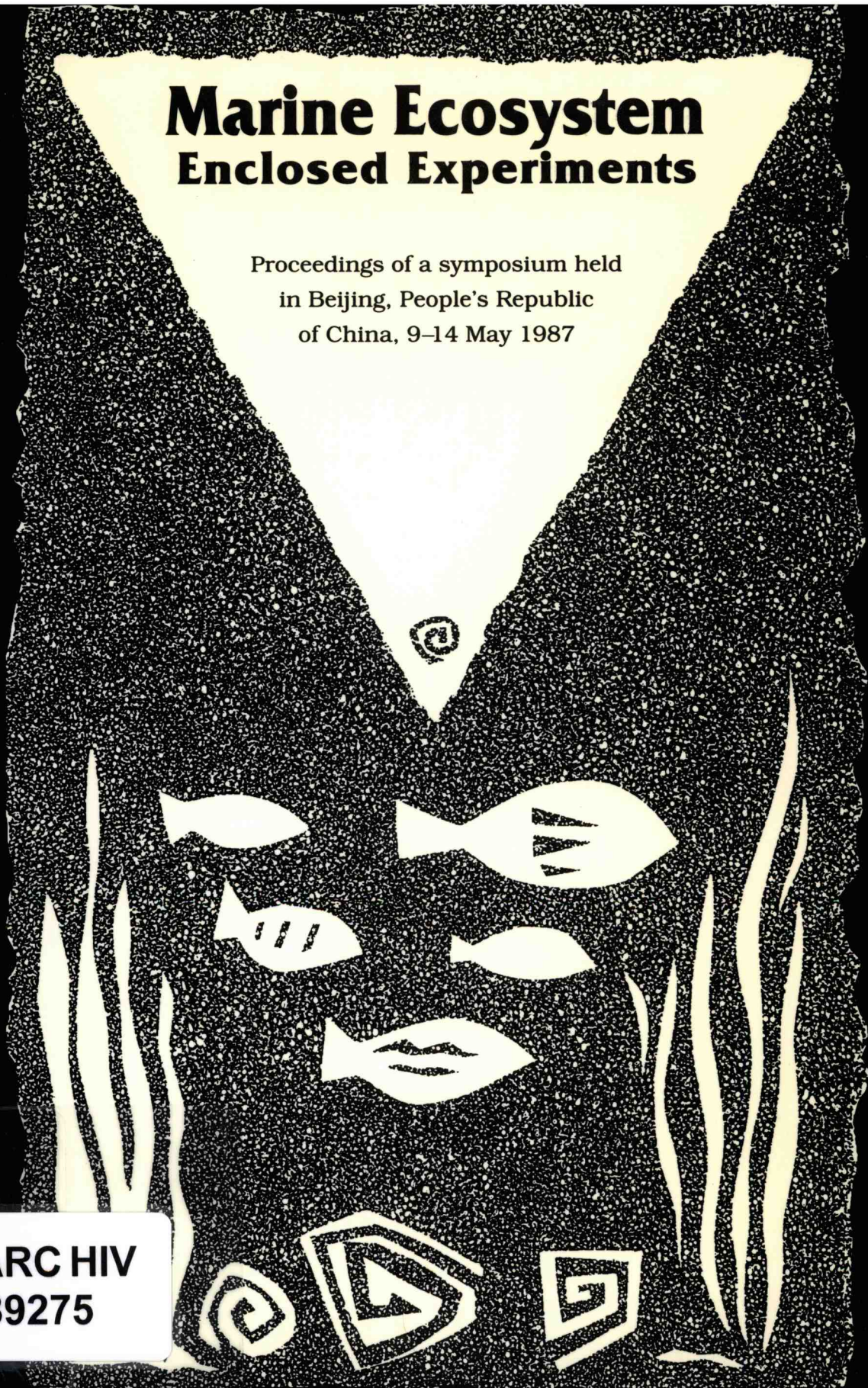
Marine Ecosystem
Enclosed Experiments

Proceedings of a symposium held
in Beijing, People's Republic
of China, 9–14 May 1987



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Editor: C.S. Wong and P.J. Harrison

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Abstract

This symposium on marine ecosystem enclosed experiments (MEEE) consists of nine review papers that describe various types of ecosystem enclosures and a series of papers resulting from enclosure experiments in Xiamen, People's Republic of China, and Saanich Inlet, BC, Canada. The reviews on types of enclosures include benthic enclosures for rocky and sandy shores and the effects of pollutants (primarily hydrocarbons) on bacteria, macroalgae, and invertebrates. The pelagic enclosures were used to study the control of phytoplankton blooms, the uptake and release of dissolved organic substances, and the effects of pesticides on freshwater ecosystems.

Six enclosure experiments were conducted in China and Canada from 1986–87. Some of these experiments examined the effects of contaminated sediments, primarily heavy metals, on bacteria, phytoplankton, and zooplankton and the pathways and fates of these heavy metals in the seawater. Other experiments studied the chemistry and biological effects of chemically dispersed oil.

Résumé

Ce compte rendu du symposium sur les expériences faites en écosystèmes marins comprend neuf communications qui décrivent les écosystèmes retenus et les expériences faites à Xiamen en République populaire de Chine et à Saanich Inlet, C.-B., au Canada. Les communications portent, notamment, sur les écosystèmes benthiques des littoraux rocheux et sablonneux et sur les effets des polluants (surtout les hydrocarbures) sur les bactéries, les grandes algues et les invertébrés. Les expériences sur le contrôle des brutales pullulations ("blooms") du phytoplancton furent menées dans les écosystèmes pélagiques, ainsi que l'absorption et le dégagement des substances organiques dissoutes et les effets des pesticides sur les écosystèmes d'eau douce.

Six expériences ont été faites en Chine et au Canada entre 1983 et 1987. Certaines ont porté sur les effets des sédiments contaminés, principalement par des métaux lourds, sur les bactéries, le phytoplancton et le zooplancton et sur le cheminement et le sort de ces métaux lourds dans l'eau salée. D'autres expériences portaient sur la chimie et les effets biologiques du pétrole dispersé chimiquement.

Resumen

Este simposio sobre Experimentos Marinos en Ecosistemas Cerrados (MEEE) consistió en nueve trabajos de análisis que describen varios tipos de enclaustramientos ecosistémicos y una serie de trabajos derivados de experimentos con estos enclaustramientos en Xiamen, República Popular de China, y en Sannich Inlet, Canadá. Los estudios incluyen enclaustramientos bentónicos para costas rocosas y arenosas, y los efectos de los contaminantes (fundamentalmente hidrocarburos) sobre bacterias, macroalgas e invertebrados. Los enclaustramientos pelágicos se utilizaron para estudiar el control de la reproducción del fitoplancton, la ingestión y expulsión de substancias orgánicas disueltas y los efectos de pesticidas en los ecosistemas de agua dulce.

Se realizaron seis experimentos en ecosistemas cerrados en China y Canadá, de 1983 a 1987. Algunos de estos experimentos examinaron los efectos que ejercen los sedimentos contaminados, fundamentalmente los metales pesados, sobre bacterias, fitoplancton y zooplancton, y el ciclo y destino final de estos metales pesados en el agua de mar. Otros experimentos estudiaron los efectos químicos y biológicos de los aceites crudos dispersados por medios químicos.

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A. Sediments and Heavy Metals

B. Hydrocarbons

Pathways and Fates of Heavy-Metal Mixtures in the Xiamen MEEE

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In 1985, the pathways and fates of two concentrations of heavy-metal mixtures in separate 10 m^3 bags were studied at Xiamen Bay. Initially, the dissolved metals were removed exponentially with the settling particles and their removal rate followed the order Pb > Hg > Zn > Cu > Cd. During a phytoplankton bloom, Zn was transferred biologically onto particles. Twenty-seven days after the experiment, most of the Cd and Cu remained in the dissolved phase, Hg and Pb were mainly transferred to the particles, and the amount of Zn was almost equal in both phases. The amount of metals retained on the wall of the bags was less than 2% of that in the bags. The association of heavy metals with zooplankton was rather unstable. Organic matter was found to be very important in the transfer of heavy metals.

Recently, the problem of heavy-metal pollution has received much attention. Some studies have been conducted to observe the toxic effects of heavy metals on marine organisms and the movement of metals in the marine environment. Over the last decade, the Marine Ecosystem Enclosure Experiment (MEEE) has been developed as a new tool to study the transfer and fate of marine pollutants (Topping and Windom 1977; Kremling et al. 1978; Santschi et al. 1980, 1983; Hunt et al. 1982; Santschi 1982; Wallace et al. 1982).

The coastal region of North America, where the Controlled Ecosystem Pollution Experiment (CEPEX) was conducted, is an area with deep water where biogeochemical cycles of elements are mainly regulated by the life cycle of planktonic organisms. In China, Xiamen Harbour is a relatively shallow and semienclosed bay. The seawater is affected by tidal action and the large amount of suspended matter carried down by the Jiulongjiang River. In this area, the effects of organic detritus and plankton on the transfer of elements may differ from those in North America. In 1985, scientists from Canada and China conducted a MEEE in Xiamen to study the transfer of heavy metals.

This report discusses the removal rates of two mixtures of heavy metals (Cd, Cu, Hg, Pb, and Zn) in low concentrations from the water column of the enclosures. It also discusses the effects of suspended particulate matter (SPM) and biological activities on transfer mechanisms and the fate of heavy trace metals.

Methods

Enclosures

Five cylindrical bags constructed from woven nylon and strengthened with polyethylene were used as the experimental enclosures. The bags, each 2 m in diameter and 3 m in depth, with the last 1 m in a conical shape, were mounted on a wooden raft placed in a pool (20 × 10 × 5 m) near the shore. The exchange rate of seawater between the pool and the harbour was 15 $m^3 \cdot h^{-1}$. At high tide, a diaphragm pump was used to fill the bags with seawater taken from 3 m depth 150 m offshore. The pool was shaded with a semiopaque roof to reduce the incident light intensity by about 50% (Wu, J., et al., this volume).

In each bag, polyethylene sediment traps (68 mm in diameter and 125 mm high), supported on a polypropylene rod and arranged at right angles, were placed at levels of 1 and 2 m below the surface. Several strips of bag material were hung at the end of the rod. A polyethylene cup (95 mm in diameter and 150 mm high) was suspended at the 3-m layer and used as another sediment trap (Fig. 1).

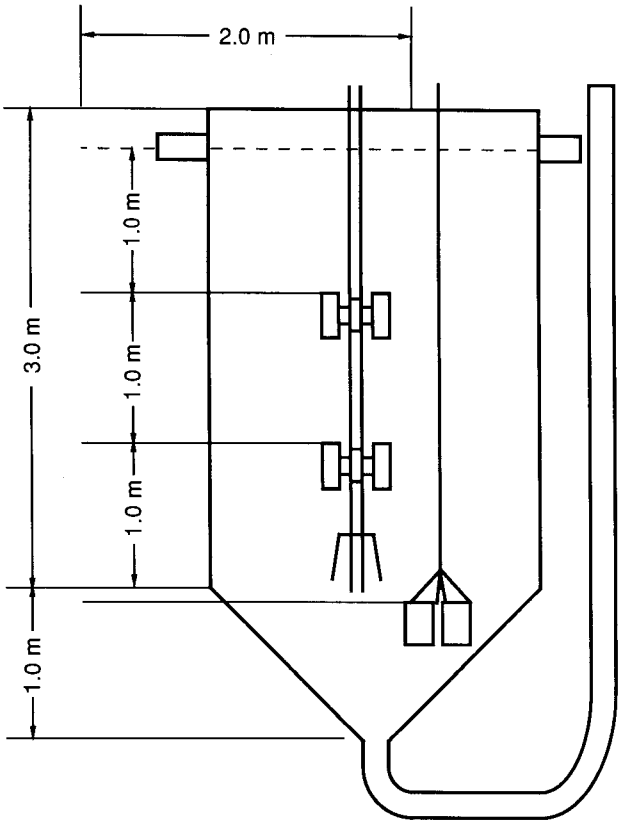

Fig. 1. Position of sediment traps inside the enclosure (dimensions in metres).

Metal treatments and sampling

Two bags (C1 and C2) were used as the control (no treatment), two bags (M1 and M2) were treated with a mixture of heavy metals in low concentrations, and the last bag (M3) was treated with a mixture of heavy metals in high concentrations. Background levels of metals in the control bags and concentrations of metals used in the treatments are listed in Table 1.

All of the bags were filled with about 10 m^3 of seawater before the experiment, which began on 18 April and ended on 15 May 1985. On day 0, additional nutrients (NO_3:SiO_4:PO_4 = 5:5:0.5 $\mu mol \cdot L^{-1}$) were mixed into the enclosures before seawater from the top 3 m was sampled using a peristaltic pump to determine background levels of various parameters. Appropriate metal mixtures were then added to the bags. Seawater and sediment samples were taken on days 1, 3, 5, 8, 11, 14, 17, 20, and 27. A strip of bag material was also removed periodically for analysis.

Sample analyses

Seawater samples were filtered through 0.4-μm Nuclepore filters under low vacuum. Material retained on the filters was washed with 5 mL of water, air dried at 50±2°C, and then weighed.

The filtrate was complexed with ammonium 1-pyrrolidine dithiocarbamate/ diethyl ammonium diethyl dithiocarbamate (APDC/DDDC), extracted with Freon-TF, back-extracted with dilute nitric acid, and then analyzed using a flameless atomic absorption spectrophotometer (PE-703) fitted with an HGA-500 graphite furnace (Li et al. 1986) for dissolved metals.

A subsample of the filtered material was agitated with 0.5 *N* HCl for 24 h and then analyzed using the flameless atomic absorption spectrophotometer for weakly bound particulate metals.

After extraction of the weakly bound metals, the residue was digested with a mixture of aqua regia and HF and analyzed using the flameless atomic absorption spectrophotometer for strongly bound particulate metals.

To determine total particulate metals, material retained on the filter was digested with aqua regia and HF and analyzed using the flameless atomic absorption spectrophotometer.

Data on Hg, particulate organic carbon (POC), particulate organic nitrogen (PON), chlorophyll *a*, and particle sizes are presented in the *MEEE-85 Xiamen Data Report* (MEEE Group 1985).

Chemical properties of the seawater in the bags during the experiment are listed in Table 2.

Table 1. Background and treatment levels ($\mu g \cdot kg^{-1}$) of heavy metals in the bags.

	Cd	Cu	Pb	Zn	Hg
C1, C2 background	0.03	0.38	0.02	0.25	0.002
M1, M2 treatment	1.0	3.5	0.3	3.5	0.2
M3 treatment	5.0	10.0	1.5	17.5	1.0

Table 2. Chemical properties of seawater in the experimental bags.

Parameter	Range
Surface sea temperature (°C)	17.6–23.5
Salinity (‰)	20.00–21.92
pH	8.11–8.54
$NO_2 + NO_3$ (μM)	25.4–0.1
NH_4 (μM)	0.43–9.5
PO_4 (μM)	0.94–0.00
$Si(OH)_4$ (μM)	56.5–21.0

Table 3. Half-removal time (d) of dissolved metals and suspended particles in the water column.

Bag	Cd	Cu	Pb	Zn	Hg	Particles
M1	89	21	5.4	13	6.7	3.4
M2	40	29	5.7	11	14.0	3.4
M3	30	16	5.8	22	9.0	3.9

Results and discussion

Because the experimental bags were supplemented with nutrients, growth of phytoplankton was fairly rapid. Phytoplankton bloomed from days 8 to 11 in bags C1, C2, M1, and M2. In bag M3, the bloom was delayed for 6 d. In this paper, the focus is on the transfer and fate of metal pollutants in the enclosures.

Removal of dissolved metals

Figure 2 shows changes in concentrations of dissolved metals with time. The curves illustrated can be divided into two time periods, the first 8 d, during which rapid changes in concentrations took place, and the last 20 d, during which changes, except for Zn, were relatively slow.

During the first 3 d of the experiment, concentrations of dissolved metals decreased rapidly. Trends, which were similar to the sinking of SPM (Fig. 2), could be described by first-order kinetic equations (Wallace et al. 1982). Calculated half-removal times of metals and SPM (Table 3) increased in the order SPM < Pb < Hg < Zn < Cu < Cd. Because Hg and Pb are particle-reactive elements (Santschi et al. 1980, 1983), their removal rates probably depended on the settling fluxes of particles in the water column. In contrast, Cd existed mainly in its dissolved phase, which only interacted with particulate matter through ion exchange or weak adsorption. It was less affected by sinking particulate matter, so its removal time was much longer.

During the last 20 d of the experiment, the total amount of SPM stayed almost the same. There was an obvious biological transfer of Zn during the bloom, indicating its bioreactivity. The relatively small changes in concentrations of Cd, Cu, Hg, and Pb indicated that biological transfer of these elements is either very slow or in an equilibrium state.

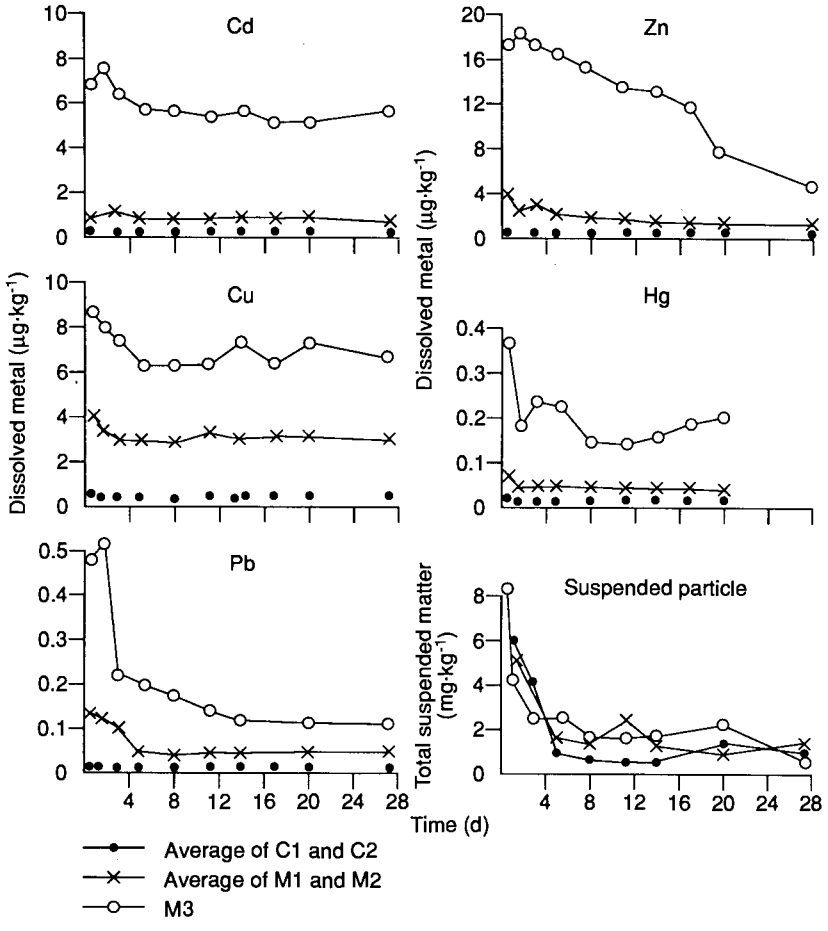

Fig. 2 (a). Changes with time in the concentrations of dissolved metal and total suspended matter (TSM).

Thus, when heavy metals were added in the enclosed ecosystems, they became involved in the physical, chemical, and biological aspects of transfer processes. The action of SPM adsorption, the activity of organisms, and the synergistic action of organisms all played an important role in removing metals from the water body.

Suspended particulate matter and particulate metals

Suspended particulate matter

Total SPM decreased exponentially from an initial concentration in the seawater of 8 $mg \cdot kg^{-1}$ to 1–2 $mg \cdot kg^{-1}$ near the end of the experiment. The decrease was accelerated both by the exclusion of turbulence and advection in the water in the bags and by the coagulation and sinking of particles during phytoplankton blooms. The addition of metals had no significant influence on the total amount of SPM.

Fluxes of sinking particles at the 3-m layer were calculated from the sediment trap data (Fig. 3). On day 1, the fluxes were the largest and were greater than

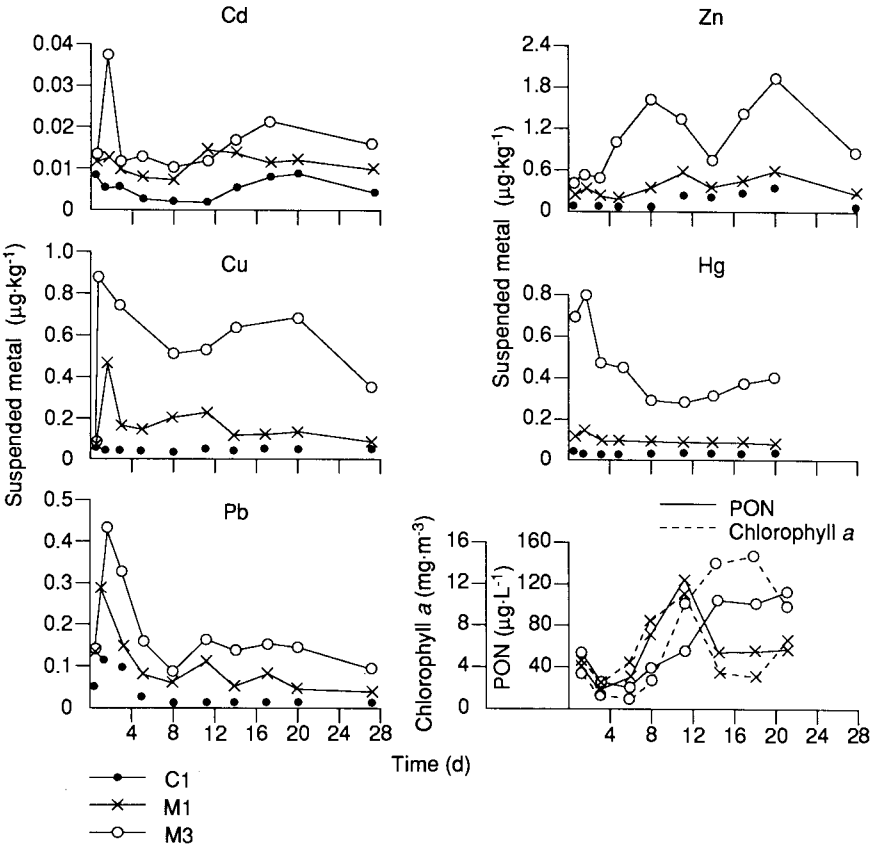

Fig. 2 (b). Changes with time in the concentrations of suspended metal, particulate organic nitrogen (PON), and chlorophyll *a*.

40 mg·cm^{-2}·d^{-1}. Thereafter, values decreased gradually, and 7 d later they fluctuated between 5 and 25 mg·cm^{-2}·d^{-1}.

The fluxes of particles among the 1-, 2-, and 3-m layers did not increase proportionally (Fig. 4). Maximum collection of particles occurred at the 1-m layer in which the density of plankton was probably the greatest among the three layers. At this layer, light attenuation was only about 50%, so photosynthesis was mainly carried out there. The next highest collection occurred at the 3-m layer, which was affected by resuspension of bottom sediment. From this layer, the amount of particles collected was far greater than the estimated loss of SPM. This indicated some authigenic production of particles in the bags. Other contributions included coagulation of fine particles (Lal 1980), deposition from the atmosphere, and resuspension of settled materials.

Values of R, i.e., the ratio between the amount collected from the sediment trap and the loss of particles from the water column, were also calculated. During the first 3 d, R values from all of the bags were in the range of 1.2±0.1. The value increased with the occurrence of resuspension, but its value was <1 during the bloom. Thus, R could be used as an index to investigate the mechanism of particle removal (Santschi et al. 1983).

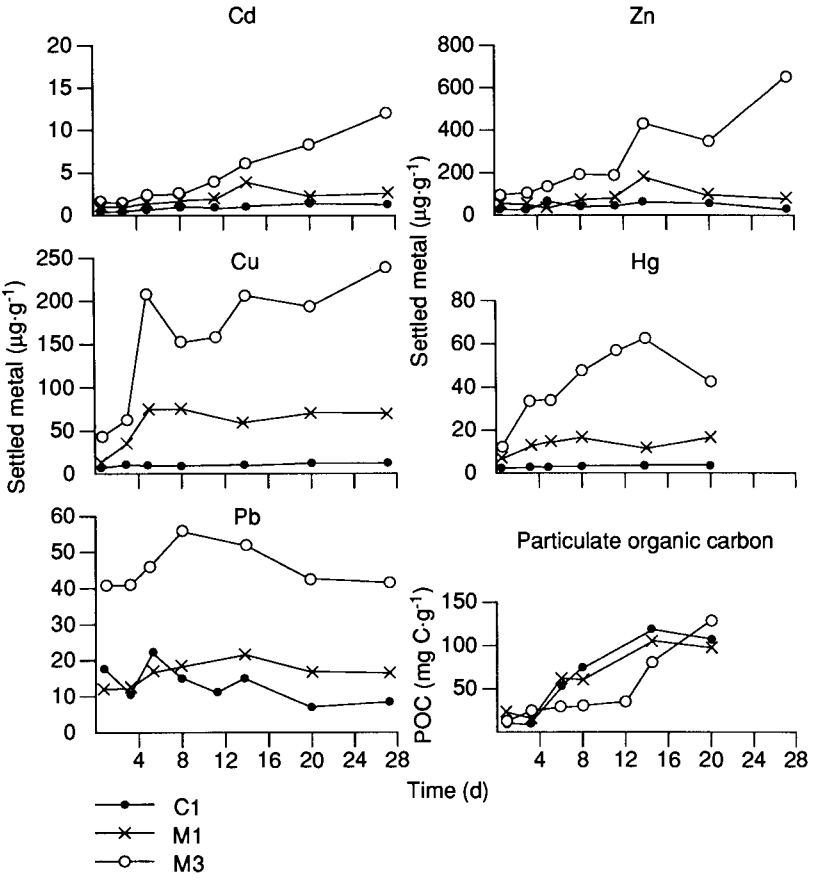

Fig. 2(c). Changes with time in the concentrations of settled metal and particulate organic carbon (POC).

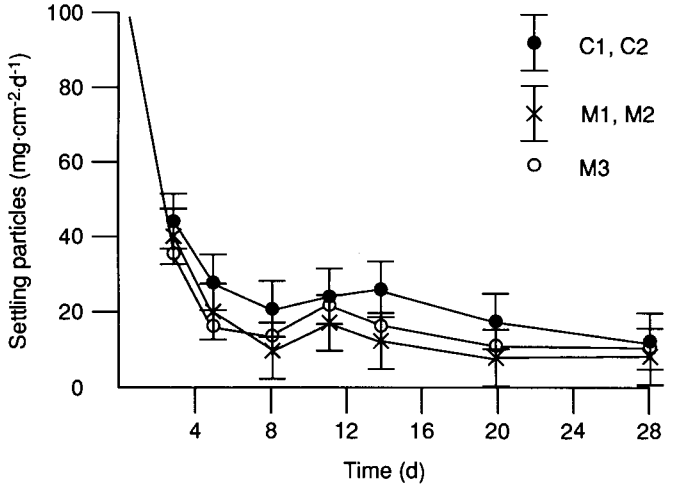

Fig. 3. Fluxes of settling particles at the 3-m layer.

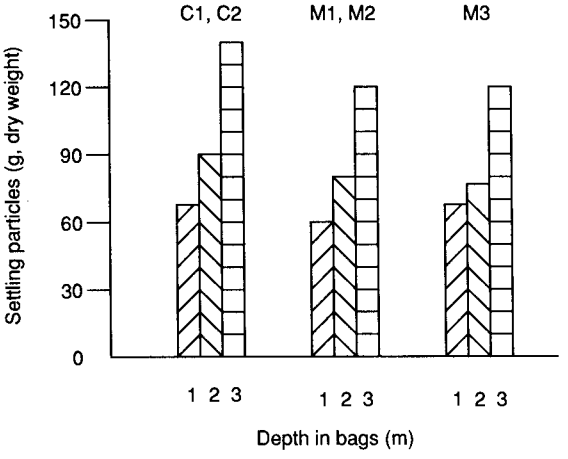

Fig. 4. Amounts of settling particles at the 1-, 2-, and 3-m layers.

Particles

Changes in the POC of suspended and settled materials were also measured to elucidate the effects of biological activity on the composition of particles (Fig. 5). It was found that the concentration of POC in suspended particles was twice the concentration measured in settled particles. During the early part of the experiment, the concentration of organic matter in the bags was relatively low and was basically within 2–5% of the total particulate dried weight. On day 11, the concentration of POC increased substantially in all of the bags. In the control and in bag M1, phytoplankton blooms were observed. The concentration of POC in the control, which increased to 22% of the total dried weight of the particles, was slightly higher than the concentration in bag M1. In bag M3, the bloom was delayed until day 20, at which time its POC concentration also increased. Suspended particles collected during the early part of the experiment were mainly composed of fine particles (<4 μm), but shifted toward larger particles (8–20 μm) in the latter part of the experiment (Fig. 6).

Concentrations of POC and PON at the end of the experiment were higher than those measured during the early part of the experiment (Fig. 7). Throughout the experiment, concentrations at the 1-m layer were consistently higher than those at the lower layers. During the experiment, the C:N ratio decreased from about 10:1 to about 6:1, similar to the ratio of healthy phytoplankton.

In summary, particulates in the bags shifted from inorganic fine particles during the early stages of the experiment to larger, mainly biogenic particles at the end of the experiment. Organisms in the upper layer were also more active than those in the lower layers.

Particulate metals

Figure 2 shows the variations in the concentrations of particulate (suspended) metals. In the bags treated with metals, concentrations reached their peak values early in the experiment, indicating adsorption of dissolved metals by particles. Concentrations decreased with the sinking of particles. For Zn, the bimodal curves

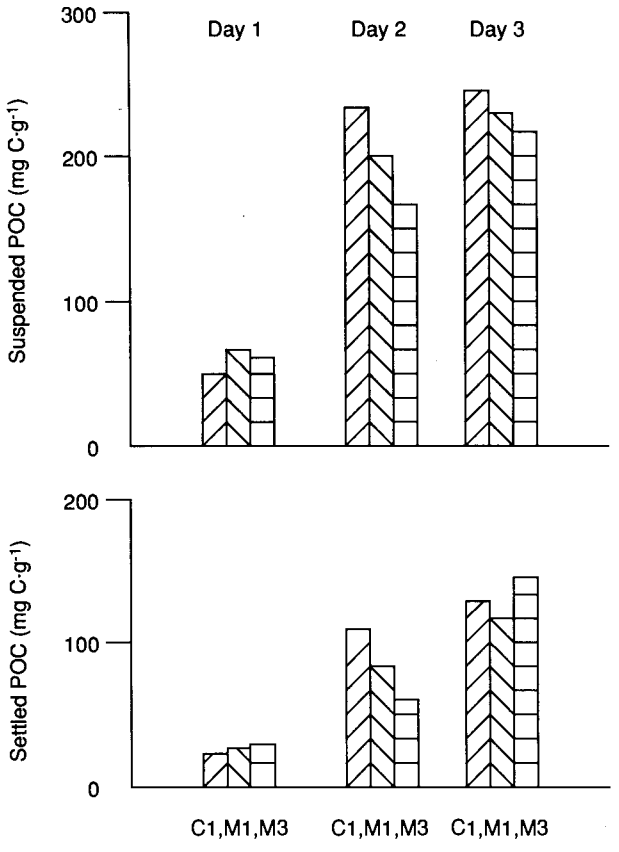

Fig. 5. Concentrations of particulate organic carbon (POC) in suspended particles and settling materials on days 1, 11, and 20.

suggest the uptake by organisms during the bloom correspond with decrease in the dissolved phase.

A partition coefficient, K_d, can be used to represent the degree of metal accumulation during the particulate phase. The K_d value for a given element reflects the particulate activity of the element. In bag M3, K_d values decreased in the order Pb > Hg > Zn > Cu > Cd (Fig. 8). This was the order observed for removal rates of dissolved metals.

During the first few days, the K_d of Hg increased rapidly, indicating that the added dissolved Hg was being transformed to the particulate phase. For Cd, the situation was reversed; most of the Cd remained in the dissolved phase in the water. The curve for Zn shows three different slopes, representing the early increase in the dissolved phase, the biological transfer, and the particulate adsorption and sinking phase.

After the addition of metals, large portions of the metals were adsorbed onto settling inorganic and organic particles. The amounts settled increased with the amounts of metals added. As the POC content increased, there were corresponding

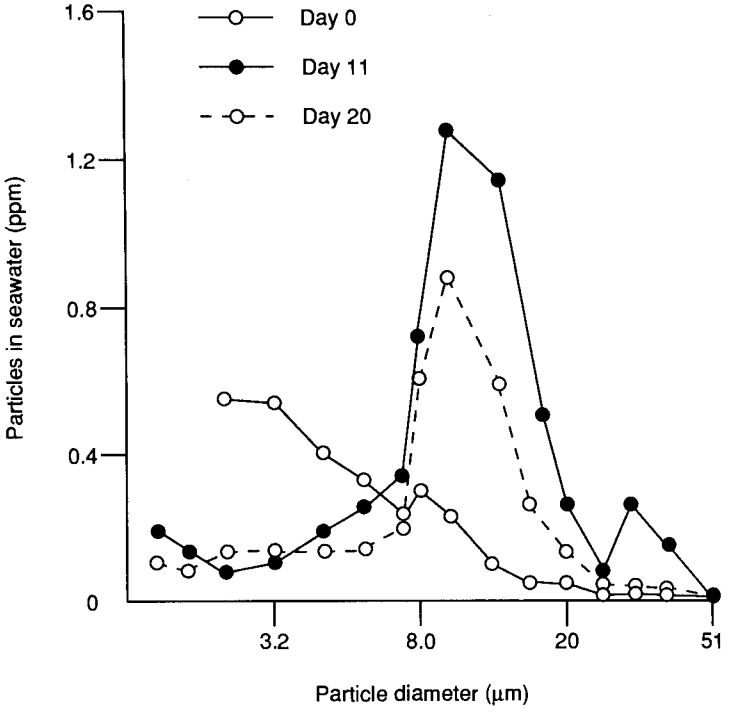

Fig. 6. Particle-size distribution of suspended particulate matter in bag M3 on days 1, 11, and 20.

increases in the concentrations of settled Cd, Cu, Hg, and Zn (Fig. 2), indicating that organic carbon was able to undergo complexing with these metals.

Some interesting results were obtained by comparing the concentrations of metals in suspended matter and settling materials collected from the three layers (Fig. 9). The concentrations of Cd, Zn, and Pb decreased in the order suspended matter, 1-m, 2-m, and 3-m settling materials, which was the same order as the decreases of POC. However, the concentration of Cu increased in the same order. These variations were probably the result of different biogeochemical processes involving the metals in the enclosures. Some of the Cd, Pb, and Zn was released to the water body with the weakly bound ligands following the death and decay of planktonic organisms. In the case of Cu, it accumulated on settled materials as organic matter decomposed during remineralization. Organic matter was the main factor controlling the distribution of trace metals in the enclosures. It could enhance the solubility of metals in water or the partition of trace metals on particles (Kuiper 1982; Morel et al. 1983; Hong 1984).

Budget of metal in the enclosures

Table 4 lists the amounts of the various metals in their respective phases during the experiment. Some of the results are summarized below.

- The metals adsorbed on the bag wall amounted to less than 2% of those in the water.

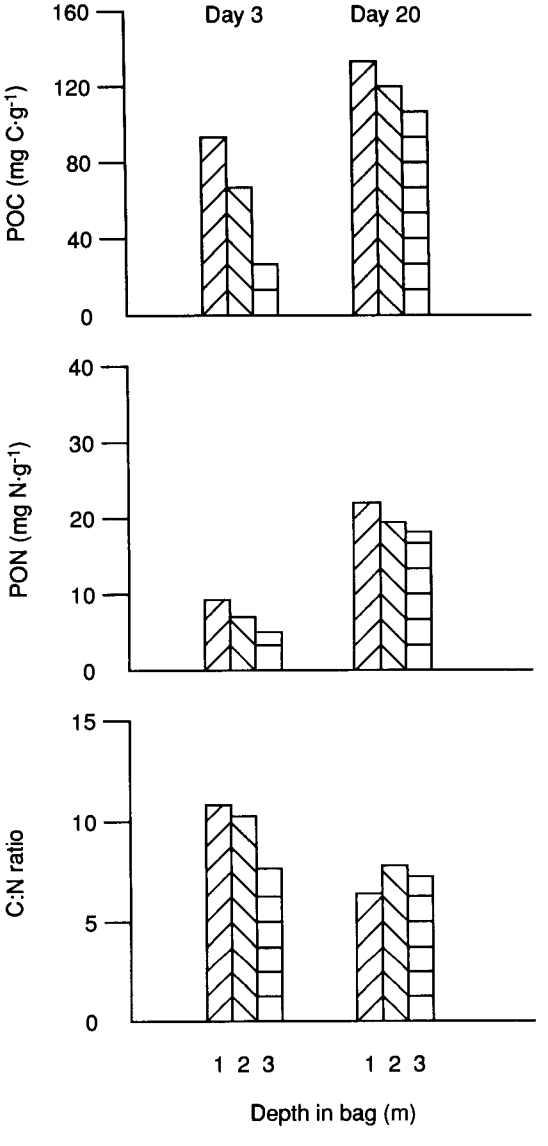

Fig. 7. Particulate organic carbon (POC) and particulate organic nitrogen (PON) in settling materials from depths of 1, 2, and 3 m in bag M1 on days 3 and 20.

- In the two control bags, total amounts of each metal on day 27 were higher than those present on day 0. The proportion of the increase varied among the different metals, but was highest in the cases of Pb and Zn. These increases indicated the existence of some other sources of heavy metals, such as contamination or atmospheric deposition during the experiment.

- During the experiment, bag M2 slanted considerably, which increased resuspension. Most of the data for bag M2, especially total amounts of metals recovered, were not acceptable. In bags M1 and M3, recovery rates

Table 4. Budget of metals (mg per bag).

	Cd		Cu		Pb		Zn		Hg	
	Day 0	Day 27	Day 0	Day 27	Day 0	Day 27	Day 0	Day 27	Day 0	Day 20
Bag C1										
Dissolved	0.30	0.34	3.7	4.5	0.13	0.18	2.3	2.5	0.021	0.031
Particulate	0.08	0.03	0.5	0.07	0.69	0.15	3.7	0.4	0.012	0.001
Added	—	—	—	—	—	—	—	—	—	—
On wall	—	0.01	—	0.14	—	0.04	—	0.1	—	—
Settled	—	0.14	—	1.75	—	2.1	—	9.1	—	0.028
Total	0.38	0.52	4.2	6.5	0.82	2.5	6.0	12.1	0.033	0.060
Bag C2										
Dissolved	0.36	0.39	3.9	4.7	0.13	0.11	2.4	2.5	0.035	0.030
Particulate	0.14	0.02	0.5	0.14	0.53	0.16	3.6	0.7	0.023	0.003
Added	—	—	—	—	—	—	—	—	—	—
On wall	—	0.01	—	0.13	—	0.05	—	0.1	—	—
Settled	—	0.10	—	1.45	—	1.9	—	7.1	—	0.029
Total	0.50	0.52	4.4	6.4	0.66	2.2	6.0	10.4	0.058	0.062
Bag M1										
Dissolved	0.35	8.4	3.7	23.4	0.12	0.45	2.7	9.3	0.053	0.27
Particulate	0.12	0.10	0.5	0.6	0.75	0.24	3.8	2.5	0.000	0.32
Added	10	—	35	—	3.0	—	35	—	2.0	—
On wall	—	0.03	—	0.3	—	0.08	—	0.2	—	—
Settled	—	0.24	—	4.1	—	2.4	—	18.0	—	0.93
Total	10.5	8.8	39.2	28.4	3.9	3.2	41.5	30.0	2.1	1.5

Bag M2										
Dissolved	0.29	11.9	3.5	33.9	0.12	0.42	2.8	9.8	0.031	0.43
Particulate	0.13	0.14	0.6	1.6	0.78	0.35	3.8	3.0	0.006	0.56
Added	10	—	35	—	3.0	—	35	—	2.0	—
On wall	—	0.03	—	0.4	—	0.09	—	0.2	—	—
Settled	—	0.25	—	9.1	—	2.9	—	26.1	—	2.38
Total	10.4	12.3	39.1	45.0	3.9	3.8	41.6	39.1	2.0	3.4
Bag M3										
Dissolved	0.28	52	3.1	67.3	0.14	1.05	2.3 45	0.037	2.0	—
Particulate	0.13	0.15	0.5	3.7	0.64	0.90	2.7 10	0.001	2.6	—
Added	50	—	100	—	15	—	175	—	10	—
On wall	—	0.04	—	1.4	—	0.14	—	1.4	—	—
Settled	—	0.57	—	18.0	—	5.6	—	42	—	4.9
Total	50.4	52.8	103.6	90.4	15.8	7.7	180	98.4	10	9.5

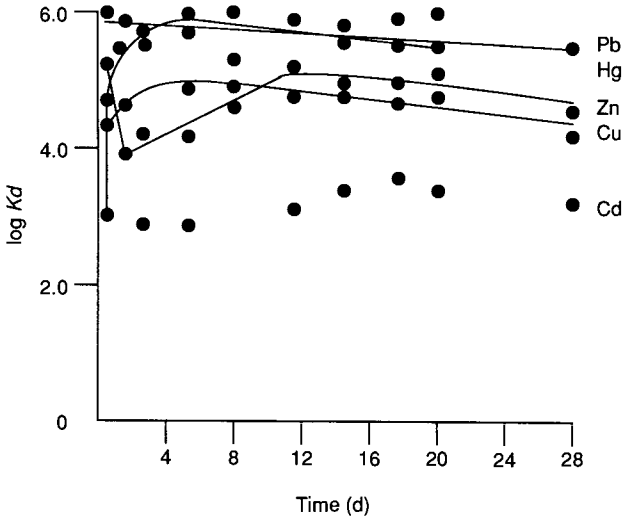

Fig. 8. Changes in the partition coefficient (K_d) of metals between solid and liquid phases in bag M3 with time. K_d = [particulate metal ($\mu g \cdot g^{-1}$ dry weight)/dissolved metal ($\mu g \cdot kg^{-1}$)] $\times 10^3$.

fluctuated between 50 and 90%. Incomplete recovery was probably caused by leaking of the enclosures, changes in water volume, evaporative loss of metals, or errors introduced during sampling and analysis.

- More than 80% of the Cd and 60% of the Cu remained in dissolved phases. More than 60% of the Pb and 50% of the Hg transferred to settled materials. For Zn, amounts were equally split between the two phases.

Heavy metals in zooplankton

Table 5 lists the concentrations of various heavy metals and their concentration factors (K_d) in zooplankton at the end of the experiment. Cd, Cu, Pb, and Zn added during the experiment have now been transferred to zooplankton. A high concentrations of dissolved metals always corresponded with small K_d values. Amounts of Cd, Cu, and Zn in zooplankton were higher than their respective concentrations in the particles before treatment, whereas amounts of Pb in zooplankton and initial suspended particulate matter were about the same in M1 and M2.

Bonds between heavy metals and zooplankton were very weak. Most of these metals could be extracted with dilute acid (Table 6). The percentages of weak-binding metals decreased in the order Cd, Zn, Cu, and Pb, and they also decreased in the order zooplankton, SPM, and settling particles. In an enclosed ecosystem, only a very small proportion of each heavy metal was removed by zooplankton.

Conclusions

During the first few days of the experiment, the concentration of dissolved metals decreased exponentially together with the original particles in the bags.

Table 5. Concentration of heavy metals and their concentration factor (K_d)[a] in zooplankton.

Bag	Cd		Cu		Pb		Zn		Co		Ni	
	ppm	K_d	ppm	K_d	ppm	K_d	ppm	K_d	ppm	K_d	ppm	K_d
C1, C2	4.5	1.5×10^5	29	6.3×10^4	31	2.1×10^6	264	1.1×10^6	5.6	4.3×10^5	13	4.5×10^4
M1, M2	7.9	7.9×10^3	105	3.7×10^4	36	8.2×10^5	293	3.3×10^5	6.1	—	11	—
M3	21	4.0×10^3	118	1.8×10^4	68	6.4×10^5	353	7.8×10^4	6.2	—	13	—
Initial SPM[b]	0.64	2.1×10^4	32	9.1×10^4	39	2.8×10^6	112	4.7×10^5	29	2.9×10^5	71	2.3×10^5
Ocean plankton[c]	0.19–54		3–26				21–400				1–25	

[a] K_d = [metal content in zooplankton ($\mu g \cdot g^{-1}$ dry weight)] / [dissolved metal concentration in seawater ($\mu g \cdot kg^{-1}$)] $\times 10^3$.
[b] SPM = Suspended particulate matter.
[c] From Collier and Edmond (1984).

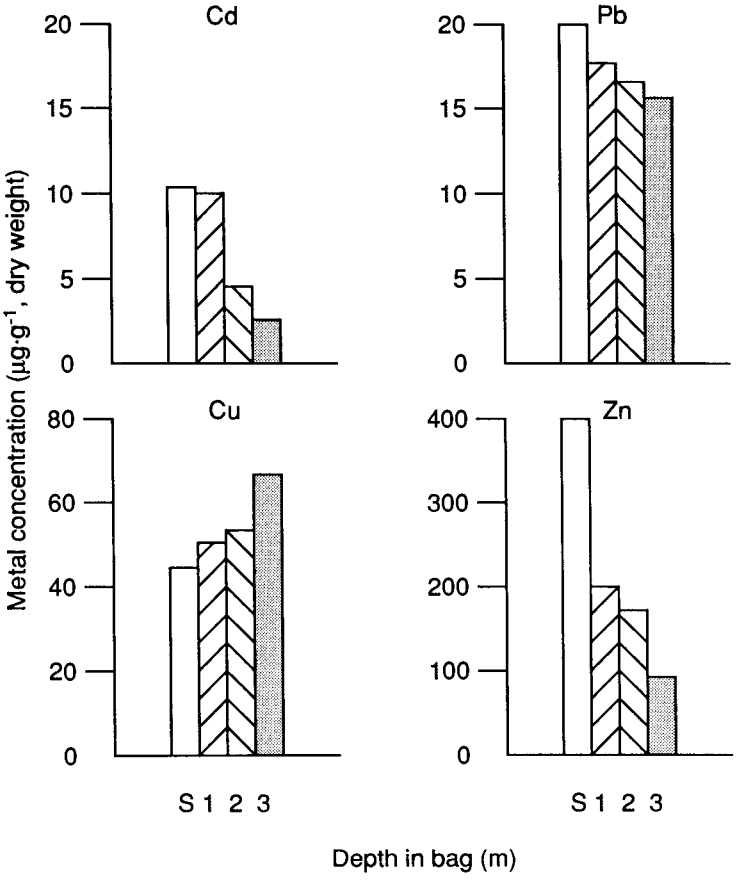

Fig. 9. Concentrations of metals in suspended particles (S) at depths of 0–3 m and settling materials at depths of 1, 2, and 3 m in bag M1 at the end of the experiment.

Table 6. Percentage of weak-binding metals in various types of particles at the end of the experiment.

Particle	Bag	Cd	Cu	Pb	Zn
Zooplankton	C1	87	72	42	75
	M1	95	66	55	81
	M3	96	93	75	93
Suspended particles	C1	65	54	31	60
	M1	86	66	45	72
	M3	85	76	67	70
Settled particles	C1	76	49	27	53
	M1	80	53	34	63
	M3	39	53	54	60

Removal rates decreased in the order Pb, Hg, Zn, Cu, and Cd. After the bloom, the concentration of Zn continued to decrease, whereas concentrations of Cd, Cu, Hg, and Pb changed little. On day 27, more than 80% of the Cd and 60% of the Cu remained in dissolved phases, and more than 60% of the Pb and 50% of the Hg transferred to settled materials. For Zn, the partition was about the same between the two phases.

Organic matter was an important factor in the partition of heavy metals between particulate and dissolved phases. Different trends in the concentrations of Cd, Cu, Pb, and Zn among suspended matter and settling materials from the three collection layers indicated the complexity of biogeochemical cycles of heavy metals in a marine environment.

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