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HEAVY METAL ACCUMULATION IN ANTARCTIC KRILL *EUPHAUSIA SUPERBA*

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Abstract: Seventy-six samples of the Antarctic krill were collected from the stomach contents of the southern minke whales hauled up on the Japanese factory ship during her cruises in 1984/85 and 1985/86, and were analyzed for Cu, Zn, Fe, Mn, Ni, Cd, Pb, Co, and Hg. The mean concentrations of metals in the Antarctic krill were Cu-12.7, Zn-9.6, Fe-3.6, Mn-0.71, Ni-0.45, Cd-0.43, Pb-0.04, Co-0.02, and Hg-0.008 μg/wet g. Although no significant difference in concentrations of the metals with size and location was found, metal concentrations varied seasonally: High concentrations of Fe, Mn, Zn, Pb, and Hg were observed during January–February, 1985/86, and during January, 1984/85. The concentrations of Cu, Cd, Ni, and Co were higher in January to mid-February, 1986, and during January, 1985, and thereafter their concentration levels except for Cu decreased.

1. Introduction

Studies on accumulations of heavy metals in zooplankton have been reported widely, leading to a better understanding of the distribution and bioaccumulation processes of heavy metals in marine ecosystem. Such an extensive literature is available on zooplankton because of their high abundance in the ocean and their high ability to concentrate certain metals (BENAYOUN *et al.*, 1974; HAMANAKA and MISHIMA, 1981; HAMANAKA and TSUJITA, 1981; MARTIN and KNAUER, 1973; RIDOUT *et al.*, 1985). However, data of heavy metal levels in the Antarctic krill, *Euphausia superba*, are very scarce (HENNIG *et al.*, 1985; SOSZKA *et al.*, 1981; STOEPPLER and BRANDT, 1979). The Antarctic krill is widely distributed in the Antarctic ocean and is a key species as a staple food source for higher trophic animals such as baleen whales, seals, and penguins in the simple Antarctic ecosystem (EVERSON, 1984a, b; LAWS, 1977; KNOX, 1970). Thus an analysis of the levels of heavy metals in the Antarctic krill will serve as a key to understand the behavior and bioaccumulation processes of these elements through food web in the Antarctic marine ecosystem.

This report describes concentration levels of Fe, Mn, Zn, Cu, Cd, Pb, Ni, Co, and Hg in the Antarctic krill, and their variations with body size, sampling location, and season.

2. Materials and Methods

Antarctic krills were collected from the 1st stomachs of the southern minke whales hauled up on the Japanese factory ship, NISSIN MARU No. 3, in the Antarctic

Table 1. Sample list of Antarctic krill.

Area*	Whaling season	Location Long.	Lat.	Date	N
A	1984/85	64°S	126–128°W	Dec. 1, 2, 1984	3
	1985/86	63°S	129°W	Dec. 8, 1985	1
B	1984/85	64°S	147°W	Nov. 27, 1984	1
		64–65°S	154–158°W	Dec. 14–16, 1984	6
	1985/86	64–65°S	151–161°W	Dec. 19, 1985–Jan. 10, 1986	12
C	1984/85	65–66°S	133–157°E	Jan. 4–24, 1985	12
		66°S	146°E	Mar. 4, 1985	2
	1985/86	66–68°S	140–152°E	Jan. 22–Feb. 26, 1986	21
D	1984/85	65–66°S	107–122°E	Jan. 28–Feb. 14, 1985	8
	1985/86	65–66°S	108–123°E	Mar. 4–23, 1986	10
		64–66°S	126°W–107°E	Nov. 27, 1984–Feb. 14, 1985	32
		63–68°S	129°W–108°E	Dec. 8, 1985–Mar. 23, 1986	44

N: Number of sample analyzed.
* See Fig. 1.

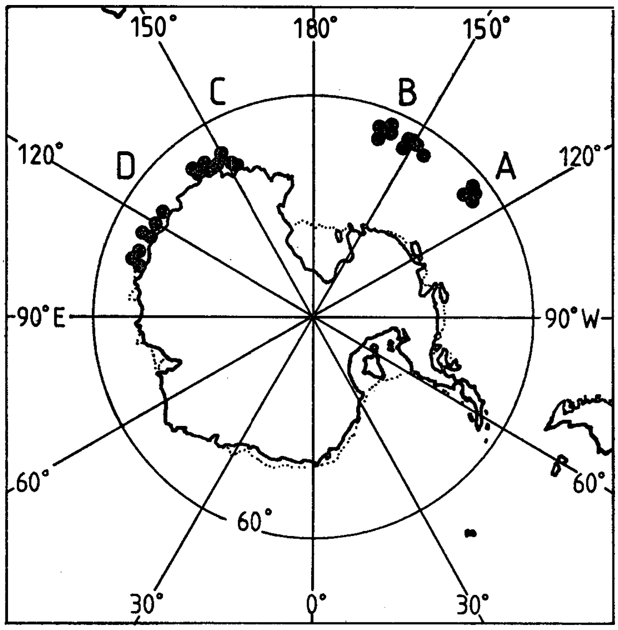

Fig. 1. Map showing sample collection sites around Antarctica.

during the austral summer seasons from 27th November 1984 to 14th February 1985 and from 8th December 1985 to 23rd March 1986 (Table 1, Fig. 1). Samples of the krill were collected from un-digested contents of the 1st stomach to minimize any loss and/or contamination of metals. All samples of the krill were stored in polyethylene bags at below −20°C until analysis. Body lengths were measured for all specimens. Moisture content was calculated by weighing the specimens before and after drying the specimens for 12 h at 80°C.

For the analyses of Fe, Mn, Zn, Cu, Pb, Ni, Co and Cd, the samples were homogenized, and 0.5 g of dry samples were digested in a mixture of nitric, hydrochloric and perchloric acids. The resultant solutions were diluted to 50 m*l* with deionized water. The concentrations of Fe, Mn, Zn, and Cu were directly measured by atomic absorption spectrophotometry (AAS). For determinations of Pb, Ni, Co, and Cd, extraction with methyl isobutyl ketone was performed after diethyl dithiocarbamate chelation, and final measurement was made by AAS (HONDA *et al.*, 1982).

The presence of Hg was determined by cold vapor AAS (HONDA *et al.*, 1983). It consisted of the mineralization of samples with a nitric, perchloric and sulfuric acid mixture in a flask equipped with a Liebig condenser and followed by potassium permanganate ($KMnO_4$) digestion. The excess of $KMnO_4$ was reduced with a 20% hydroxylamine hydrochloride solution and the mercury was reduced to Hg^0 with tin (II) chloride. Determinations were made with a Shimadzu AA-670 spectrophotometer.

3. Results and Discussion

3.1. Concentration levels of heavy metals in the Antarctic krill

Table 2 shows the metal concentrations in the Antarctic krill. The concentrations of heavy metals in the krill were in the order of Cu·Zn>Fe>Mn>Ni·Cd>Pb>Hg, and the bioconcentration factors (metal concentration in krill/metal concentration in seawater) were high for Cu and Zn, and decreased in the order of Cd, Fe, Hg, Mn, Ni, and Pb. Wide variations (CV%) of Ni, Cd, Co, and Cu were observed, which indicate that these metals varied among the individuals, and the details are discussed in a latter section.

Table 2. Concentrations (μg/wet g) and bioconcentration factors of the heavy metals in Antarctic krill.

	N	Min.	Max.	Mean	SD	CV%	BCF
Cu	76	1.6	31.1	12.7	7.1	56	2.4×10^4
Zn	76	5.2	14.9	9.6	1.8	19	1.1×10^4
Fe	74	1.3	9.9	3.6	1.4	40	4.8×10^3
Mn	76	0.34	1.3	0.71	0.19	27	1.2×10^3
Ni	76	0.09	1.8	0.45	0.35	79	1.1×10^3
Cd	76	0.04	1.7	0.43	0.31	71	6.5×10^3
Pb	56	0.01	0.1	0.04	0.02	45	1.2×10^2
Co	53	<0.01	0.06	0.02	0.01	59	—
Hg*	53	4	23	8	3	38	1.4×10^3
WC	76	61	90	77	7	9	—

N: Number of sample analyzed.
BCF: Bioconcentration factor (metal in krill/metal in seawater).
WC: Water content (%).
*: ng/wet g.

Concentration data on heavy metals in the Antarctic krill are scarce. STOEPPLER and BRANDT (1979) examined the concentrations of Cu, Cd, Pb, Ni, and Hg in the Antarctic krill from the Scotia Sea, and reported the mean concentrations as Cu-6.5, Cd-0.17, Pb-0.34, Ni-0.30, and Hg-<0.02 μg/wet g. Their values for Cu, Cd, Ni, and Hg were nearly in the same range as those in this study. But, the value for Pb was about one order of magnitude higher than that in our results. SOSZKA *et al.* (1981) also reported that the mean metal concentrations in the Antarctic krill from the Scotia

Sea were Zn-123, Cd-2.5, and Pb-3.4 μg/dry g. These values for Zn and Pb were higher than those in our results, and especially apparent with Pb. Usually, determining the exact value of Pb is difficult because of possible contamination (rust, paints, other dusts and impurities in reagents, etc.), and therefore, the differences of Pb concentration mentioned above can be reasonably attributed to the different sampling and analytical procedures. The concentration values of Fe, Mn, Zn, Cu, and Cd obtained in this study were lower when compared with the results in the formalin-preserved samples of *E. triacantha* collected between New Zealand and McMurdo Sound, Antarctica (HENNIG *et al.*, 1985). Further information is needed to discuss whether this difference is due to the species-specific accumulations of metals in the krills.

3.2. *Variations of heavy metal concentrations in the Antarctic krill with the size, collection site, and season*

Relationships between the metal concentration in krill and the size are shown in Table 3. The results indicate that the difference in concentration of the metals with

Table 3. Variations of the metal concentrations (μg/wet g) and water content (%) in Antarctic krill with body length (mm).

Sample	BL	Fe	Mn	Zn	Cu	Cd	Ni	WC
No. 871	35–40	4.1	1.3	12.0	21.6	1.3	1.0	76
Feb. 5, 1986	40–45	3.7	0.9	11.2	18.3	1.0	0.9	75
66°11′S	45–50	3.8	1.0	11.5	17.1	0.8	1.0	75
148°21′E	50–55	3.8	1.1	11.4	16.5	1.0	1.0	74
No. 929	30–35	6.2	0.6	9.7	13.9	1.0	0.7	77
Feb. 7, 1986	35–40	3.3	0.9	10.6	14.2	0.8	0.9	76
66°13′S	40–45	4.6	1.0	10.9	18.2	1.2	0.9	74
148°27′E	45–50	4.0	0.9	10.6	16.6	0.9	0.9	74
	50–55	4.0	0.8	10.8	18.1	1.2	0.9	74
No. 1093	30–35	5.0	1.4	15.2	22.4	1.3	1.5	68
Feb. 14, 1986	35–40	4.2	1.2	14.4	20.9	1.3	1.5	69
66°30′S	40–45	4.0	1.1	14.3	23.9	1.4	1.6	69
151°50′E	40–45	4.1	1.3	11.9	24.5	1.1	1.4	69
	45–50	3.4	1.0	11.9	24.0	1.3	1.4	71
	50–55	3.3	1.0	11.9	24.5	1.3	1.3	71
	55–60	3.6	1.0	12.9	27.0	1.6	1.4	70

BL: Body length (mm).
WC: Water content (%).

size was not significant. In order to see if there are any seasonal and locational variations of the metal concentrations in the krill, the metal concentrations for each sampling site (A–D) were plotted against each sampling date, and the results for Zn, Cu and Cd are shown in Fig. 2, as examples. The metal concentrations showed wide variations among the individuals, and especially this was apparent for Cd, Ni, and Cu. When the metal concentrations in the krill collected from the same location were compared, the concentrations varied with sampling dates. For example, the concentrations of Cu in the krill collected in 1985/86 from area B increased gradually from December to January (Fig. 2). Same trend was also observed with those from area C. This indicates that variations in the metal concentrations might be dependent on season rather than location, and also that the variations with season were metal-specific. The

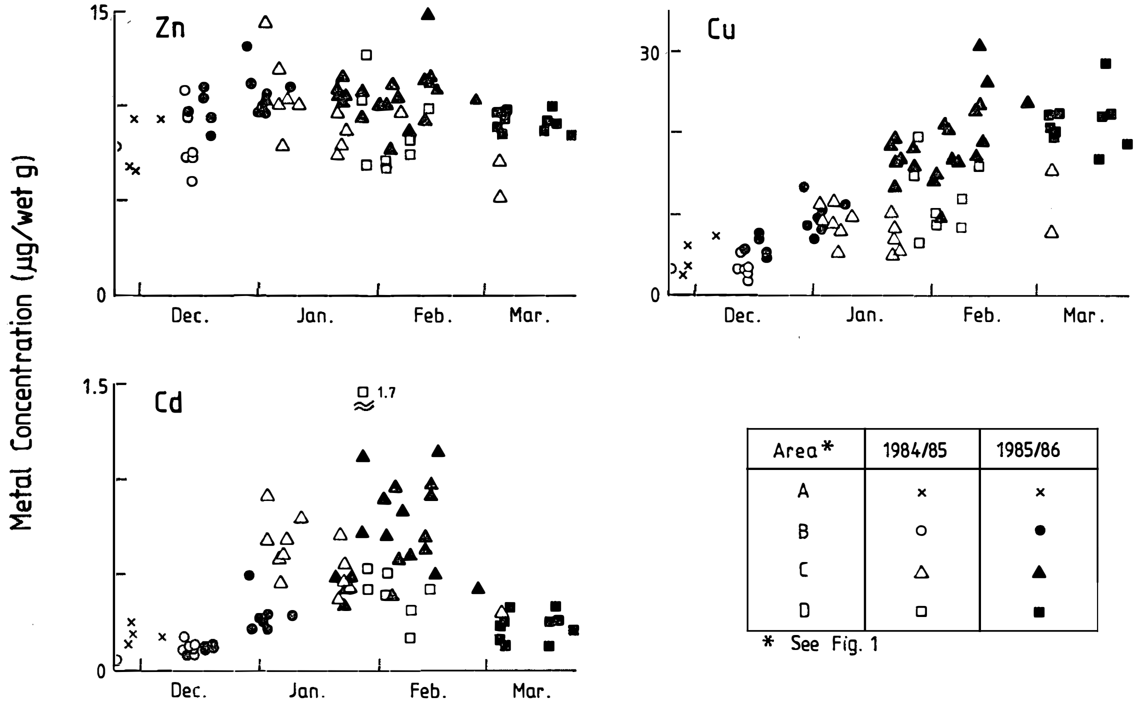

Fig. 2. Variations of heavy metal concentrations in the Antarctic krill with sampling date and location.

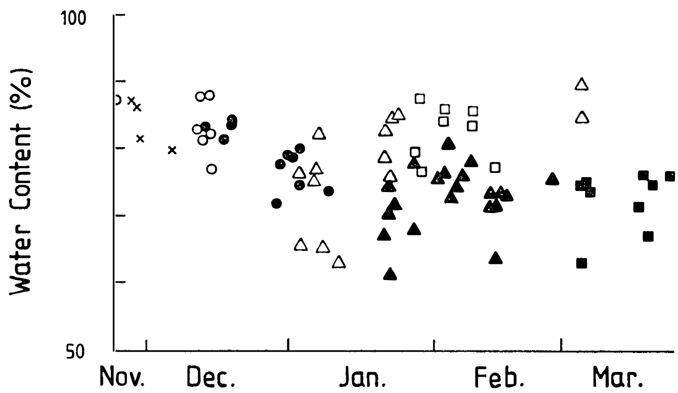

Fig. 3. Variation of water content of the Antarctic krill with sampling date and location. Different signs in the graph indicate the area and date of sample collection, which are shown in Figs. 1 and 2.

concentrations of Fe, Mn, Zn, Pb and Hg were comparatively high during the period from January to mid-February compared with other months. The seasonal variation of Zn concentration is shown in Fig. 2, as an example. During this period, the levels of Cu, Cd, Ni, and Co increased (not shown for Ni and Co), and thereafter the Cu level was almost constant. Similar trends were observed in the specimens collected in 1985 also. However, in the case of 1984/85 samples, the period of increase or decrease shifted to about one month earlier when compared to those in 1985/86.

No literature on seasonal variations of heavy metals in the Antarctic krill is available. According to some laboratory studies by DETHLEFSEN (1978), and WHITE and RAINBOW (1984a, b, 1986), the concentrations of Cd and Zn in crustacean increased with temperature rise and/or moulting. Also, it is known that the growth rate of the krill is relatively fast during the austral summer, as a result of increased amounts of food availability because of high production in the waters of high ambient temperature (IKEDA, 1984; EVERSON, 1984a, b). On the contrary, during a period of food paucity or starvation, an increase in water content was found in two species of zooplankton (*Calanus finmarchicus* and *Gnathophausia ingens*) (MARSHALL and ORR, 1955; HILLER-ADAMS and CHILDRESS, 1983). In the present study, a relatively high water content in the Antarctic krill was found during the early period of the austral summer, *i.e.*, November (Fig. 3). Although mechanism of this seasonal change of water content is not clear, it apparently affects the concentration levels of metals in the krill. Therefore, elevated concentrations of the metals in the krill during the period from January to mid-February might be due to the decreased water content and also due to increased amount of metal intake through food. However, a very little decrease in the Cu levels after mid-February might be due to high accumulation of Cu which is probably related with the synthesis of Cu-containing respiratory protein, haemocyanin.

The results described above indicate that consideration of seasonal variations of metal concentrations is needed to understand the accumulation processes of metals in the krill and their toxic effects on it. Especially, wide variations of Cu, Cd, and Ni concentrations in the krill should be taken into account when considering the bio-accumulation processes of these metals in higher trophic animals, such as baleen whales, penguins and seals which feed exclusively on the krill.

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References

BENAYOUN, G., FOWLER, S. W. and OREGIONI, B. (1974): Flux of cadmium through euphausiids. Mar. Biol., **27**, 205–212.

DETHLEFSEN, V. (1978): Uptake retention and loss of cadmium by brown shrimp (*Crangon crangon*). Meeresforschung, **26**, 137–152.

EVERSON, I. (1984a): Zooplankton. Antarctic Ecology, Vol. 2, ed. by R. M. LAWS. London, Academic Press, 463–490.

EVERSON, I. (1984b): Marine interactions. Antarctic Ecology, Vol. 2, ed. by R. M. LAWS. London, Academic Press, 783–819.

HAMANAKA, T. and MISHIMA, S. (1981): Cadmium and zinc concentrations in marine organisms in the northern North Pacific Ocean. Res. Inst. North Pac. Fish., Hokkaido Univ., Spec. Vol., 191–206.

HAMANAKA, T. and TSUJITA, T. (1981): Cadmium and zinc concentrations in zooplankton in the subarctic region of the North Pacific. J. Oceanogr. Soc. Jpn., **37**, 160–172.

HENNIG, H. F.-K. O., EAGLE, G. A., MCQUAID, C. D. and RICKETT, L. H. (1985): Metal concentrations in Antarctic zooplankton species. Antarctic Nutrient Cycles and Food Webs, ed. by W. R. SIEGFRIED *et al.* Berlin, Springer, 656–661.

HILLER-ADAMS, P. and CHILDRESS, J. J. (1983): Effects of prolonged starvation on O_2 consumption, NH_4^+ excretion, and chemical composition of the bathypelagic mysid *Gnathophausia ingens*. Mar. Biol., **77**, 119–127.

HONDA, K., TATSUKAWA, R. and FUJIYAMA, T. (1982): Distribution characteristics of heavy metals in the organs and tissues of striped dolphin, *Stenella coeruleoalba*. Agric. Biol. Chem., **46**, 3011–3021.

HONDA, K., TATSUKAWA, R., ITANO, K., MIYAZAKI, N. and FUJIYAMA, T. (1983): Heavy metal concentrations in muscle, liver and kidney tissues of striped dolphin, *Stenella coeruleoalba*, and their variations with body length, weight, age and sex. Agric. Biol. Chem., **47**, 1219–1229.

IKEDA, T. (1984): Sequences in metabolic rates and elemental composition (C, N, P) during the development of *Euphausia superba* Dana and estimated food requirements during its life span. J. Crust. Biol., **4** (Spec. No. 1), 273–284.

KNOX, G. A. (1970): Antarctic marine ecosystems. Antarctic Ecology, Vol. 1, ed. by M. W. HOLDGATE. London, Academic Press, 69–96.

LAWS, R. M. (1977): Seals and whales of the Southern Ocean. Philos. Trans. R. Soc. London, Ser. B, **279**, 81–96.

MARSHALL, S. M. and ORR, A. P. (1955): The Biology of a Marine Copepod *Calanus finmarchicus* (Gunnerus). Edinburgh, Oliver & Boyd, 188 p.

MARTIN, J. H. and KNAUER, G. A. (1973): The elemental composition of plankton. Geochim. Cosmochim. Acta, **37**, 1639–1653.

RIDOUT, P. S., WILLCOCKS, A. D., MORRIS, R. J., WHITE, S. L. and RAINBOW, P. S. (1985): Concentrations of Mn, Fe, Cu, Zn and Cd in the mesopelagic decapod *Systellaspis debilis* from the East Atlantic Ocean. Mar. Biol., **87**, 285–288.

SOSZKA, G. J., SUPLIŃSKA, M. M., BARAŃSKI, A., GRZYBOWSKA, D. and PIETRUSZEWSKI, A. (1981): Trace metals, fluorine and radionuclides in antarctic krill *Euphausia superba* Dana. Pol. Polar Res., **2**, 109–117.

STOEPPLER, M. and BRANDT, K. (1979): Comparative studies on trace metal levels in marine biota. Z. Lebensm. Unters. Forsch., **169**, 95–98.

WHITE, S. L. and RAINBOW, P. S. (1984a): Regulation of zinc concentration by *Palaemon elegans* (Crustacea: Decapoda)-zinc flux and effects of temperature, zinc concentration and moulting. Mar. Ecol. Prog. Ser., **16**, 135–147.

WHITE, S. L. and RAINBOW, P. S. (1984b): Zinc flux in *Palaemon elegans* (Crustacea: Decapoda)-moulting, individual variation and tissue distribution. Mar. Ecol. Prog. Ser., **19**, 153–166.

WHITE, S. L. and RAINBOW, P. S. (1986): Accumulation of cadmium by *Palaemon elegans* (Crustacea: Decapoda). Mar. Ecol. Prog. Ser., **32**, 17–25.

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