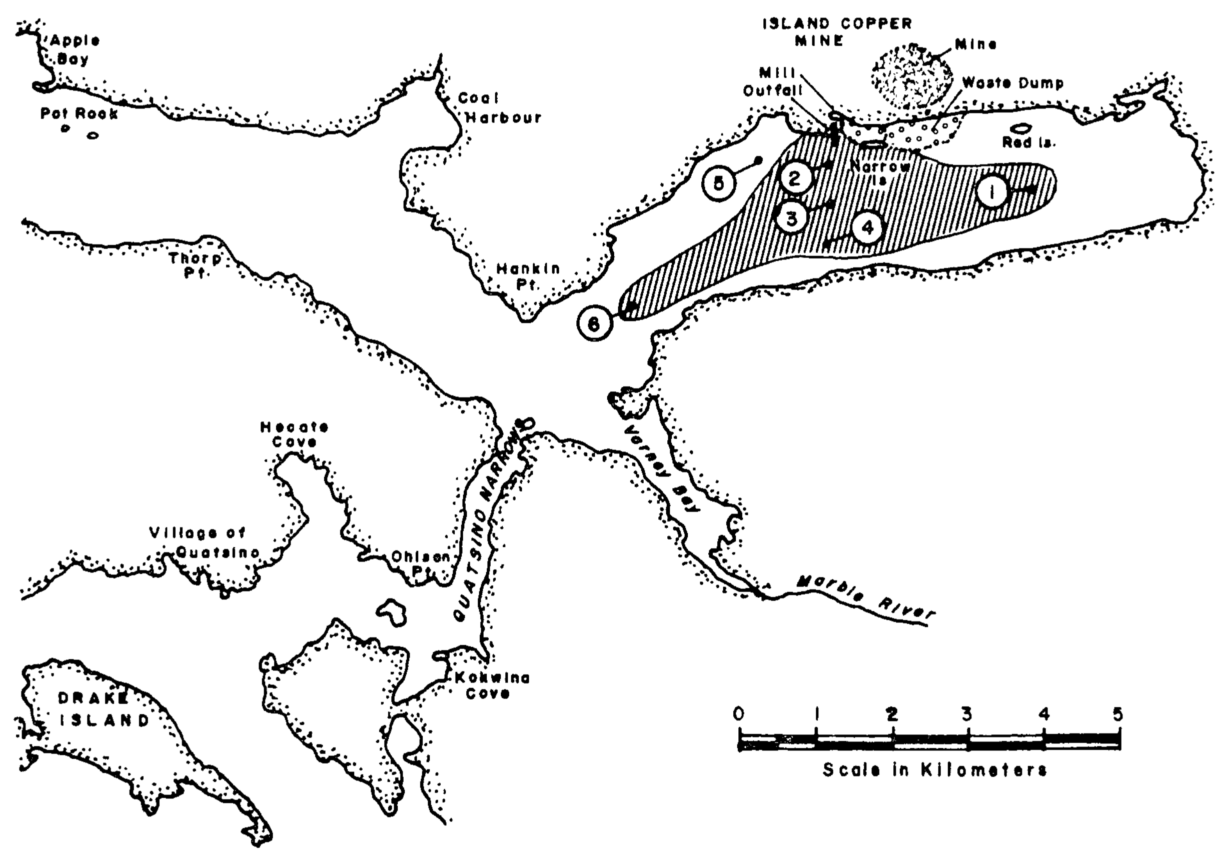

FIGURE 3 TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - MARCH 7, 1972

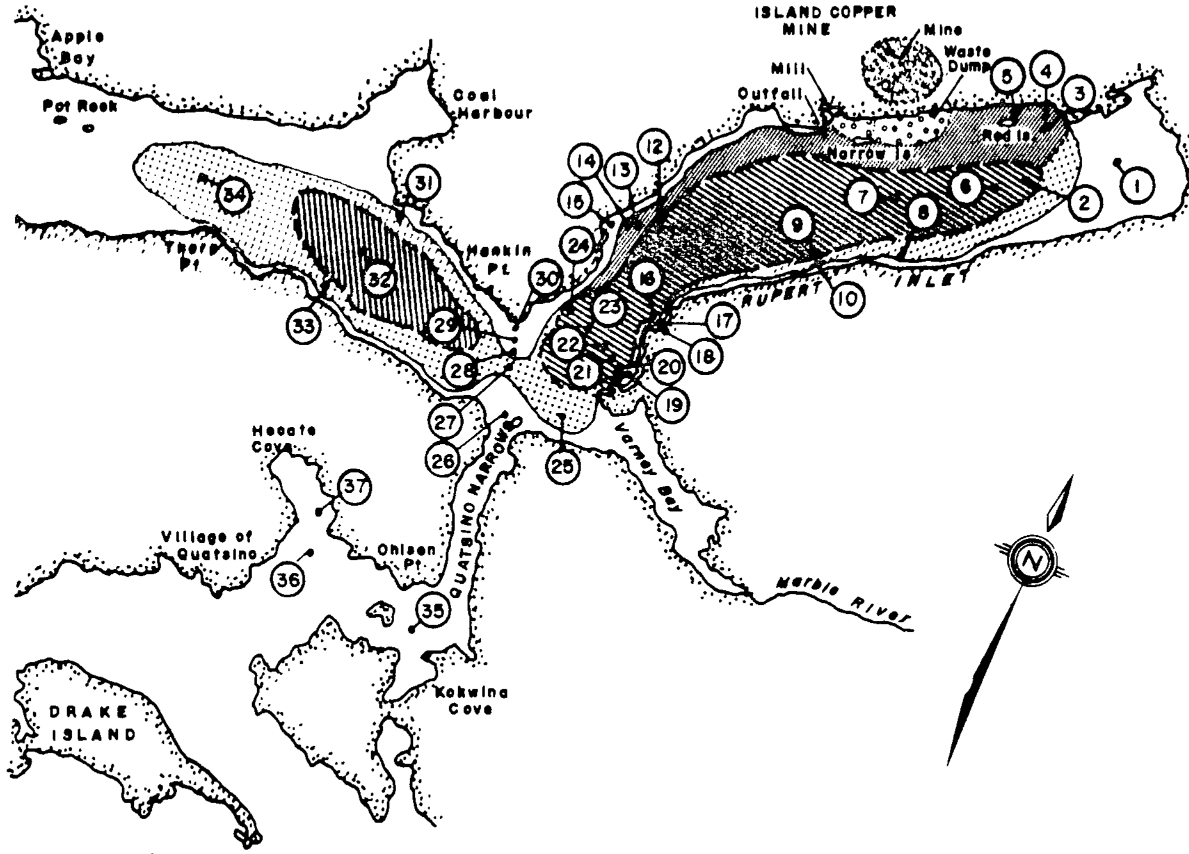

FIGURE 4 TAILING DISTRIBUTION AS DEFINED BY GRAB SAMPLES - OCTOBER 6, 1973

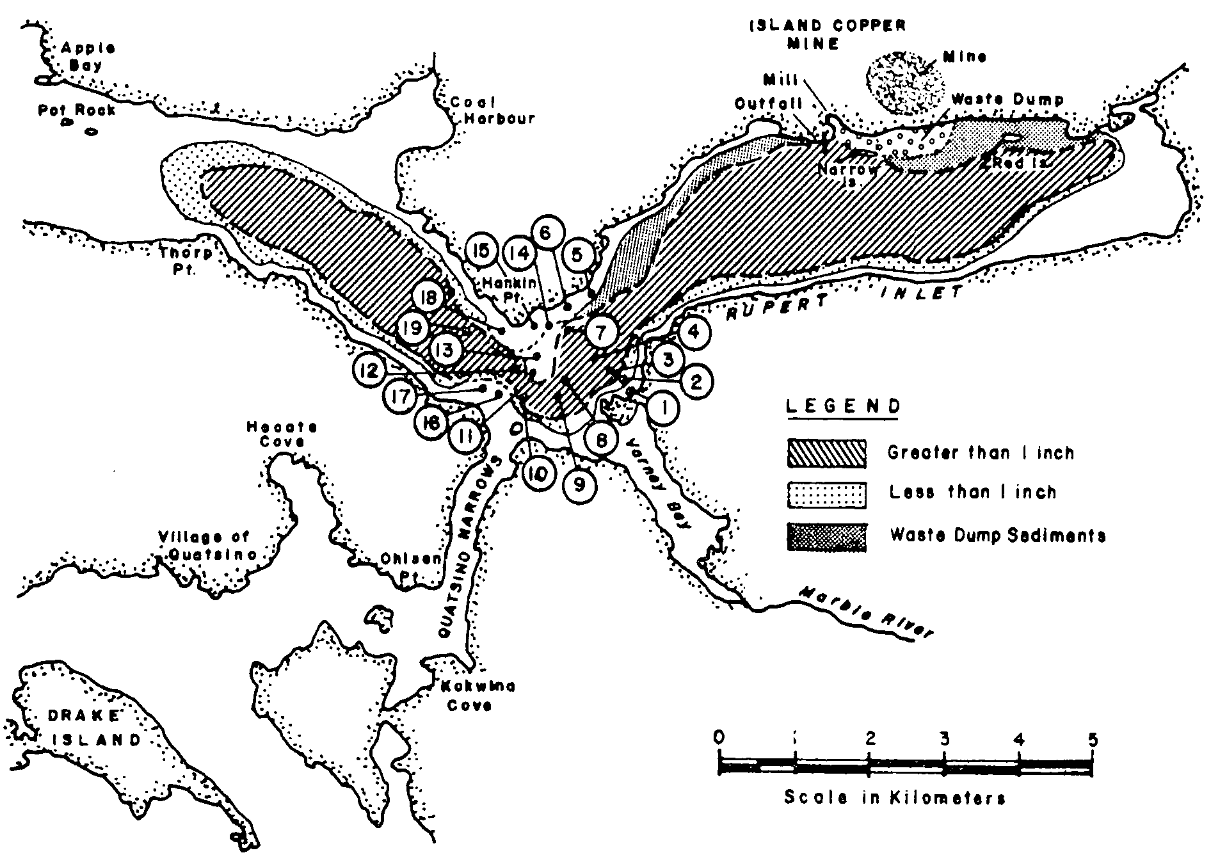

FIGURE 5 TAILING DISTRIBUTION AS DEFINED BY GRAB SAMPLES - MAY-JUNE 1974

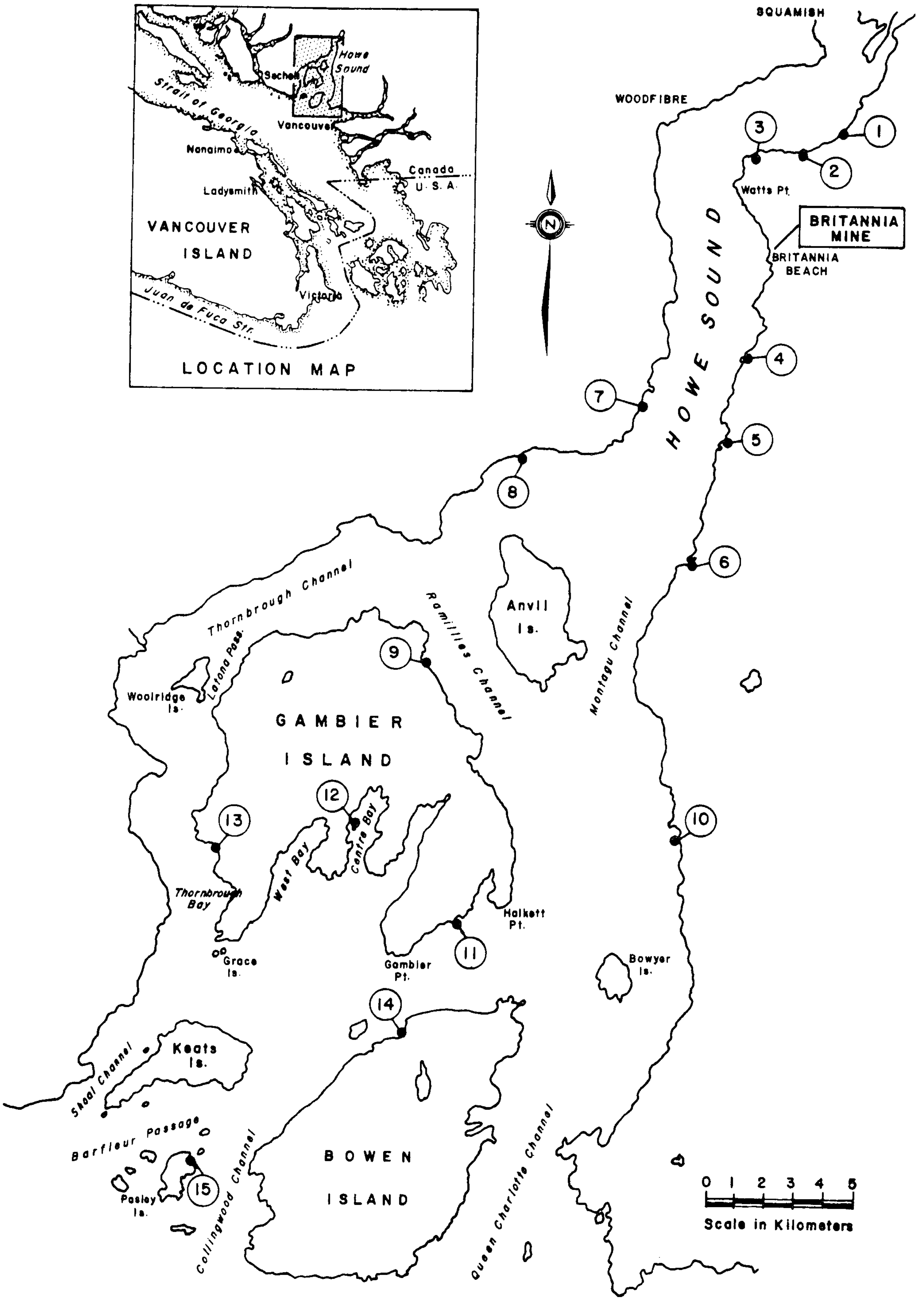

FIGURE 6.
HOWE SOUND SHELLFISH SAMPLING STATIONS - JUNE 1975

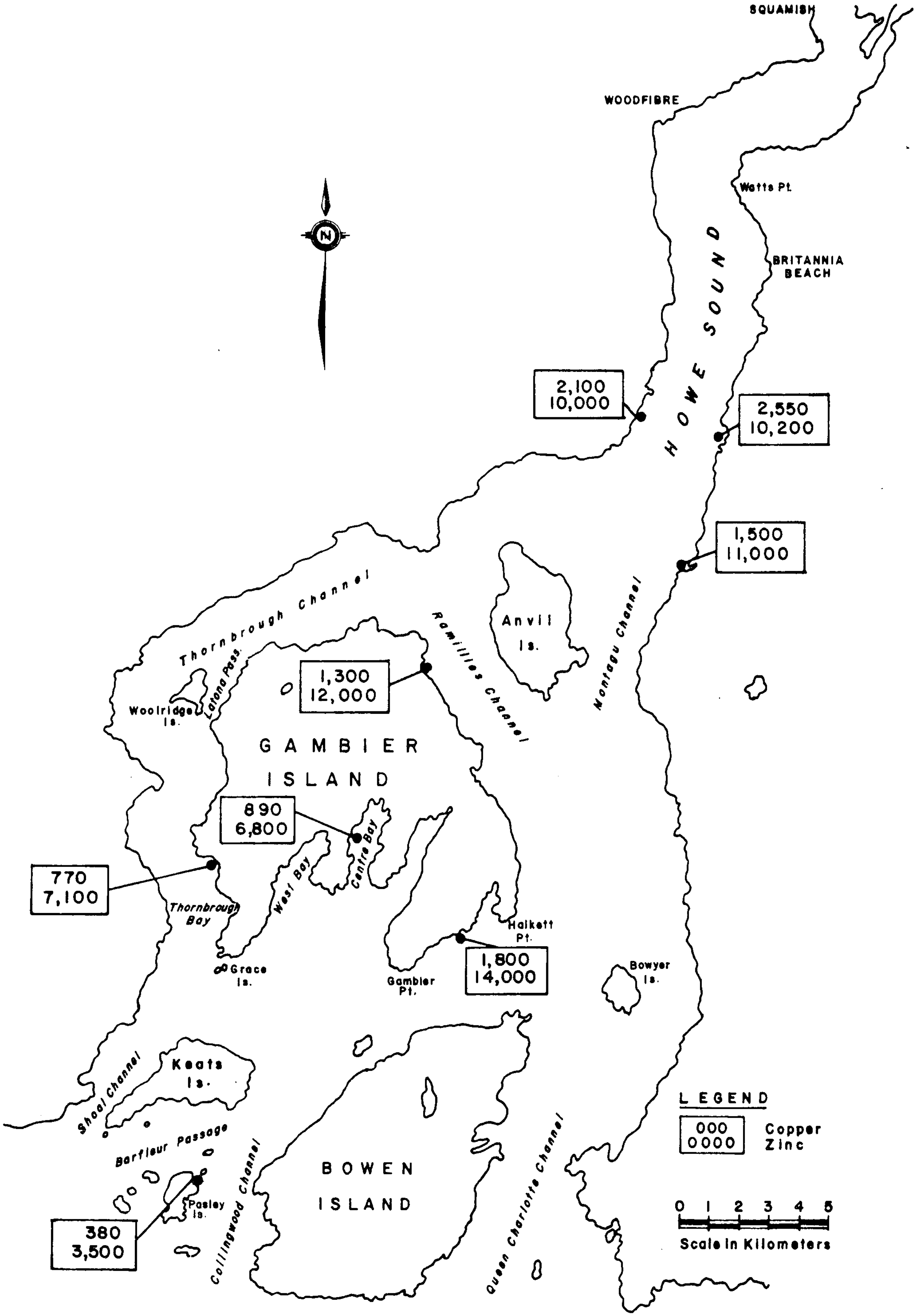

FIGURE 7.
MEAN DRY WEIGHT COPPER & ZINC CONCENTRATIONS ($\mu g/gm$) IN OYSTERS, *Crassostrea gigas* - JUNE 1975

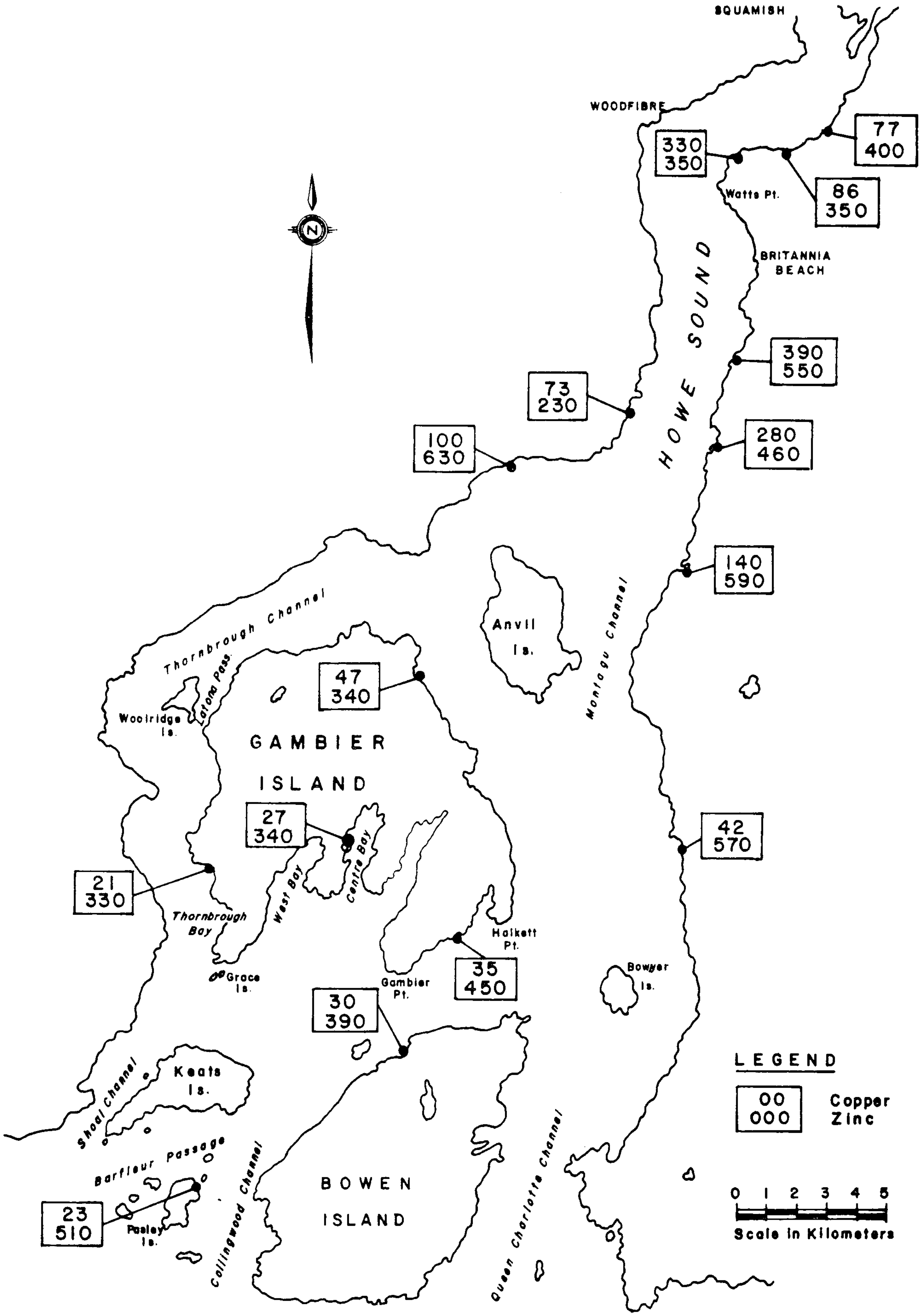

FIGURE 8

MEAN DRY WEIGHT COPPER & ZINC CONCENTRATIONS

(µg/ m) IN MUSSELS Mytilus edulis JUNE 75

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