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Report on Ocean Dumping R and D Pacific Region, Department of Fisheries and Oceans, 1980-1981

Edited by S.C. Byers and G.S. Calderwood
Dobrocky SEATECH Limited

Institute of Ocean Sciences
Department of Fisheries and Oceans
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REPORT ON OCEAN DUMPING R AND D PACIFIC REGION

DEPARTMENT OF FISHERIES AND OCEANS

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ABSTRACT

A review of ocean dumping research for 1980-81 was carried out at a workshop at the Institute of Ocean Sciences and proceedings assembled for publication. The focus of the review was primarily on analytical problems associated with bioaccumulation, bioavailability and biotoxicity as related to ocean dumping legislation which is currently under review. The presence and environmental impact of cadmium on marine and freshwater systems with respect to ocean dumping criteria is presented and the emphasis is placed on the distinction between bioaccumulation and ecotoxicity. Case studies demonstrate gross discrepancies between prevailing concentrations of cadmium in biota and those measured in sediments. The direct effect of silt on cod eggs and their indirect effect on cadmium and polyaromatic hydrocarbons accumulation in polychaete worms and bivalves is reported. Monitoring equipment for fish entrainment in Arctic dredging projects and statistical analysis of benthic communities in Tuktoyaktuk Harbour and McKinley Bay, N.W.T. are presented.

Résumé

La recherche sur les rejets en mer au cours de l'année 1980-1981 a fait l'objet d'un examen durant un Atelier tenu à l'Institut des sciences de la mer. Les minutes ont été recueillies pour fins de publication. Cet examen a porté principalement sur le problèmes analytiques liés à la bioaccumulation, la biodisponibilité et la biotoxicité en rapport avec la législation sur les rejets en mer, législation actuellement sous révision. On y a présenté la présence et l'impact environnemental du cadmium sur les systèmes d'eaux saline et douce tenant compte des critères que représentent les rejets en mer, et souligné la distinction entre la bioaccumulation et l'éco-toxicité. Des études de cas ont démontré l'écart énorme entre les concentrations prédominantes de cadmium sur la biota et celles recontrées dans les mesures de sédiments. On a observé l'effet direct des boues ou limon sur les oeufs de morue et leurs consequences indirectes, soit une accumulation d'hydrocarbures polyaromatiques et cadmium sur les vers polychètes et les mollusques bivalves. On y a présenté les instruments de contrôle servant dans les projets de dragage dans l'Arctique afin de ne pas entraver le développement des stocks de poissons et les analyses statistiques des communautés benthiques dans le port de Tuktoyaktuk et la baie McKinley dans les Territoires du nord-ouest.

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We would like to express thanks to the speakers, contractors and workshop participants who contributed to the workshop and the contents of this report. Special thanks go to A. Cornford of R.O.D.A.C., I.O.S. for chairing the workshop and to the guest speakers D. MacGregor of Ottawa and D.W. McLeese of St. Andrews, N.B. Our appreciation is extended to D. Herlinveaux for his assistance.

1. SUMMARY AND CONCLUSIONS

Research contracts for 1980-1981 in support of Ocean Dumping legislation were reviewed at a workshop held on December 2, 1981 at the Institute of Ocean Sciences, Sidney, B.C. This report summarizes the information presented at the workshop.

The studies focused primarily on analytical problems associated with bioaccumulation, bioavailability and biotoxicity. Several of the presentations identified difficulties in the evaluation of ocean dumping permit applications and of the ecological effects of dredging and dredge spoil disposal.

In a review of current legislation on ocean dumping in Canada and the United States, suggestions were made for modifications and additions to the current parameters used in the Canadian System 2000 Ocean Dumping Data Base. Standardization of methodologies for physical, chemical and biological sampling and analysis, and more biological evaluation was recommended for future ocean dumping research.

These recommendations were supported by an examination of the analytical methods and speciation of cadmium in sediments. Existing upper limits in ocean dumping legislation for cadmium were critically compared with levels of cadmium in a range of uncontaminated and contaminated environments and biota. The distinction between bioaccumulation and ecotoxicity was stressed. Case studies demonstrated gross discrepancies between prevailing environmental concentrations of Cd in biota and measurements of Cd that produced toxic effects on the biota. Future efforts should be encouraged to consider the presence of Cd in organisms and possibly assess ecotoxic hazards.

The bioavailability of sulphide-bound cadmium phases to the bivalve *Macoma balthica* and the polychaete *Capitella capitata* was determined using ^{109}Cd and ^{115}Cd-labelled sediments from False Creek, B.C. Cadmium sulphide phases were not available for uptake over a 60 day period due to their lack of solubility. Cadmium, however, was detected in False Creek biota, probably from the water column rather than from the sediments.

The study of production of lead alkyls in marine sediment supports the case for careful monitoring and standardizing of chemical methods. In contrast to earlier work (PMSR 79-18, pp 23) the present study concluded that the bioconversion of inorganic Pb (II) to organo-tetramethyllead (TML) is an unimportant factor in lead mobilization in marine environments. The greatest recovery of TML occurred under unsterile anoxic conditions but represented only 4% of the original trimethyllead acetate used to spike the culture.

Bioaccumulation of polynuclear aromatic hydrocarbons (PAH) by the clams *Mya arenaria* and *Mytilus edulis* was compared to that of the polychaete worm *Nereis virens*. The bioconcentration factors increased with increasing complexity and molecular weight of the PAH compounds. Data tend to indicate that bioavailability to clams of PAH compounds in sediment is dependent on the presence of these compounds in the surficial water. Polychaete worms, which live in greater contact with the sediment than filter-feeding clams, accumulated 3 times the uptake of PAH by clams from sediment but only 1/6 that of clams from water.

The ecological consequences of dredging and dredge spoil disposal in Canadian waters was discussed but the abstract is unavailable for review at the time of this publication.

It was concluded that the eggs of Pacific cod, *Gadus macrocephalus*, are adversely affected by high silt concentrations, and sediment contaminated witn heavy metals and polychlorinated biphenyls. The highest degree of mortality occurred in the early germ ring egg stage, particularly under high concentrations of suspended silt, although silt in quiescent tests increased hatchability. Contaminated sediment above 2 g L^{-1} sharply decreased hatchability in all test conditions but did not effect any differences in hatching time when compared to similar concentrations of silt. After 4 hours, the tested concentrations of sediments were not toxic to cod larvae nor was there any effect on their feeding behaviour.

As a result of increased dredging operations in the Arctic two contracts were undertaken. One was directed toward the statistical analysis of benthic communities from Tuktoyaktuk Harbour, N.W.T. A community of euryhaline species in the shallow water was distinguished from stenohaline species at the deep stations. Species diversity was higher in the shallow stations and independent of sediment type.

The other Arctic study tested devices for monitoring of fish entrainment in McKinley Bay and Tuktoyaktuk Harbour. All devices were considered poorly designed and inadequate for the intended purpose.

A brief overview of ocean dumping contracts in the Atlantic region provided some insight into research in progress on the east coast.

Extended abstracts of the studies contracted in 1980-1981 are contained in this report. Inquiries regarding the presented information and further publications should be directed to the listed scientific authorities at their associated institutions. Appendix I lists the abbreviations and addresses of these Institutions.

A list of those who attended the workshop is contained in Appendix II. Appendix III outlines contracts for 1980-1981. Studies contracted for 1981-1982 are listed in Appendix IV.

The Canadian Contractor Report of Hydrography and Ocean Sciences reports are available for distribution from the Institute of Ocean Sciences.

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2. EFFECTS OF SILT AND CONTAMINATED SEDIMENT ON EGGS AND LARVAE OF PACIFIC COD (*Gadus macrocephalus*)

E.R. McGreer and D.R. Munday

Contractor: E.V.S. Consultants Ltd.
Prepared for: M.D. Nassichuk, D.F.O.

Fertilized eggs of the Pacific cod (*Gadus macrocephalus*) were exposed to different concentrations of silt, and a marine sediment contaminated with heavy metals and polychlorinated biphenyls. Concentrations tested ranged from 2 to 30 g L^{-1} for silt, and 2 to 15 g L^{-1} for contaminated sediment. Each sediment concentration was tested under two experimental conditions: "quiescent" and "in suspension". Quiescent tests were designed to simulate burial of eggs by deposited dredge spoil. Effects measured included mortality in three different stages of embryonic development, percent hatchability, and time to 50% hatch. The toxicity of test sediments to newly hatched larvae of Pacific cod, and the ability of larvae to ingest each sediment were also assessed.

Mortalities were consistently higher in the early germ ring egg stage, than in other stages tested. Elevated mortalities compared to controls were observed at the highest silt concentrations of 22 and 30 g L^{-1} in tests with silt in suspension. Increased mortalities with contaminated sediments occurred at concentrations of 15 g L^{-1} under quiescent conditions, and 7.5 and 15 g L^{-1} with the sediment in suspension. The presence of silt in quiescent tests increased hatchability compared to controls. Concentrations of contaminated sediment above 2 g L^{-1} resulted in a sharp decrease in hatchability in all test conditions. A slight increase in hatching time over controls was apparent with increasing silt concentrations, however no obvious differences in time to 50% hatch were observed for similar concentrations of silt and contaminated sediment. Sediments were not toxic to cod larvae in concentrations tested after 4 hours, and there was no apparent difference in the percentage of larvae feeding on silt or the contaminated sediment.

3. PRODUCTION OF LEAD ALKYLS IN MARINE SEDIMENTS *

J.A.J. Thompson, I.O.S.
and M.B. Yunker, Dobrocky SEATECH Limited

Contractor: Dobrocky SEATECH Limited

The potential for microbial conversion of inorganic lead (II) and organolead (IV) has been studied in two B.C. coastal sediments of widely differing types. Samples containing lead (II) (nitrate, sulfide or acetate) were taken from Saanich Inlet (high organic carbon) and Alice Arm (mine tailings, low organic carbon).

The production of tetramethyllead (TML) in marine sediments from coastal waters of the British Columbia coast was described recently (Ref 1 and PMSR 79-18, pp 23). This was the first reported instance of this process being seen in saline environments whereas a number of studies had been made using lacustrine sediments or bacterial isolates (Ref 2,3,4,5).

In the previous study (Ref 1) it was found that Pb(II) added as the nitrate was methylated to TML in extremely low quantities. No more than 0.03% of the total Pb added was detected in this form after incubation of sediments up to 4 wk at 15°. Conversely, and like other workers (Ref 2, 3,4,5), it was found that trimethyllead ion underwent facile methylation to give TML. In an effort to better understand these reactions and the factors governing them we undertook experiments to repeat some of the earlier work using the more sensitive analytical methods of gas chromatography interfaced to atomic absorption (GC/AA) (Ref 6). As well, open, flow-through experiments allowing both anoxic and oxic conditions for bacterial growth were conducted.

Experiments using sealed septum vials were essentially identical to work reported previously (Ref 1) with the exception that sediment and vital volumes were approximately 1/5 in the latter work and a marine nutrient broth was used. It was expected that the smaller volumes would be compensated by the use of the more sensitive analytical method. However, unlike the previous work using sediments from the same locations, methylation of Pb(II) added as the nitrate in particular was not observed to be a time dependent process. Detection of TML in head-space gases was observed in most series of vials throughout the experiment, even those containing PbS or sterile sediments. There was also no relationship between nutrients and the amounts of TML detected. In most cases, responses were only slightly above the detection limit of 0.01 ng for head-space gases.

In the second set of experiments 250 mL filter flasks filled with open-tube gas bubblers were charged with sediments (50 g wet) spiked with either $PB(NO_3)_2$ or $(CH_3)_3PbOAc$ (0.64 mg L^{-1} in each case). After addition of nutrient solution or sterile seawater the flasks were connected to two bubblers in series containing hexane. Asceptically filtered nitrogen or air were passed slowly through the sediment mixtures to maintain anoxic or oxic conditions, respectively.

*Published in part originally in Proc. Intl. Conf. Heavy Metals in the Environment, Amsterdam. Sept. 1981: 653-6.

The flow-through experiments were designed for two purposes: 1. to permit both anoxic and oxic growth conditions for sediment bacteria; and 2. to remove any volatiles produced in the cultures and hence reduce possibility for readsorption and/or further chemical processes. Trimethyllead acetate was used because of its known facility for methylation, therefore, it served as a positive indicator of the applicability of the flow-through methodology.

Sediment spiked with $Pb(NO_3)_2$ again did not produce TML. This was the case for both sediment types studied under both anaerobic and aerobic conditions. No response from the AAS detector was obtained even when 100 µL injections of hexane onto the column were made. Hexane solutions were also slowly concentrated (5x) in an effort to detect TML.

Expectedly, TML was evolved from all non-sterile cultures spiked with $(CH_3)_3PbOAC$ in the 2-week flow-through experiments. Table 3.1 shows that the greatest quantity of TML produced was in the anaerobic culture of the Alice Arm sediment. This represented 4% of the lead originally added and was a 3-fold greater amount than that evolved in the comparable aerobic culture. The anaerobic culture of the Saanich Inlet sediment produced TML equivalent to just over 1% of lead added and represented a 5-fold greater quantity than the aerobic culture of the same sediment. Slight but detectable quantities of TML were found in sterile cultures of the Saanich Inlet sediments only under both atmospheric regimes.

From this study we have determined that bioconversion of Pb (II) to TML is strongly in doubt as even a minor factor in lead mobilization in marine environments. It has been shown recently by Ahmad *et al.* (Ref 7) that lead (II) can be methylated to TML by simple methyl donors such as CH_3I, $(CH_3)_3S^+I$ and $(CH_3)_3SO^+I^-$. The presence of CH_3I in natural waters has been reported (Ref 8) and it is possible that this compound may also have a role in lead methylation. This process requires further investigation.

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TABLE 3.1 Analytical data from flow-through experiments.

		TML Detected (ng Pb)	TML in 50 mL Hexane (μg Pb)	Recovery Based on on Pb Added (%)
A.	Alice Arm Sediment			
	Anoxic			
	$(CH_3)_3PbOAc$	0.19±0.02*	3.3 ±0.43	4.0 ±0.4
	$(CH_3)_3PbOAc$, sterile	0	-	-
	Oxic			
	$(CH_3)_3PbOAc$	0.05±0.01*	0.89±0.24	1.1 ±0.3
	$(CH_3)_3PbOAc$, sterile	0	-	-
B.	Saanich Inlet Sediment			
	Anoxic			
	$(CH_3)_3PbOAc$	0.19±0.01**	0.87±0.04	1.1
	$(CH_3)_3PbOAc$, sterile	0.01 **	0.06	0.1
	Oxic			
	$(CH_3)_3PbOAc$	0.01±0.01*	0.18±0.08	0.23±0.06
	$(CH_3)_3PbOAc$, sterile	0.01 **	0.02	-

* 3 μL injections
** 10 μL injections

4. EXPERIMENTAL INVESTIGATION INTO THE ACCUMULATION OF CADMIUM BY THE POLYCHAETE WORM *Capitella capitata* AND THE BIVALVE *Macoma balthica*

B.J. Reid[1], R.W. Deverall[2], P.M. Chapman[1] and A.W. Maynard[2]

[1]Contractors: E.V.S. Consultants Ltd.
[2]Subcontractors: Can Test Ltd.

Prepared for: R.W. Macdonald, I.O.S.

The bioavailability of sulphide-bound cadmium phases to the bivalve *Macoma balthica* and the polychaete *Capitella capitata* was determined. Sixty day laboratory experiments were conducted using ^{109}Cd and ^{115}Cd-labelled sediments from False Creek, B.C., under constant temperature and salinity conditions. Seawater and biota were removed for isotope counting at intervals of 2, 4, 8, 16, 32 and 60 days. Sediments from the uptake experiment were chemically analysed at the beginning and end of the experiment using a selective extraction scheme (method modified from Brannon *et al* 1976). Laboratory data were compared with measurements of background cadmium levels in selected False Creek biota.

Measurable levels of ^{109}Cd in *M. balthica* were only determined on day 60; similarly, measurable release of ^{109}Cd to the overlying water was only determined on day 60 of the experiment. ^{115}Cd was not detected in biota or seawater over 60 days. Results of the sediment characterization and selective extraction suggested that due to their lack of solubility cadmium sulphide phases were not available for uptake by biota.

In contrast to the laboratory experiments, measurable cadmium body burdens were detected in False Creek biota, suggesting that cadmium was present in an available form in this area. Highest body burdens were detected in filter feeding *Mytilus edulis* (mean = 5.33 μg g^{-1} dry wt) from the northern inner side of False Creek (Fig. 4.1-Site 3). Lowest cadmium levels were detected in deposit feeding *C. capitata* (mean = 0.14 μg g^{-1} dry wt) suggesting that cadmium uptake is primarily from the water column, which is consistent with published information. Cadmium body burdens in False Creek biota were elevated in some areas, and the elevated levels were typical of polluted industrial nearshore sites.

The study showed that cadmium sulphide phases were not readily accumulated in two marine deposit feeders. Investigations into the routes of cadmium cycling,mobilization and speciation in False Creek sediments are required. Background information on cadmium levels in False Creek sediments and waters should also be collected to help explain geographic and species specific differences in cadmium body burdens.

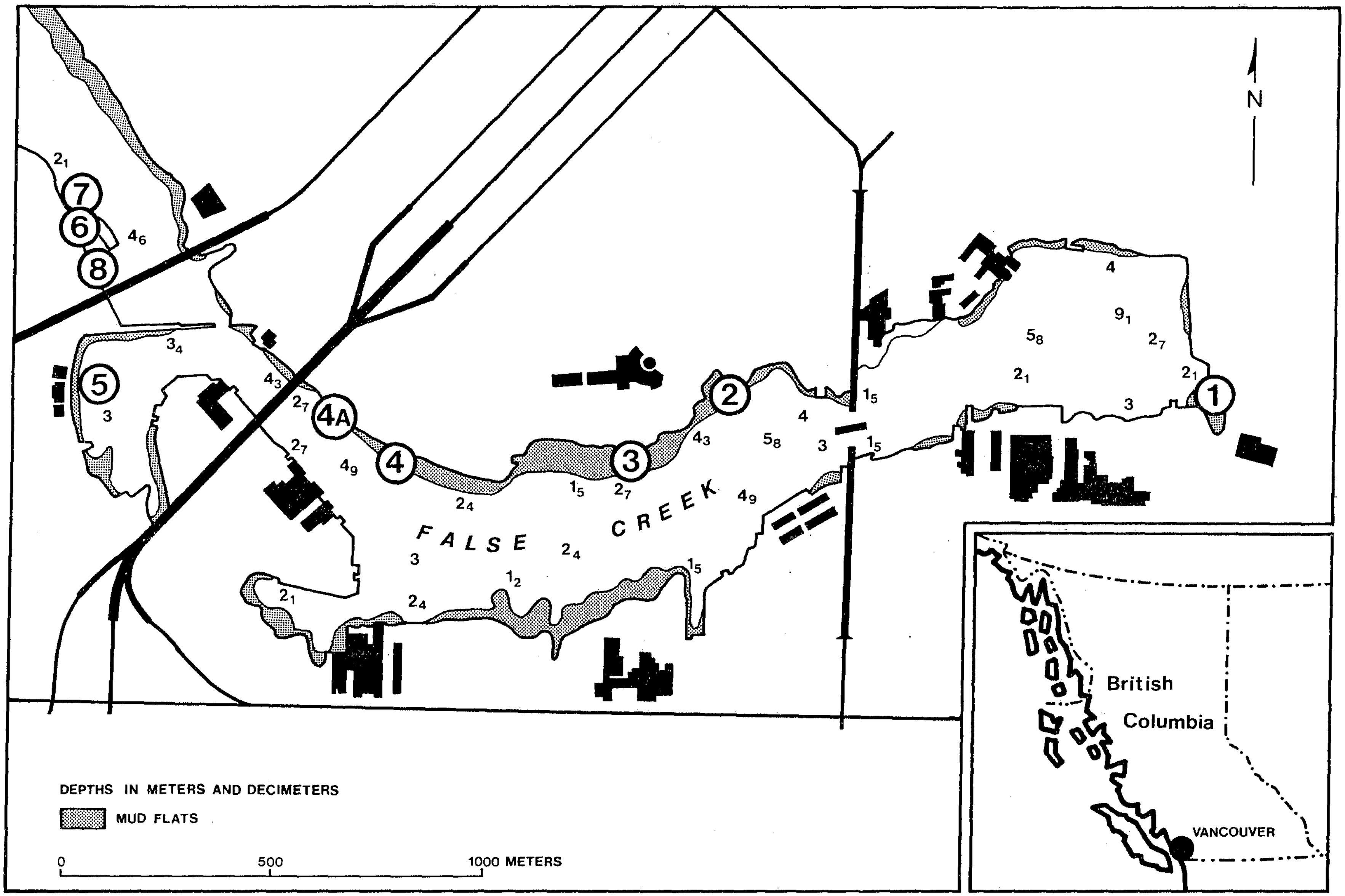

FIGURE 4.1 Sampling locations for sediment and biota.

5. REVIEW OF THE PRESENCE AND ENVIRONMENTAL IMPACT OF CADMIUM IN MARINE AND FRESHWATER SYSTEMS

D. MacGregor
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A brief overview of the analysis and speciation of cadmium in marine and freshwater systems was presented.

Tables 5.1-5.5 illustrate several important considerations with regard to cadmium analysis: size distribution in sediments (Table 5.1) and in suspended and dissolved solids (Table 5.2); errors associated with insensitive analytical methods (Table 5.3); and the variability encountered with sequential (Table 5.4) and single (Table 5.5) extraction methods for sediments. It was noted that chemical extraction techniques have generally given poor estimates of "bioavailable" cadmium.

Existing ocean dumping criteria for cadmium and cadmium compounds specify a maximum of 0.6 mg kg^{-1} in the solid phase of a waste, and 3.0 mg kg^{-1} in the liquid phase of a waste. These criteria were compared critically with levels of cadmium in a range of uncontaminated and contaminated media and biota. Tables 5.6 and 5.7 illustrate that many natural background levels in the environment exceed the criterion for solid waste. The complex relationships between species, total and "available" cadmium, and plant tissue concentrations at a common level of toxic response are shown by the data in Table 5.8. Tables 5.9-5.11 present data on environmental cadmium concentrations in polluted areas; the latter table shows that tissue levels are not always easily rationalized in terms of simple variables such as water and sediment concentration, distance from a pollution source, pH, etc.

Emphasis was placed on the distinction between bioaccumulation and ecotoxicity. Toxicity data, in many cases for the most sensitive species identified to date, are presented in Table 5.12. It was pointed out that, in all of these cases, prevailing environmental concentrations in unpolluted areas are below these toxicity thresholds. Furthermore, comparison of the tissue concentrations entry 3, Table 5.12 with entry 12, Table 5.9, for example, shows that tissue levels associated with a toxic response may be very much higher than tissue levels in severely contaminated biota. A plea was made for the measurements of the tissue levels associated with effects determined in future toxicological investigations, so that "high" cadmium concentrations could be assessed in terms of associated hazards.

TABLE 5.1 Concentration (mg kg^{-1}) and proportion (%) of cadmium in stream sediments.

Sample		Size Fraction (μ)					
		< 0.2	0.2-2	2-5	5-50	50-100	> 100
1	mg kg^{-1}	7	4	2	3	3	3
	%	0.4	2.6	1.9	17.2	8.3	69.7
2	mg kg^{-1}	8	5	6	7	6	3
	%	0.4	2.5	4.6	28.3	18.4	45.8

TABLE 5.2 Concentration (mg L^{-1}) and proportion (%) of cadmium in dissolved and particulate solids in river water.

Sample	Dissolved Solids		Coarse Particulate*		Colloidal Particulate**	
	mg L^{-1}	%	mg L^{-1}	%	mg L^{-1}	%
1	12	95.4	15	3.9	227	0.8
2	14	95.3	21	4.2	167	0.5
3	9	95.8	24	3.5	63	0.7
4	5	77.4	15	21.9	52	0.7
5	11	85.1	13	8.9	1615	6.0

* > 0.15 - 0.20 μ

**< 0.15 - 0.20 μ

TABLE 5.3 Interlaboratory comparison of marine mud and rock samples.

Laboratory	Mud(mg kg^{-1})	Rock(mg kg^{-1})	Digestion Method*	Analytical Method
1	0.1	0.1	L	GFAAS
2	0.2	0.1	L	"
3	0.3	0.3	T	"
4	0.2	0.4	T	"
5	0.3	0.1	L	"
6	< 5	< 5	L	AAS
7	< 0.5	< 0.5	T	"
8	1.5	1.3	L	"
9	1.4	0.9	L	"
10	4	3	L	"
11	2.8	2.1	T	"

* L: Sample leached with strong mineral acids.

T: Sample completely digested with hydrofluoric and strong mineral acids.

TABLE 5.4 Sequential extractions of sediments from Los Angeles Harbour.

Extractant	Cadmium Concentration (mg L^{-1})			
	Sample 1	Sample 2	Sample 3	Sample 4
Water	-	-	-	-
Ammonium Acetate	-	-	-	-
Acetic Acid	0.16	0.07	0.35	0.35
Hydroxylamine	0.90	0.23	0.16	0.08
Hydrogen Peroxide, plus:				
(a) Ammonium Acetate	0.51	0.74	0.13	0.07
(b) Nitric Acid	0.50	0.62	0.12	0.06
Dithionate-Citrate (a)	-	-	-	-
Hydroxylamine/Acetic Acid (b)	0.40	0.78	0.12	0.08
Residual Cadmium (a)	0.31	0.82	0.12	0.06
Residual Cadmium (b)	0.05	0.28	0.07	0.03
Sum (a)	1.88	1.86	0.76	0.56
Sum (b)	2.01	1.98	0.82	0.60
Total Cadmium Content	1.90±0.07	2.20±0.2	0.66±0.01	0.66±0.03
Mean Mass Balance	102%	87%	120%	88%

TABLE 5.5 Cadmium extraction efficiencies (mg kg^{-1}) for sediments by different methods.

Sample	Ashing	Hydrochloric Acid	Citrate-dithionate		Hydroxylamine
			pH3	pH7	
1	0.98	1.38	2.02	0.89	0.98
2	27.5	15.4	7.40	4.26	10.2
3	1.37	1.32	1.57	1.94	1.21
4	0.06	0.11	0.64	0.21	0.04
5	1.69	1.85	2.04	0.32	1.31
6	0.60	0.54	0.84	0.40	0.16
7	1.44	1.68	2.38	0.83	1.22
8	0.88	0.88	1.22	0.75	0.62
9	0.25	0.17	0.62	0.23	0.66
10	4.46	6.42	6.83	3.10	7.24
Mean(%)	100(ref)	110±12.6	146±22	70.9±13.7	80.8±13.6

TABLE 5.6 "Background" cadmium levels in selected environmental media.

Entry	Medium		Approx. Concentration Ranges
1	Rock	- igneous	1 μg kg^{-1} - 2 mg kg^{-1}*
2		- metamorphic	40 - 260 μg kg^{-1}
3		- sedimentary	<300 μg kg^{-1} - 11 mg kg^{-1}*
4		- marine phosphorite shales	30 - 800 mg kg^{-1}*
5	Water	- Canadian rivers	<10 - 540 ng L^{-1}
6		- Canadian lakes	<10 - 1130 ng L^{-1}
7		- Lake Superior	6 - 34 ng L^{-1}
8	Marine water	- surface layers	5 - 60 ng L^{-1}
9		- 1000-2000 m	25 - 120 ng L^{-1}
10		- inshore	50 ng L^{-1} - 5 μg L^{-1}
11	Sediments	- Great Lakes	0.0 - 17 mg kg^{-1}*
12		- rivers	30 μg kg^{-1} - 2 mg kg^{-1}*
13		- river mouths	100 μg kg^{-1} - 17 mg kg^{-1}*
14		- estuarine	0.2 - 8 mg kg^{-1}*
15		- continental shelf	0.0 - 2.2 mg kg^{-1}*
16		- marine	23 - 900 μg kg^{-1}*
17	Surficial Soils	- worldwide	60 μg kg^{-1} - 7 mg kg^{-1}*
18		- Canadian survey	<300 μg kg^{-1}
19		- Ontario survey	100 μg kg^{-1} - 8.1 mg kg^{-1}*
20		- Manitoba survey	400 μg kg^{-1} - 1.7 mg kg^{-1}*
21		- Alberta survey	30 μg kg^{-1} - 1 mg kg^{-1}*
22	Wastewaters	- Ontario municipal	<10 - 1300 μg kg^{-1}
23		- Canadian smelters, mines	1 - 420 μg kg^{-1}
24		- Ontario effluents	10 μg kg^{-1}
25	Sewage Sludge	- U.S. survey	0.1 - 3650 mg kg^{-1}*
26		- Ontario survey	0.3 - 236 mg kg^{-1}*
27		- Alberta, Manitoba	4 - 23 mg kg^{-1}*

* Denotes quantity in excess of ocean dumping criterium.

TABLE 5.7 "Background" cadmium levels in selected biota.

Entry	Organism	Approx. Concentration Ranges
1	Freshwater algae	< 10 mg kg^{-1}*
2	Marine algae	50 μg kg^{-1} - 20 mg kg^{-1}*
3	Higher freshwater plants	30 μg kg^{-1} - 8.5 mg kg^{-1}*
4	Mosses and lichens	60 μg kg^{-1} - 2.7 mg kg^{-1}*
5	Grains and vegetables	50 μg kg^{-1} - 4 mg kg^{-1}*
6	Marine microorganisms	1.2 - 2.6 mg kg^{-1}*
7	Marine annelids	80 μg kg^{-1} - 3.6 mg kg^{-1}*
8	Marine crustacea (muscle)	30 μg kg^{-1} - 13 mg kg^{-1}*
9	Marine molluscs (soft parts)	10 μg kg^{-1} - 140 mg kg^{-1}*(wet)
10	Marine fish (muscle)	< 10 μg kg^{-1} - 2.4 mg kg^{-1}*(wet)
11	(liver)	140 μg kg^{-1} - 54 mg kg^{-1}*(wet)
12	(kidney)	190 μg kg^{-1} - 10 mg kg^{-1}*(wet)
13	Marine mammals (liver)	500 μg kg^{-1} - 5 mg kg^{-1}*(wet)
14	(kidney)	100 μg kg^{-1} - 16 mg kg^{-1}*(wet)
15	Freshwater fish (muscle)	30 - 150 μg kg^{-1}
16	Aerobic sludge biomass	<275000 mg kg^{-1}*
17	Slug (digestive gland)	3.3 - 10 mg kg^{-1}*
18	Earthworms	300 μg kg^{-1} - 10 mg kg^{-1}*
19	Rock squirrel (liver)	100 μg kg^{-1} - 56 mg kg^{-1}*
20	Fulmar (kidney)	116 - 480 mg kg^{-1}*
21	Tern (kidney)	10.4 - 54 mg kg^{-1}*
22	Robin (kidney)	1.1 - 1.4 mg kg^{-1}*(wet)
23	Horse (kidney cortex)	30 - 76 mg kg^{-1}*(wet)
24	Sheep (muscle)	< 80 μg kg^{-1}
25	Swine (muscle)	<160 μg kg^{-1}
26	Cattle (muscle)	<250 μg kg^{-1}
27	Poultry (muscle)	<120 μg kg^{-1}

TABLE 5.8 Cadmium concentrations in soil and plant tissue associated with a 25% decrease in crop yield.

Plant Species	Cd in Soil (mg kg^{-1})*		Cd in Plant (mg kg^{-1})*
	"Total"	"Extractable"	
Spinach	4	2.4	75
Soybean	5	3.0	7.0
Curlycress	8	4.8	80
Lettuce	13	7.8	70
Corn	18	11	2.0
Carrot	20	12	19
Turnip	28	17	15
Field Bean	40	24	1.7
Wheat	50	30	11.5
Radish	96	58	21
Tomato	160	96	7.0
Zucchini	160	96	10
Cabbage	170	102	11
Rice	> 640	> 384	2**

* Dry weight basis

** Maximum tissue concentration attained at highest cadmium concentration in soil.

TABLE 5.9 Cadmium concentrations in contaminated compartments and biota.

Entry	Specimen	Approx. Concentration Ranges
1	Water - Foundry Cove	1 - 91 $\mu g\ L^{-1}$
2	- Palestine Lake	2 - 9.8 $\mu g\ L^{-1}$
3	Sediment - Foundry Cove	42000 $mg\ kg^{-1}$
4	- Foundry Cove	1500 - >10000 $mg\ kg^{-1}$
5	- Palestine Lake	6 - 1070 $mg\ kg^{-1}$
6	- Flin Flon area stream	1300 $mg\ kg^{-1}$
7	- Flin Flon area lakes	<4 - 516 $mg\ kg^{-1}$
8	- Belledune Harbour	<0.1 - 190 $mg\ kg^{-1}$
9	Soil - near B.C. battery smelter	0.45 - 95 $mg\ kg^{-1}$
10	Soil litter - Trail area	1 - 22 $mg\ kg^{-1}$
11	Forage grasses - 0.5 miles from Belledune	3 - 60 $mg\ kg^{-1}$
12	Algae - Palestine Lake	80 - 430 $mg\ kg^{-1}$
13	Aquatic Plants - Foundry Cove	5 - 513 $mg\ kg^{-1}$
14	Marine Biota - (see Table 5.10)	15 - 550 $mg\ kg^{-1}$
15	Lettuce - hydroponic culture, 50 $mg\ kg^{-1}$ Cd	125 - 19000 $mg\ kg^{-1}$
16	Vegetables - Shipham	60 $\mu g\ kg^{-1}$ - 2.5 $mg\ kg^{-1}$
17	Vegetables - Shipham	20 $\mu g\ kg^{-1}$ - 3.6 $mg\ kg^{-1}$(wet)
18	Fungi - near smelter	<5 $mg\ kg^{-1}$
19	Lichens - near smelter	<90 $mg\ kg^{-1}$
20	Mosses - near smelter	<10 $mg\ kg^{-1}$
21	Grasses - near smelter	<50 $mg\ kg^{-1}$
22	Vegetables - near smelter	8 - 41 $mg\ kg^{-1}$
23	Tree leaves - near smelter	<50 $mg\ kg^{-1}$
24	Transplanted moss - near smelter	138 $mg\ kg^{-1}$
25	Carp liver - Foundry Cove	600 $mg\ kg^{-1}$
26	Perch liver - Foundry Cove	450 $mg\ kg^{-1}$
27	Mussels - soft parts - Belledune area	3 - 112 $mg\ kg^{-1}$
28	Scallops - viscera - Belledune area	88 - 493 $mg\ kg^{-1}$
29	Lobsters - hepatopancreas - Belledune harbour	48 - 372 $mg\ kg^{-1}$(wet)
30	- outside harbour	5 - 399 $mg\ kg^{-1}$(wet)

TABLE 5.10 Cadmium concentrations as a function of distance from a smelter in water, sediments, and marine biota.

Analyte	Sampling Station (Distance from smelter increasing →)							
	A	B	C	D	E	F	G	H
Water*	5.8	3.8	3.0	1.3	1.0	1.2	0.5	0.3
Sediment**	4.2	4.0	1.6	-	-	-	-	-
*Fucus vesiculosis***	220	200	50	25	20	44	30	15
*Putella vulgata***	550	220	200	110	50	70	30	30
*Littorina littorea***	-	210	140	30	25	40	16	15
*Thais lapillus***	-	-	425	330	270	120	65	62

* In µg L^{-1}
** In mg kg^{-1}, dry weight.

TABLE 5.11 Field data from six lakes near Flin Flon.

Parameter	Lake					
	A	B	C	D	E	F
Distance from smelter (km)	4.0	4.2	5.2	9.5	12.5	20.2
Annual Cd deposition *	3	3	2	2	0.7	0.4
Cd in plant tissue **	10	7	31	4	9	1
Cd in water (ng L^{-1})	400	700	300	600	300	<100
Cd in sediment **	5	16	28	6	0.8	0.8
Lake pH	8.1	7.8	8.0	8.4	8.2	7.9
Ca in water (mg L^{-1})	16.2	14.9	15.0	38.8	10.0	14.7

* Deposition in mg m^{-2} yr^{-1}
** Dry weight basis, in mg kg^{-1}

TABLE 5.12 Cadmium toxicity to a variety of organisms.

Entry	Test Species	Effect
1	Terrestrial moss	Death - tissue concentration ca. 138 mg kg^{-1}
2	Freshwater green alga	Death - 650 μg kg^{-1} Zero growth - 80 μg kg^{-1}
3	Freshwater alga	EC50 - 600 μg kg^{-1} - 4.7 mg kg^{-1} Tissue - 3000 - 20000 mg kg^{-1}
4	Freshwater alga	Slight growth inhibition - >2 μg kg^{-1}
5	Freshwater diatom	90% growth rate reduction - 2 μg kg^{-1}
6	Freshwater diatom	50% reduction in C uptake - 100ng kg^{-1} 0% reduction in growth - 8.5 μg kg^{-1}
7	Aquatic fungi	Slight growth inhibition - 2.5 mg kg^{-1}
8	*Daphnia magna*	LC50 - 5 μg kg^{-1}
9	*Daphnia magna*	Reduced reproduction - 150ng kg^{-1}
10	Rainbow trout, soft water	LC50 - 1 μg kg^{-1}
11	Bass larvae	LC50 - 1 μg kg^{-1}
12	Marine fungus	Inhibition of spore formation - 6.3 mg kg^{-1}
13	Marine phytoplankton	96-hr EC50 - 160 μg kg^{-1}
14	Marine diatom	Slight growth inhibition - 100 μg kg^{-1}
15	Mysid shrimp	LC50 - 15.5 μg kg^{-1}
16	Lobster larvae	96-hr LC50 - 78 μg kg^{-1}
17	Polychaete larvae	Death - 215 μg kg^{-1}
18	Atlantic Silversides	LC50 - 557 μg kg^{-1}
19	Mysid shrimp, life cycle	NOEL - 4.8 μg kg^{-1}

6. AN OVERVIEW OF THE ECOLOGICAL CONSEQUENCES OF DREDGING AND DREDGE SPOIL DISPOSAL IN CANADIAN WATERS

C.D. Levings, W.V.L.

The abstract of this talk is unavailable at this time. It is anticipated that the full report will be available from the National Research Council of Canada, published under the auspices of the NRCC Associate Committee on Scientific Criteria for Environmental Quality.

7. ACCUMULATION OF POLYNUCLEAR AROMATIC HYDROCARBONS (PAH) FROM WATER AND SEDIMENT BY MARINE INVERTEBRATES

D.W. McLeese
Fisheries and Environmental Sciences
D.F.O., St. Andrews, New Brunswick

Sources of PAH to the marine environment include creosote oil used to preserve wood, petroleum spillage, and long-range aerial transport of PAH's derived from combustion. PAH's are relatively insoluble in water and are readily transported to sediments in association with particulate matter. Some PAH's are carcinogens. Dredging of harbours and harbour channels and disposal of the spoils redistributes sediments that may contain high levels of PAH.

The bioavailability of PAH was investigated by exposing clams (*Mya arenaria*), shrimp (*Crangon septemspinosa*), polychaete worms (*Nereis virens*), and mussels (*Mytilus edulis*) to seawater containing a mixture of five PAH compounds and also to contaminated sediment. Data for clams and worms are summarized.

The animals were exposed for 96 h to flowing seawater at 10°C containing a mixture of PAH compounds. The compounds were phenanthrene (4 $\mu g\ L^{-1}$) fluoranthene (2.4 $\mu g\ L^{-1}$), triphenylene (0.4 $\mu g\ L^{-1}$) and perylene (0.3 $\mu g\ L^{-1}$). After 96 h, the animals were maintained in uncontaminated water for 2 wk. Sediment contaminated with PAH was collected from a site in northeastern New Brunswick that received wastes from a wood-treatment plant. Animals were exposed to a 4 cm layer of contaminated sediment for 96 h and then transferred to uncontaminated sediment.

Clams exposed to five PAH compounds in water had relatively high uptake rate constants (k_1 of 8.2 to 36 h^{-1}), and low excretion rate constants (k_2 of 0.0064 to 0.0011 h^{-1}). Calculated bioconcentration factors (BCF) ranged from 1,280 (phenanthrene) to 10,000 (perylene). Clams exposed to sediment contaminated with PAH showed similar uptake and excretion patterns for the five PAH compounds. The BCF's, calculated in relation to the concentration of the PAH in surficial water, ranged from 890 (phenanthrene) to 3900 (triphenylene) and were smaller than the BCF's from water exposure. The BCF increased with increasing complexity and molecular weight of the PAH compounds. The percent loss of PAH during 14 d excretion decreased with increasing complexity and molecular weight of the compounds, the loss ranging from 80 to 100% for phenanthrene to 20 to 40% for perylene.

Although not proven conclusively, the bioavailability of PAH compounds in sediment to clams is dependent on the presence of the compounds in the surficial water which is consistent with their filter feeding behaviour.

The data for worms are not fully analyzed. However, the 96 h uptake data for fluoranthene indicate major differences in uptake by worms and clams. The uptake of fluoranthene from water by worms is relatively low (1/6 that of clams) and from sediment is relatively high (3 x that of clams). Expressed differently, the uptake of the PAH by worms from sediment is 10 times greater than from water compared with clams where uptake from sediment is about 0.5 times that from water. Such differences probably reflect species differences as well as behaviour differences. Worms live in greater contact with the sediment than the filter feeding clam.

8. A REVIEW OF CRITERIA FOR EVALUATING OCEAN DUMPING PERMIT APPLICATIONS WITH RECOMMENDATIONS FOR FUTURE MONITORING REQUIREMENTS

E.R. McGreer and D.E.Konasewich

Contractor: E.V.S. Consultants Ltd.
Prepared for: H. Nelson, E.P.S.

Current legislation on ocean dumping in Canada, and the United States was reviewed with emphasis on assessing the parameters used to evaluate ocean dumping permits. Generally, the review showed a trend towards the use of biological testing to assess possible ecological impacts of dredge spoil disposal. Scientific studies which pointed to the need for biological evaluations, and to the inadequacies of relying solely on chemical criteria (e.g. bulk chemical content) to assess dumping impacts were discussed. The current parameters used in the Canadian, System 2000 Ocean Dumping Data Base were evaluated, and suggestions made for modifications and additions to those presently listed. Specific modifications included the need for more accurate reporting of field sampling methods and chemical, analytical data. Trends in monitoring data from selected dredge and dump sites in the Pacific Region were reviewed but trends were not well defined due to the paucity of time series data, and differences in sampling methods and analytical techniques employed. Recommendations for future monitoring included implementation of bioassay testing for evaluating long-term effects of spoil disposal, and standardization of methodologies for physical, chemical and biological sampling and analysis.

9. A STATISTICAL ANALYSIS OF BENTHIC INVERTEBRATE SAMPLING IN TUKTOYAKTUK HARBOUR, N.W.T.

B. Heath
Arctic Laboratories Ltd.

Contractor: Arctic Laboratories Ltd.
Prepared for: W. Byrant, E.P.S., Yellowknife

In 1980, Arctic Labs conducted a combined chemical, physical and biological oceanographic survey in Tuk Harbour, N.W.T. on behalf of Dome Petroleum Limited. Included was the collection of benthic invertebrate samples. The statistical analysis of these samples was completed under a contract issued by E.P.S. in Yellowknife.

The benthos sampling stations were selected to provide good harbour coverage and the greatest density of sampling in the area, within the harbour, where the most intense dredging activity would occur. Some stations provided a baseline against which future recolonization and changes in community structure could be compared. Samples were collected on two occasions; shortly after breakup and toward the end of the open water season. This provided information on possible seasonal variability due to the large changes in the environmental surroundings at Tuk Harbour, and an estimate of sampling variance.

The infaunal species data were analysed for community associations by unweighted pair-group cluster analysis, reciprocal averaging ordination and Zurich-Montpellier (Z-M) analysis. Results of all these community analysis methods appear to indicate that two distinguishable communities of benthic infauna are present in Tuk Harbour. There are species with strong affinities for shallow water stations where salinity variations can be large and episodic (euryhaline species) and also species which thrive best in deeper water of higher and less variable salinity (stenohaline species). The reciprocal averaging ordination technique when applied to July data produced two clusters, one corresponding to deep stations (> 6 m depth) and the other to shallow stations (< 6 m depth). The Z-M results for July show both the deep and shallow clusters but also a grouping of overlapping stations composed of species found in both deep and shallow associations. The results for ordination and Z-M analysis of the September samples were similar to the July results although more species were included in each analysis for September. The cluster analysis produced generally low values of the index of similarity for July and September data indicating that the degree of overlap of species composition between stations was limited. Highest similarities tended to occur for stations of similar depth grouping but station clusters were not as clearly depth or salinity-related as in the ordination and Z-M results. The normal cluster analysis, however, was unable to provide as clear a distinction between shallow and deep stations as demonstrated by the other two methods and provided no information on species habitat preferences.

Species diversity was somewhat higher in the shallow station groups at both sampling times. The mean for Margalef's d was 2.15 and 2.44 for shallow stations in July and September, respectively; these values compared with 1.82 and 2.26 for the deep stations. In comparison with shallow water benthic communities in temperate waters, the values of diversity are relatively low, due to the lower number of species present in Arctic estuarine waters as compared to estuarine waters of temperate location.

Sediment type did not appear to influence infaunal distribution in Tuk Harbour, likely because of the relatively small range of sediment particle sizes present. Sediment varied from silt-clay to medium sand but most stations were in silt-clay or fine sand.

10. MONITORING OF FISH ENTRAINMENT BY A 90 cm SUCTION DREDGE IN MCKINLEY BAY AND TUKTOYAKTUK HARBOUR, NORTHWEST TERRITORIES

L.H.H. Pelletier
and D.J. Wilson

Contractor: Personal Service Contract
Prepared for: J. Stein, D.F.O., Winnipeg

Monitoring for fish entrainment by a large cutter-suction dredge was undertaken using two monitoring systems (on-line and decant). The usefulness of the monitoring devices and techniques were assessed and modifications recommended. A total of 69 fish were retrieved at McKinley Bay and Tuktoyaktuk Harbour using the on-line monitoring system. A decant monitoring system used in Tuktoyaktuk Harbour yielded 60 fish.

All of the devices tested were considered to be poorly designed and constructed and inadequate for the purpose intended. Monitoring efforts were frequently frustrated by long periods of delay due to dredge shutdowns, equipment repairs and by the inability to accurately interpret results. Equipment design modifications and extensive planning will be required for any future monitoring attempts.

APPENDIX I

LOCATIONS OF PARTICIPANTS 1981

I. Government

Environment Canada

E.P.S. - Environmental Protection Service
Kapilano 100, Park Royal
WEST VANCOUVER, B.C. V7T 1A2

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II. Industry

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Seakem Oceanography Ltd.
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SIDNEY, B.C.

APPENDIX II

OCEAN DUMPING WORKSHOP ATTENDANCE LIST

E.P. Anderson, University of Victoria
J. Baumann, E.P.S., Vancouver
H. Beach, E.P.S., Toronto
A. Bohn, B.C. Research, Vancouver
R.O. Brinkhurst, Ocean Ecology, I.O.S., Sidney
D. Brothers, E.P.S., Vancouver
W.J. Cretney, Ocean Chemistry, I.O.S., Sidney
L. Cuypers, Beak Consultants Ltd., Vancouver
R.W. Drinnan, Dobrocky SEATECH Limited, Sidney
W.M. English, Plumper Ocean Projects Ltd., Victoria
M.B. Flynn, D.F.O./Habitat Management, Vancouver
P. Futer, D.F.O./Habitat Management, Vancouver
L. Harding, E.P.S., Vancouver
R.H. Herlinveaux, O.I.D./I.O.S., Sidney
J.T. Hollibaugh, MacLaren Plansearch Corp., Vancouver
K. Hutton, D.F.O./Habitat Management, Vancouver
A.J. Jordon, Rescan, Vancouver
R. Kussat, E.P.S., Vancouver
G. Kruzynski, Saanichton
H.E. Lanz, B.C. Research, Vancouver
C.D. Levings, D.F.O./W.V.L., Vancouver
R.W. Macdonald, Ocean Chemistry, I.O.S., Sidney
D.J. MacGregor, E.P.S./Contaminants Control Branch, Ottawa
S. McCormack, LGL Ltd., Sidney
H. McElderry, Archipelago Marine Research, Victoria
E.R. McGreer, E.V.S. Consultants Ltd., Vancouver
A.R. McIver, E.P.S./Atlantic Region, Dartmouth, N.S.
D.W. McLeese, D.F.O./Biological Station, St. Andrews, N.B.
D. Morse, Chemex Labs, Vancouver
N. Munteanu, Beak Consultants Ltd., Vancouver
H. Nelson, E.P.S., Vancouver
D. Pophan, Seakem Oceanography Ltd., Sidney

APPENDIX II - Ocean Dumping Workshop Attendance List (Cont'd)

B.J. Reid, E.V.S. Consultants Ltd., Vancouver
G. Roe, Seakem Oceanography Ltd., Sidney
J.A.J. Thompson, Ocean Chemistry, I.O.S., Sidney
K. Thompson, Seakem Oceanography Ltd., Sidney
N.C. Treloar, Beak Consultants Ltd., Vancouver
M. Waldichuk, D.F.O./W.V.L., Vancouver
R. Young, MacMillan Bloedel Ltd., Vancouver
M. Yunker, Dobrocky SEATECH Limited, Sidney

APPENDIX III

1980-1981 CONTRACTS

A. PACIFIC REGION

1. Experimental investigation into the accumulation of Cd by the polychaete worm *Capitella capitata* and the bivalve *Macoma balthica*. — $17,368.00

   Scientific Authority: R.W. Macdonald, I.O.S.
   Contractor: E.V.S. Consultants Limited

2. Effects of silt and contaminated sediment on eggs and larvae of Pacific cod(*Gadus macrocephalus*). Phase I. — $14,817.00

   Scientific Authority: M. Nassichuk, D.F.O.
   Contractor: E.V.S. Consultants Limited

3. Production of lead alkyls in marine sediments. — $14,175.00

   Scientific Authority: J.A.J. Thompson, I.O.S.
   Contractor: Dobrocky SEATECH Limited

4. Organization and summary of ocean dumping workshops. — $ 3,740.00

   Scientific Authority: R.H. Herlinveaux, I.O.S.
   Contractor: Dobrocky SEATECH Limited

5. A review of criteria for evaluating ocean dumping permit applications with recommendations for future monitoring requirements. — $ 9,684.00

   Scientific Authority: H. Nelson, E.P.S.
   Contractor: E.V.S. Consultants Limited

B. NORTHWEST REGION

1. A statistical analysis of benthic invertebrate sampling in Tuktoyaktuk Harbour, N.W.T. — $ 8,600.00

   Scientific Authority: W. Bryant, E.P.S., Yellowknife
   Contractor: Arctic Laboratories Limited

2. Monitoring of fish entrainment by a 90 cm suction dredge in McKinley Bay and Tuktoyaktuk Harbour, Northwest Territories. — $17,400.00

   Scientific Authority: J. Stein, D.F.O., Winnipeg
   Contractor: Personal Service Contract

APPENDIX IV

1981-1982 CONTRACTS

A. PACIFIC REGION

1. A histological assessment of sublethal effects of ocean dumped material on benthic organisms in Alberni Inlet, B.C. Scientific Authority: W. Cretney, I.O.S. Contractor: Seakem Oceanography Limited	$10,000.00
2. *Rate of uptake and effects of bioaccumulation of contaminants from marine sediments for ocean dumping. Scientific Authority: Hal Nelson, E.P.S. Contractor: E.V.S. Consultants Limited	$22,000.00
3. Effects of dumped mud on Dungeness Crab (*Cancer magister*). Scientific Authority: C. Levings, W.V.L. Contractor: Archipelago Marine Research	$12,000.00
4. Effects of silt and organic debris on eggs and larvae of Pacific Cod (*Gadus macrocephalus*), PHASE II. (Phase I funded during 1980-1981) Scientific Authority: M. Nassichik, D.F.O. Contractor: E.V.S. Consultants Limited	$ 7,500.00
5. Organization and summary of ocean dumping workshops. Scientific Authority: R.H. Herlinveaux, I.O.S. Contractor: Dobrocky SEATECH Limited	$ 5,000.00

B. NORTHWEST REGION

To be held in abeyance pending the design of a more specific research problem.	$25,000.00

* Received partial funding.