Bull. Fac. Fish. Hokkaido Univ.
35(3), 171-178. 1984.

Cadmium and Zinc Concentrations in the Hyperiid Amphipod, *Parathemisto libellula* from the Bering Sea*

Tsuneyasu HAMANAKA** and Haruo OGI***

Abstract

Cadmium and zinc concentrations were analyzed in the pelagic amphipod, *Parathemisto libellula*, collected in the Bering Sea during the summers of 1974-1979. Concentrations were 3.35-33.3 mg Cd/g dry wt and 51-162 μg Zn/g dry wt, respectively. Cadmium accumulation was correlated with body length (r=0.497) and body weight (r=0.558), and was higher than in other zooplankton groups. Zinc concentrations in this species were within the same range as in other planktonic crustaceans. The elevated cadmium level in *P. libellula* was probably the result of biomagnification through the food web. The biological implication of cadmium accumulation in this species is discussed relative to what is known about crustaceans.

Introduction

The concentrations of heavy metals in zooplankton have been studied recently because of the importance of these organisms in marine food webs (Fowler *et al.*, 1971; Martin and Knauer, 1973). Cadmium and zinc levels in species of predominant zooplankton from the subarctic North Pacific have been reported by Hamanaka and Tsujita (1981) and Hamanaka and Mishima (1981). These authors observed that hyperiid amphipods had the highest cadmium concentrations among the several zooplankton groups studied.

Wright (1980) has shown that the amphipod, *Gammarus pulex*, can accumulate considerably higher levels of cadmium than many other freshwater crustaceans. Among marine amphipods, however, though the uptake, accumulation, and flux of cadmium or zinc have been extensively studied in decapod crustaceans (Bryan, 1966; Wright, 1977a, 1977b) and lobsters (Thurberg *et al.*, 1977; Ray *et al.*, 1981), there exists a decided lack of data. In addition, the mechanism involved in the accumulation of these metals and their physiological significance are poorly understood.

The pelagic amphipod, *Parathemisto libellula* (Mandt), widely distributes from Arctic seas to Alaskan coastal waters (Bowman, 1960; Wing, 1976) and is an important constituent of the food web. This organism is consumed by pelagic- and semipelagic-fishes (Yoshida, 1984), seabirds (Bédard, 1969; Hunt *et al.*, 1981; Ogi

---

* Contribution No. 155 from the Research Institute of North Pacific Fisheries, Faculty of Fisheries, Hokkaido University.

** *Chuo-ku, Minami-1, Nishi-23, Sapporo, 064 Japan.*
(北海道札幌市中央区南1西23)

*** *Research Institute of North Pacific Fisheries, Faculty of Fisheries, Hokkaido University.*
(北海道大学水産学部北洋水産研究施設)

* This was supported in part by a Grand-in-Aid for Scientific Research (Project No. 58030053) from the Ministry of Education, Science and Culture of Japan.

and Tsujita, 1973 ; Ogi *et al.*, 1980 ; Ogi and Hamanaka, 1982), phocid seals and fur seals (Dunbar, 1941 ; Dunbar, 1946 ; Harry and Hartley, 1981), and whales (Frost and Lowry, 1981).

The bulk of *Parathemisto libellula* samples analyzed by Hamanaka (1981) were obtained from the northern Bering Sea and relatively higher cadmium concentrations were observed in the larger sized amphipods. The present study was undertaken to confirm these findings and to know natural level of heavy metals in the pelagic zooplankton.

Materials and Methods

Zooplankton sampling and preliminary procedures

Zooplankton samples were collected using a larval net aboard RV *Habomai Maru No. 21* of the Japanese Fisheries Agency in 1974 and TS *Oshoro Maru* of Hokkaido University in 1975, 1978 and 1979. With the exception of one sample (Sample No. Hb74069), all samples were taken from the southeastern shallow shelf of the Bering Sea (Fig. 1). Details of sampling, preliminary procedures, and the problem of contamination were described in Hamanaka and Tsujita (1981) and Hamanaka (1981). Information on the ecology of *Parathemisto libellula* in relation to the feeding habits of seabirds is provided by Ogi *et al.* (1980) and Ogi and Hamanaka (1982).

After thawing in the laboratory, amphipods were grouped into several size classes using a large glass rod. One sample was classified after fixation in 3% formalin within 3 hrs to avoid zooplankton degradation (Hamanaka, 1981 ; see

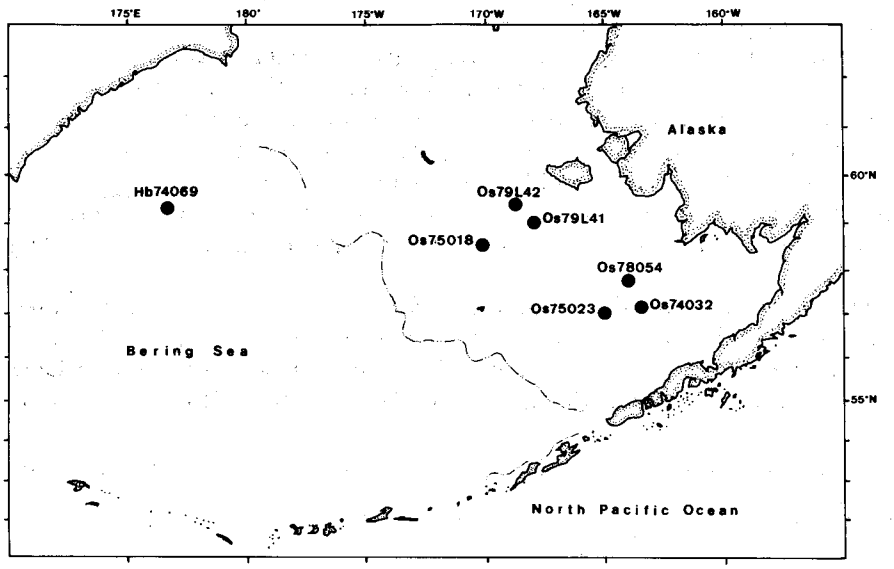

Fig. 1. Map showing locations where amphipods, *Parathemisto libellula*, were collected during 1974-1979. Figures denote the station number (Os : TS *Oshoro Maru*, Hb : RV *Habomai Maru No. 21*).

Table 1). We defined body length as the approximate straight-line distance from the anterior end of the head to the tip of the telson when the amphipod is gently straightened using a glass rod. Body length is expressed here in mm and body weight in mg.

Analytical procedures

Each sample was digested in a mixture of nitric and sulfuric acids on a hot plate. Cadmium was chelated and extraced with DDTC-MIBK (Hamanaka and Tsujita, 1981). For Zinc assay, the digested solution was brought to a specified volume using deionized water. Metal concentrations were then measured with a Hitachi flame absorption spectrophotometer. The accuracy of the analytical method was checked by simultaneous measurements of standard materials from the National Bureau of Standards (NBS SRM No. 1571; orchard leaved) and the National Institute of Environmental Studies of Japan (SRM No. 4; pepperbush). More detailed analytical procedures of these two heavy metals were described in two reports, Hamanaka and Tsujita (1981) and Hamanaka and Mishima (1981).

Results and Discussion

Metal concentrations

Cadmium and zinc levels ranged from 3.35 to 33.3 and from 51 to 162 μg/g dry wt, respectively (Table 1). The mean concentration of cadmium (mean: 9.07 ± 7.71 μg/g, median: 7.14 μg/g) in *P. libellula* was higher than in copepods, euphausiids, salps and chaetognaths, and comparable to or somewhat less than in other hyperiid amphipods (Hamanaka and Tsujita, 1981; Hamanaka and Mishima, 1981). In contrast to cadmium, the concentration of zinc (an essential metal) in *P. libellula* fell within the range of copepods, euphausiids, chaetognaths and other hyperiid amphipods (Hamanaka and Tsujita, 1981; Hamanaka and Mishima, 1981).

According to a study by Wing (1976) on the feeding habits of *P. libellula* in southeastern Alaska, this species is exclusively carnivorous. The most important food items were calanoid copepods (43.1%), euphausiids (7.8%), chaetognaths (6.7%) and others (42.4%). The last group consisted of small zooplankton species: copepod nauplii, cladocerans, hyperiid amphipods, cyclopoid copepods, polychaetes, tintinnids, fish larvae and phytoplankton. The higher cadmium concentration in *P. libellula*, thus, appears to be a reflection of their carnivorous feeding habits and to biomagnification through the food web.

The previous study showed that other amphipod species (genus *Parathemisto*) collected in the northern North Pacific and adjacent seas in 1977-79 had higher Cd (mean: 13.82 μg/g, range: 1.74-36.96 μg/g, N=35) than copepods (mean: 6.09, range: 0.97-18.13, N=40) and euphausiids (mean: 1.16, range: 0.36-2.17, N=11) (Hamanaka and Tsujita, 1981). Several workers reported higher cadmium contents in amphipods from various areas (Bender, 1975; Fowler *et al.*, 1976; Bryan, 1976; Bohn and McElroy, 1976). Wright (1980) showed experimentally that the freshwater amphipod, *Gammarus pulex* (25-40 mg wet wt), accumulated higher cadmium specifically in the hepatopancreas in comparison with other crustaceans. These suggest that some amphipods must have the ability to accumulate cadmium,

Table 1. Cadmium and zinc concentrations in the amphipod, *Parathemisto libellula*, collected in the Bering Sea

Code No.	Date	Station No.	Location		Body Weight (mg)		Body Length (mm)		Cd	Zn
	yr.mth.d.		Lat.	Long.	Wet	Dry	Mean	Range	(μg/g dry weight)	
1	1975.6.20	Os75018	58-32N	170-08W	7.6	1.20	4.5	(3- 6)	—	—
2	1974.7. 3	Hb74069	59-18N	176-40E	—	—	10	—	5.37	129
3	1975.7. 3	Os75023	57-00N	165-00W	—	—	10	—	7.98 ±0.38(2)	74 ±3(2)
4	1975.7. 3	Os75023	57-00N	165-00W	60.0	9.48	15	(14-16)	6.11	91
5[a]	1974.6.10	Os74032	57-09N	163-29W	84.5	13.35	ca.18	—	9.11	86
6	1975.6.20	Os75018	58-32N	170-08W	194.4	30.72	ca.25	—	24.5	97
7	1975.6.20	Os75018	58-32N	170-08W	344.2	54.4	ca.33	—	33.3	99
8	1978.6.29	Os78054	57-45N	163-59W	—	4.1	7.5	(5-10)	3.35	162
9	1979.7.16	Os79L42	59-24N	168-46W	—	4.6	11	(10-12)	10.5	60
10	1978.6.29	Os78054	57-45N	163-59W	—	5.0	12	(10-14)	6.47	119
11	1978.6.29	Os78054	57-45N	163-59W	—	13.2	17.5	(15-20)	5.53	64
12	1978.6.29	Os78054	57-45N	163-59W	—	13.2	17.5	(15-20)	3.88	80
13	1978.6.29	Os78054	57-45N	163-59W	—	13.2	17.5	(15-20)	4.66	96
14	1978.6.29	Os78054	57-45N	163-59W	—	15.7	23	(21-25)	3.62	54
15	1978.6.29	Os78054	57-45N	163-59W	—	15.7	23	(21-25)	5.11	80
16	1978.6.29	Os78054	57-45N	163-59W	—	15.7	23	(21-25)	(0.62)?[c]	99
17	1979.7.16	Os79L42	59-24N	168-46W	—	16.6	20.5	(18-23)	7.64	78
18	1979.7.15	Os79L41	59-00N	168-00W	—	(28.4)[b]	25	(20-30)	7.95	104
19	1979.7.16	Os79L42	59-24N	168-46W	—	30.5	24.5	(24-25)	9.91	115
20	1979.7.16	Os79L42	59-24N	168-46W	—	52.0	28	—	10.4	51

[a] A formalin-preserved sample.
[b] Value estimated from a relationship between body length and body weight (equation (1)).
[c] Value not included in the calculation of means and the regression analyses.

probably as a result of genetic adaptation and/or physiological characteristics such as the ability of synthesize a metal binding protein (metallothionein).

Relation between metal concentration and body size

The logarithmic relationship between dry weight (BW: 13.2-54.4 mg) and body length (BL: 17.5-33.0 mm) of *Parathemisto libellula* is given by the following equation;

$$\text{Log BW (dry wt in mg)} = -2.0862 + 2.5413 \text{ Log BL (in mm)} \quad (r=0.938,\ P<0.001,\ \text{d.f.}=6) \quad \cdots\cdots (1)$$

This relation agrees well with the data of Wing (1976) who measured amphipods 17.0 to 29.5 mm long.

In spite of considerable scattering, a significant positive correlation existed between cadmium concentration and body size, mainly because a few larger size classes showed relatively elevated cadmium levels (Table 1, Figs. 2 and 3). The logarithmic relation between body length or body weight and cadmium concentration are given by the equations;

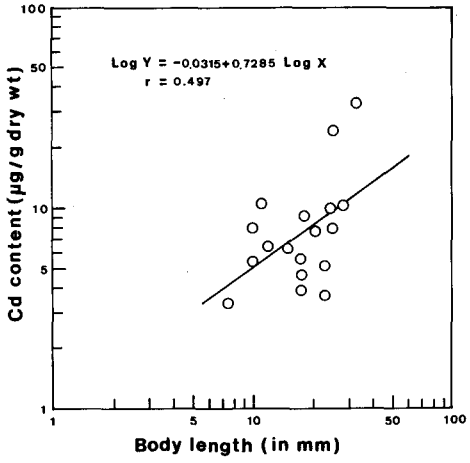

Fig. 2. Relationship between Cd concentration (μg/g dry wt) and body weight (dry weight, mg) in *Parathemisto libellula* collected in the Bering Sea.

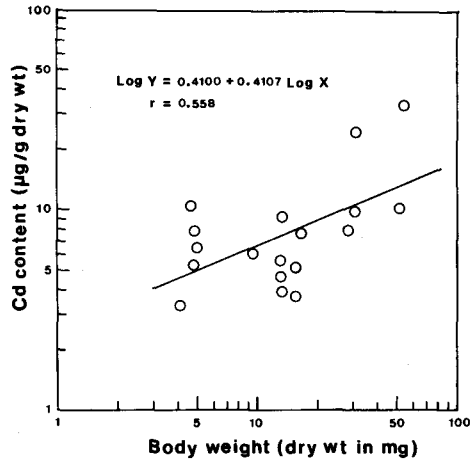

Fig. 3. Relationship between Cd concentration (μg/g dry wt) and body length (mm) in *Parathemisto libellula* collected in the Bering Sea.

$$\text{Log Cd } (\mu\text{g/g dry wt}) = -0.0315 + 0.7285 \text{ Log BL (mm)}$$
$$(r = 0.497,\ P < 0.025,\ \text{d.f.} = 16) \quad \cdots\cdots (2)$$
$$\text{Log Cd } (\mu\text{g/g dry wt}) = 0.4100 + 0.4107 \text{ Log BW (mg)}$$
$$(r = 0.558,\ P < 0.025,\ \text{d.f.} = 16) \quad \cdots\cdots (3)$$

Present evidence suggests that *P. libellula* accumulates cadmium with age (i.e. the increase in body size). The relationship, however, is not quite conclusive because of insufficient sample size. Ray *et al.* (1981) reported that lobsters, *Homarus americanus*, from a polluted harbor manifested age-related increase of cadmium and extremely elevated cadmium concentration (up to 1600 μg/g dry wt) in the hepatopancreas. This and other studies indicated that cadmium concentrates in only a few organs such as the hepatopancreas, green gland, exoskeleton, and gill of certain crustaceans (Ray *et al.*, 1981; Jennings and Rainbow, 1979; Miramand *et al.*, 1981), including amphipods (Wright, 1980). The fact that zinc level was not significantly correlated with body size indicates that concentration of this metal in tissues is under homeostatic control.

Molting is a major event during the growth of amphipods, as for all crustaceans, and is strongly related to the flux of heavy metals in the animal's body (Hamanaka and Tsujita, 1981; Benayoun, 1974). Experimental studies show that different species lose cadmium through the exoskeleton. For example, the percentage of cadmium loss ranged from 15% in the shrimp, *Lysnata seticaudata* to over 90% in the crab, *Carcinus maenas* (Fowler and Benayoun, 1974). Unfortunately, information on molting is limited for *P. libellula*. Wing (1976) observed, however, that molting interval in captivity was about 3-7 weeks which is a relatively lower frequency than in other crustaceans (Miramand *et al.*, 1981; Fowler *et al.*, 1972; Renfro *et al.*, 1975; Murray *et al.*, 1978). This lower molting frequency of *P. libellula* may contribute towards a decreased rate of cadmium loss.

The present study suggests that with age *Parathemisto libellula* accumulates such non-essential metals as cadmium. In addition, the higher cadmium concentrations in amphipods compared with other planktonic crustaceans (Hamanaka and Tsujita, 1981 ; Hamanaka and Mishima, 1981) is consistent with resulst from experimental studies on cadmium uptake by amphipods during short-term exposure (Wright, 1980). In less- or non-polluted environments, such as the Bering Sea, the uptake of cadmium through ingestion of prey must be the most important pathway for *P. libellula*.

Acknowledgements

The authors would like to express our sincere thanks to Dr. M. Nishimura, Professor Emeritus of Hokkaido University, and Dr. S. Mishima, Professor of Hokkaido University, for their helpful discussion and reading on the manuscript. We are also grateful to Dr. D.G. Ainley of the Point Reyes Bird Observatory, California for his kind correcting the manuscript. Finally, we are indebted to the following persons for kind assistance in collection of materials: Drs. T. Fujii, T. Haryu, T. Kubodera, H. Yoshida ; Messrs. M. Narita, H. Kato and I. Kuzasa.

References

Bédard, J. (1969). Feeding of the least, crested, and parakeet auklets around St. Lawrence Island, Alaska. *Can. J. Zool.* **47**, 1025-1050.

Benayoun, G., Fowler, S.W. and Oregioni, B. (1974). Flux of cadmium through euphausiids. *Mar. Biol.* **27**, 205-212.

Bender, J.A. (1975). Trace metal levels in beach dipterans and amphipods. *Bull. Environ. Contam. Toxicol.* **14**, 187-200.

Bohn, A. and McElroy, R.O. (1976). Trace metals (As, Cd, Cu, Fe, and Zn) in Arctic cod, *Boreogadus saida*, and selected zooplankton from Strathcona Sound, northern Buffin Island. *J. Fish. Res. Bd. Canada*, **33**, 2836-2840.

Bowman, T.E. (1960). The pelagic amphipod genus, *Parathemisto* (Hyperidea : Hyperidae) in the North Pacific and adjacent Arctic Ocean. *Smithsonian Inst.* **122**, 343-392.

Bryan, G.W. (1966). The metabolism of Zn and ^{65}Zn in crabs, lobsters, and freshwater crayfish. p. 1005-1016. In Aberg, B. and Hungate, F.P. (ed.). *Radioecological Concentration Processes.* 1040p. Pergamon Press, Stockholm and Oxford.

Bryan, G.W. (1976). Heavy metal contamination in the sea. p. 185-302. In Johnston, R. (ed.). *Marine Pollution.* 729p. Academic Press, New York.

Calbrese, A., Thurberg, F.P. and Gould, E. (1977). Effects of cadmium, mercury, and silver on marine animals. *Mar. Fish. Review* **1244**, 5-11.

Dunbar, M.J. (1941). On the food of seals in the Canadian eastern Arctic. *Can. J. Res.* **19**, 150-155.

Dunbar, M.J. (1946). On *Themisto libellula* in Baffin Island coastal waters. *J. Fish. Res. Bd. Canada* **6**, 419-434.

Fowler, S.W., Small, L.F. and Dean, J.M. (1971). Experimental studies on elimination of zinc-65, cesium-137, and cerium-144 by euphausiids. *Mar. Biol.* **8**, 224-231.

Fowler, S.W., Small, L.F. and LaRosa, J. (1972). The role of euphausiid molt in the transport of radionuclides in the sea. *Rapp. Comm. int. Mer. Medit.* **21**, 291-292.

Fowler, S.W. and Benayoun, G. (1974). Experimental studies on cadmium flux through marine biota. p. 159-178. In *Comparative Studies of Food and Environmental Contamination.* IAEA, Vienna.

Fowler, S.W., Oregioni, B. and LaRosa, J. (1976). Intercalibration measurements for non-nuclear

pollutants: Trace metals in pelagic organisms from the Mediteranean Sea. *Rep. Intern. Lab. Mar. Radioactivity* 110-122, 201p. Monaco (IAEA-187).

Frost, K.J. and Lowry, L.F. (1981). Food and trophic relationships of cetaceans in the Bering Sea. p. 825-836. In Hood, D.W. and Calder, J.A. (ed.), *The Eastern Bering Sea Shelf : Oceanography and Resources* 1339p. Univ. Washington Press, Seattle.

Hamanaka, T. and Tsujita, T. (1981). Cadmium and zinc concentrations in zooplankton in the subarctic region of North Pacific. *J. Oceanogr. Soc. Japan* **37**, 160-172.

Hamanaka, T. and Mishima, S. (1981). Cadmium and zinc concentrations in marine organisms in the northern North Pacific Ocean. *Res. Inst. N. Pac. Fish. Hokkaido Univ. Spe. Vol.* 191-206.

Hamanaka, T. (1981). Effects of formalin preservation on heavy metal concentration in zooplankton. *Bull. Fac. Fish. Hokkaido Univ.* **32**, 376-387.

Harry, G.Y. and Hartley, J.R. (1981). Northern fur seals in the Bering Sea, p. 847-867. In Hood, D.W. and Calder, J.A. (ed.). *The Eastern Bering Sea Shelf : Oceanography and Resources* 1339p. Univ. Washington Press, Seattle.

Hunt, G.L., Jr., Burgeson, B. and Sanger, G.A. (1981). Feeding ecology of seabirds of the eastern Bering Sea, p. 629-647. In Hood, D.W. and Calder, J.A. (ed.). *The Eastern Bering Sea Shelf : Oceanography and Resources* 1339p. Univ. Washington Press, Seattle.

Jennings, J.R. and Rainbow, P.S. (1979). Studies on uptake of cadmium the crab *Carcinus maenas* in the laboratory. I. Accumulation from seawater and a food source. *Mar. Biol.* **50**, 131-139.

Martin, J.H. and Knauer, G.A. (1973). The elemental composition of plankton. *Geochim. Cosmochim. Acta*, **37**, 1639-1653.

Miramand, P., Guary, J.C. and Fowler, S.W. (1981). Uptake, assimilation, and excretion of vanadium in the shrimp, *Lynata seticaudata* (Risso), and the crab, *Carcinus maenas* (L.). *J. exp. mar. Biol. Ecol.* **49**, 267-287.

Murray, C.N., Hoppenheit, M. and Rade, H. (1978). Accumulation of americium-243 in selected brackish and marine invertebrates. *Helgoländer wiss. Meeresunters.* **31**, 34-54.

Ogi, H, and Tsujita, T. (1973). Preliminary examination of stomach contents of murres (*Uria* spp.) from the eastern Bering Sea and Bristol Bay, June-August, 1970 and 1971. *Jap. J. Ecol.* **23**, 201-209.

Ogi, H., Kubodera, T. and Nakamura, K. (1980). The pelagic feeding ecology of the Short-tailed Shearwater *Puffinus tenuirostris* in the subarctic Pacific region. *J. Yamashina Inst. Ornithol.* **12**, 157-182.

Ogi, H. and Hamanaka, T. (1982). The feeding ecology of *Uria lomvia* in the northwestern Bering Sea region. *J. Yamashina Inst. Ornithol.* **14**, 270-280.

Ray, S., McLeese, D.W. and Burridge, L.E. (1981). Cadmium in tissues of lobsters captured near a lead smelter. *Mar. Pollut. Bull.* **12**, 383-386.

Renfro, W.C., Fowler, S.W., Heyraud, M. and LaRosa, J. (1975). Relative importance of food and water in long-term zinc-65 accumulation by marine biota. *J. Fish. Res. Bd. Canada*, **32**, 1339-1345.

Thurberg, F.P., Calabrese, A. Gould, E., Greig, R.A., Dawson, M.P. and Tucker, R.K. (1977). Response of the lobster, *Homarus americanus*, to sublethal levels of cadmium and mercury, p. 185-197. In Vernberg, F.J., Calabrese, A,, and Vernberg, W.B. (ed.). *Physiological Responses of Marine Biota to Pollutants* 462p. Academic Press, New York.

Williams, R. and Robins, D. (1979). Calorific, ash, carbon and nitrogen content in relation to length and dry weight of *Parathemisto gaudichaudii* (Amphipoda: Hyperidea) in the north east Atlantic Ocean. *Mar. Biol.* **52**, 247-252.

Wing, B.L. (1976). Ecology of *Parathemisto libellula* and *P. pacifica* (Amphipoda: Hyperiidea) in Alaskan coastal waters. Ph. D. Thesis, Univ. Rhode Island.

Wright, D.A. (1977a). The uptake of cadmium into the haemolymph of the shore crab *Carcinus maenas*: The relationship with copper and other divalent cations. *J. exp. Biol.* **67**, 147-161.

Wright, D.A. (1977b). The effect of calcium on cadmium uptake by the shore crab *Carcinus maenas*. *J. exp. Biol.* **67**, 163-173.

Wright, D.A. and Brewer, C.C. (1979). Cadmium turnover in the shore crab *Carcinus maenas*. *Mar.*

Biol. **50**, 151-156.

Wright, D.A. (1980). Cadmium and calcium interactions in the fresh water amphipod *Gammarus pulex*. *Freshwater Biol.* **10**, 123-133.

Yoshida, H. (1984). Ecology of the pelagic walleye pollock (*Theragra chalcogramma*) in the Bering Sea in summer. Ph. D. Thesis. Hokkaido Univ., Sapporo. (In Japanese)