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Distribution of Cadmium and Zinc in Tissues and Organs, and their Age-Related Changes in Striped Dolphins, *Stenella coeruleoalba*

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Abstract. Cadmium and zinc concentrations were determined in the tissues and organs, including the fetus, of striped dolphins. The kidney showed the highest cadmium concentration and the hepatic cadmium concentration was also relatively high. A similar distribution pattern among soft tissues was also observed with zinc, where its concentration varied less than that of cadmium. A significant positive correlation between zinc and cadmium was found in both the kidney and the liver; the increase of zinc concentration with cadmium was more marked in the liver (Zn:Cd ≒ 3:1 on molar basis) than kidney (Zn:Cd ≒ 1:1). Negligible cadmium concentration in the fetus suggested that cadmium is not transferred to the fetus via the placenta from the mother. Organ-specific age trends of cadmium and zinc concentrations were presented in detail for muscle, liver, kidney, pancreas, brain, and blood. Both metals showed rapid change during the periods of the fetus and weaning.

The accumulation of heavy metals, particularly mercury in marine mammals, has drawn increased attention in view of heavy metal pollution in the marine environment and their bioaccumulation in marine animals (Gaskin *et al.* 1979; Jones *et al.* 1976; Reijinders 1980; Duinker *et al.* 1979; Drescher *et al.* 1977; Harms *et al.* 1978; Koeman *et al.* 1972, 1975; Denton *et al.* 1980; Hamanaka *et al.* 1977, 1982; Arima and Nagakura 1979; Honda *et al.* 1982; Anas 1974; Buhler *et al.* 1975). However, most of the studies have been focussed on coastal mammals such as seals; data on cetaceans are scanty and, especially, on species in the northwest Pacific. Furthermore, prior studies have dealt with a limited number of selected organs and lack detailed biological information, such as age, and sexual and reproductive data.

The biology and ecology of the striped dolphin, *Stenella coeruleoalba,* in the northwest Pacific have been studied and information on age, food habits, migration, and reproductive activities, and biometry are available (Miyazaki *et al.* 1973, 1974, 1977, 1981). Also, since the dolphin is a long-living marine mammal (more than 40 years), the animal is useful as an "indicator species" to acquire complex long-term accumulation characteristics of heavy metals in the marine environment.

Our group has reported on organochlorine compounds in the striped dolphin (Tanabe *et al.* 1981, 1982) and this paper presents a discussion on cadmium and zinc concentrations in various organs and tissues of this species, and the distribution characteristics of these metals and their relationships with the age of the dolphin.

Materials and Methods

The striped dolphin is distributed in the Pacific coast and pelagic waters of Japan influenced by the warm Kuroshio current. Miyazaki *et al.* (1974) reported that the populations migrate seasonally from 33°N in the winter up to 46°N in the summer, and that the distribution of this species is restricted by the northern boundary of the Kuroshio current.

Seventy six dolphins were captured alive at Kawana, on the east coast of Izu Peninsula and at Taiji on the southern end of Kii Peninsula during the winter-catch seasons in 1977–1980. All specimens were in good health with no macroscopic pathological symptoms. The animals were frozen at −20°C as soon as field conditions allowed (1–8 hr). Body weight, length, sex, basic morphometric data, and weight of various organ and tissues were recorded for all the specimens. Mandibular teeth were taken from each animal; specimens were aged from dentinal growth

Table 1. Cadmium and zinc concentrations (mean ± standard deviation, μg/wet g) in various organs and tissues of striped dolphin, *Stenella coeruleoalba*

Sexual maturity	(year)	(N)[a]	Cd	Zn	(N)[a]
			Muscle		
Fetus		(17)	<2.5 × 10^{-3}	19.4 ± 8.17	(15)
Calf	0 − 1.75	(7)	0.03 ± 0.01	13.1 ± 1.42	(6)
Immature	1.75 − 7.5	(7)	0.05 ± 0.01	12.7 ± 1.66	(7)
Immature	7.5 − 15	(8)	0.05 ± 0.01	10.4 ± 2.13	(8)
Mature	15 − 25	(18)	0.10 ± 0.03	11.4 ± 3.19	(18)
Mature	25 − 40	(19)	0.17 ± 0.06	10.5 ± 1.53	(18)
Overall mean ± SD[b]		(59)	0.10 ± 0.06	11.4 ± 2.44	(57)
			Pancreas		
Fetus		(4)	<3.0 × 10^{-3}	17.3 ± 4.40	(13)
Calf	0 − 1.75	(1)	1.40	34.5	(3)
Immature	1.75 − 7.5	(2)	1.56 ± 0.21	32.4 ± 3.50	(3)
Immature	7.5 − 15	(4)	1.44 ± 0.51	22.9 ± 4.88	(3)
Mature	15 − 25	(5)	1.32 ± 0.48	28.0 ± 5.89	(5)
Mature	25 − 40	(2)	1.55 ± 0.15	25.0 ± 1.00	(2)
Overall mean ± SD[b]		(14)	1.43 ± 0.42	27.2 ± 5.91	(16)
Lung		(15)[b]	0.42 ± 0.10	20.7 ± 5.16	
		(5)[c]	<3.0 × 10^{-3}	15.9 ± 9.82	
Heart		(15)[b]	0.17 ± 0.08	26.1 ± 2.75	
		(4)[c]	<3.0 × 10^{-3}	24.2 ± 2.00	
Spleen		(12)[b]	0.55 ± 0.19	21.5 ± 2.25	
		(3)[c]	<3.0 × 10^{-3}	16.5 ± 0.49	
Intestine (large)		(15)[b]	0.46 ± 0.17	21.1 ± 1.97	
		(3)[c]	<3.0 × 10^{-3}	20.4 ± 0.59	
Stomach (first)		(15)[b]	0.44 ± 0.35	23.2 ± 3.70	
		(4)[c]	<3.0 × 10^{-3}	19.4 ± 3.60	
Stomach (second)		(14)[b]	1.03 ± 0.67	25.3 ± 2.35	
		(3)[c]	<3.0 × 10^{-3}	18.8 ± 0.55	
Diaphragm		(15)[b]	0.12 ± 0.06	44.9 ± 4.07	
		(3)[c]	<3.0 × 10^{-3}	29.0 ± 3.22	

[a] Number of samples analyzed
[b] Calf + immature + mature
[c] Fetus

layers following the method of Kasuya et al. (1974). The age/body length regression equation was applied to determine the age of the fetus and pup younger than 0.5 yr, as described by Miyazaki (1977). The details of relevant biometrics has been reported (Miyazaki *et al.* 1981).

Representative samples of muscle, skin, and blubber for metal determinations were taken from a site 10 cm in width under the dorsal fin, as described by Honda *et al.* (1982). Samples of liver, heart, stomach, intestine, diaphragm, and spleen were excised from the medio lateral lobe or medial region; samples of kidney, lung, ovary, and testis were from the medial region of the left organ; cerebral samples were from the superficial medial region, including tissue from both hemispheres; bone samples were cut from the thoracic vertebra. Other samples were of the whole organ, because of their relatively small size. All samples were stored in polyethylene bags at −20°C until analysis.

One to 10 g of each sample was digested with a mixture of nitric, sulfuric, and perchloric acids. Zinc was measured directly and cadmium after methyl isobutylketone-diethyldithiocarbamate treatment by atomic absorption spectrophotometry, as described by Honda *et al.* (1982). All results were usually expressed as μg/g wet weight.

Results and Discussion

Organ and Tissue Distribution of Cadmium and Zinc in Dolphins

The highest cadmium concentration of the dolphin, except the fetus, was found in the kidney, where it ranged from 0.048 to 69.6 μg/g with a mean of 26.4 μg/g. It was followed, in order, by liver, pancreas, and the 2nd stomach. The mean cadmium concentration in the other tissues, with few exceptions, was below 1 μg/g, and it ranged from 0.037 μg/g in the blood and blubber to 0.84 μg/g in the ovary (Table 1). Cadmium concentration of fetus was negligible (<5 × 10^{-3} μg/g), and it suggests that cadmium is not transferred to the fetus via the placenta from the mother.

The significant correlations among the cadmium concentrations of kidney, liver, and pancreas in im-

Table 1. (cont'd)

Sexual maturity	Liver Cd	Liver Zn	(N)[a]	Kidney Cd	Kidney Zn
Fetus	<3.4 $\times 10^{-3}$	37.1 ± 10.8	(14)	<5.0 $\times 10^{-3}$	17.4 ± 3.59
Calf	3.03 ± 2.61	66.6 ± 26.4	(6)	12.2 ± 13.8	29.8 ± 5.64
Immature	7.38 ± 0.90	51.3 ± 6.01	(5)	34.7 ± 11.2	33.4 ± 0.99
Immature	6.17 ± 1.65	41.6 ± 4.82	(8)	29.1 ± 5.08	28.9 ± 3.66
Mature	6.25 ± 2.05	40.1 ± 7.07	(9)	25.5 ± 18.4	30.0 ± 5.44
Mature	6.94 ± 2.13	38.6 ± 5.08	(3)	37.0 ± 19.3	27.8 ± 0.50
Overall mean ± SD[b]	6.26 ± 2.31	43.7 ± 14.2	(31)	26.4 ± 16.2	30.0 ± 4.59
	Brain			**Blood**	
Fetus	<1.0 $\times 10^{-3}$	8.32 ± 2.69	(5)	<5.0 $\times 10^{-3}$	9.96 ± 2.13
Calf	0.006 ± 0.004	13.3 ± 0.99	(5)	0.039 ± 0.025	3.24 ± 1.09
Immature	0.026 ± 0.004	12.3 ± 0.37	(6)	0.053 ± 0.010	4.81 ± 1.43
Immature	0.044 ± 0.005	12.4 ± 0.63	(3)	0.039 ± 0.012	3.59 ± 0.35
Mature	0.051 ± 0.023	12.4 ± 0.80	(8)	0.026 ± 0.003	3.75 ± 0.25
Mature	0.064 ± 0.014	13.2 ± 0.25	(2)	0.025 ± 0	3.67 ± 0.10
Overall mean ± SD[b]	0.038 ± 0.024	12.6 ± 0.82	(24)	0.037 ± 0.017	3.88 ± 1.05
Blubber			(16)[b]	0.037 ± 0.015	5.66 ± 5.90
			(17)[c]	<3.0 $\times 10^{-3}$	11.6 ± 3.60
Testis			(3)[b]	0.35 ± 0.10	12.1 ± 0.67
			(5)[c]	<3.0 $\times 10^{-3}$	11.0 ± 0.50
Ovary			(3)[b]	0.84 ± 0.32	20.0 ± 0.14
			(3)[c]	<3.0 $\times 10^{-3}$	23.4 ± 0.15
Skin			(5)[b]	0.14 ± 0.03	227 ± 1.67
			(2)[c]	<3.0 $\times 10^{-3}$	225 ± 2.00
Bone			(5)[b]	0.16 ± 0.03	403 ± 84.3
			(13)[c]	<5.0 $\times 10^{-3}$	82.2 ± 42.0
Placenta			(15)[b]	0.04 ± 0.02	18.0 ± 3.63
Mammary gland			(4)[b]	0.46 ± 0.17	20.7 ± 1.99
Milk			(10)[b]	0.03 ± 0.04	11.0 ± 3.29

mature and mature dolphins indicate that these are the critical organs for the storage of cadmium in striped dolphin (kidney-liver: r = 0.771, $p < 0.001$; liver-pancreas: r = 0.796, $p < 0.001$). Although the distribution pattern in the soft tissues of striped dolphin is similar to those reported for steller sea lions (Hamanaka *et al.* 1982), the cadmium concentrations in tissues and organs, including hard tissues such as bone, and skin, have not been reported for other marine mammals.

The highest zinc concentration was found in the bone and skin, followed by the diaphragm, liver, kidney, and pancreas, and the lowest in the blubber or blood; it's distribution pattern among soft tissues was similar to that of cadmium, although in a narrower range. Zinc, an essential metal in contrast to cadmium, may be subject to homeostasis in the striped dolphin.

A high accumulation of zinc has been reported in hard tissues, such as bone, hair, skin, and feathers, of some marine and terrestrial animals (Underwood 1975; Drescher *et al.* 1977; Harms *et al.* 1978; Koeman *et al.* 1972), and agrees with our results on the striped dolphin. However, the detailed age-related distributions of zinc in various tissues and organs, including fetus, of the wild animals have not been published previously.

Relationship between Zinc and Cadmium Concentration

A significant correlation between zinc and cadmium concentration was found in both the kidney and the liver, but not for the other tissues. Figure 1 shows the relationship between zinc and cadmium concentrations in the kidney; zinc concentration increased approximately on an equimolar basis with cadmium up to a cadmium level of about 50 μg/g and above this level, the increase was less pronounced with

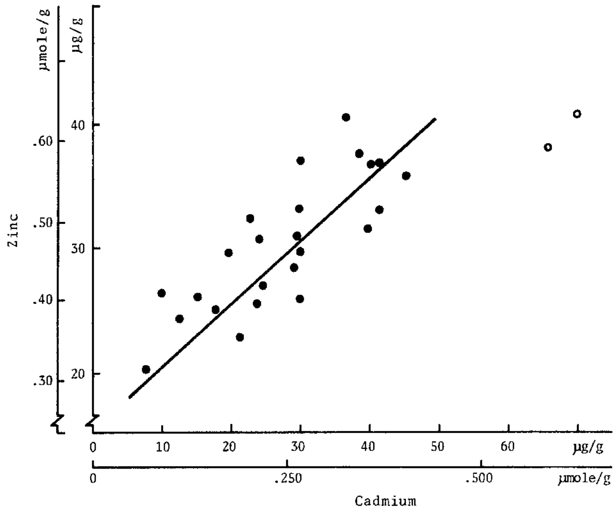

Fig. 1. Relationship between cadmium and zinc concentration (μg/wet g and μ mole/wet g) in the kidney of striped dolphin. The regression equation (Y = 0.908 X + 0.228, r = 0.725, p < 0.001) was calculated from the data of closed circle. Here, X is cadmium concentration (μ mole/wet g), and Y is zinc concentration (μ mole/wet g)

zinc. These results on the striped dolphin are in the same molar ratio (Zn:Cd ≒ 0.6–1.0:1) and cut-off point (50–70 μg/g) to terrestrial mammals of relatively large size, such as the human, horse, pig, and lamb (Elinder *et al.* 1977; Piscator 1974; Elinder and Piscator 1978; Schroeder *et al.* 1974). The zinc concentration in kidney increasing with increasing cadmium concentration has not been previously reported for marine mammals.

The increase of zinc concentration is believed to be a compensation for the increase of cadmium concentration, a mechanism which probably includes the formation of metallothionein which binds both zinc and cadmium in a molar ratio of 1:1 (Nordberg 1972). However, the reason why the less marked increase of zinc in relation to cadmium at high concentrations of cadmium is at present unknown. The finding of an equimolar increase of zinc with cadmium up to a certain level in the kidney of striped dolphins indicates a formation of metallothionein which binds equal amounts of zinc and cadmium similar to large-sized terrestrial animals (Elinder and Piscator 1978).

The relationship between hepatic zinc and cadmium is shown in Figure 2. Compared to the kidney, the increase of zinc with cadmium in liver was more marked, with a slope constant on a molar basis of about 3 (Zn/Cd). With high cadmium exposure experiments, the higher slope constants for liver than for kidney have been found in many animal species, such as the rat, rabbit, mouse, chicken, and goat (Doyle and Pfander 1975; Elinder and Piscator 1978),

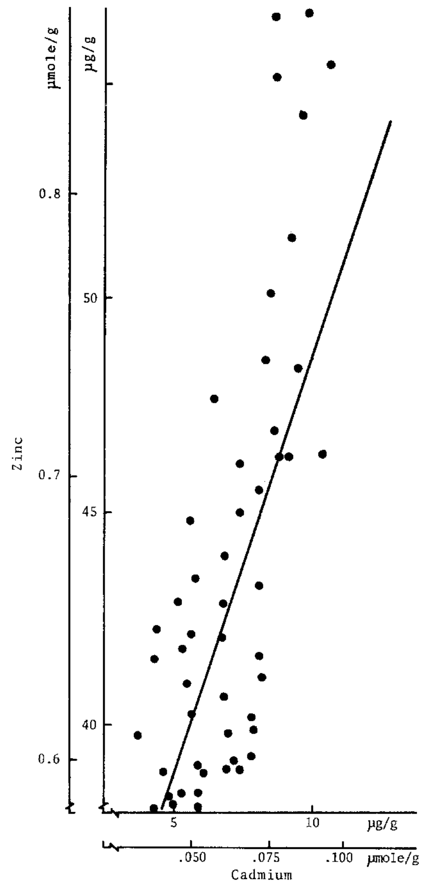

Fig. 2. Relationship between cadmium and zinc concentration (μg/wet g and μ mole/g) in the liver of striped dolphin. The regression equation: Y = 3.13 X + 0.462, r = 0.400, p < 0.005. (X: cadmium concentration, μ mole/g; Y: zinc concentration, μ mole/g)

Table 2. Cadmium and zinc concentrations (μg/wet g) in the muscle and liver of squid and the whole body of myctophid

Species		(N)[a]	Cd	Zn
Squid	Muscle	(3)	0.21– 0.90	15.0–19.0
			0.65	16.6
Todarodes pacificus	Liver	(3)	20.3 –41.8	51.3–63.7
			31.1	57.5
Myctophid	Small-sized fish[b]	(10)	0.03	12.9
	Large-sized fish[c]	(4)	0.02	8.71

[a] Number of samples analyzed, Range/Mean. The samples of myctophid fish were collected off Izu and Kii Peninsula.
[b] pooled sample of 10 fish (3.8–4.5 cm)
[c] pooled sample of 4 fish (6.5–7.5 cm)

whereas pig and lamb with low cadmium exposure showed the lower slope constants of liver compared with those of kidney (Doyle and Pfander 1975). The main food items of the striped dolphin from the northwest Pacific are squid, myctophid, and shrimp

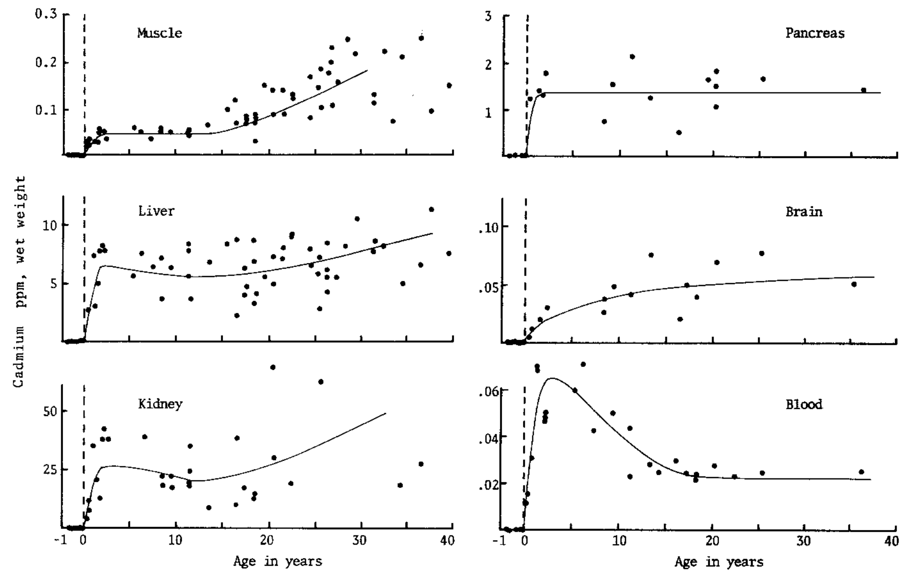

Fig. 3. Relationships between age and cadmium concentrations (μg/wet g) in muscle, liver, kidney, pancreas, brain, and blood of striped dolphin. The fetus age is shown in the periods of −1 to 0 year on the abscissa of the graphs

(myctophid fish is dominant, Miyazaki *et al.* 1973), and squid may be dominant by weight. Most of the squids identified in the stomach contents were the species *Todarodes pacificus* (Miyazaki *et al.* 1974). As shown in Table 2, the elevated cadmium levels found in squid livers, ranged from 20.3 to 41.8 μg/g, and are in the same range as those of ommastrephid, gonatid, and lolignid squids reported by Hamanaka *et al.* (1977), and Martin and Flegal (1975). In contrast, the cadmium concentration of myctophid was very low. Therefore, the higher slope constant of liver than that of the kidney of the striped dolphin may reflect a relatively high cadmium exposure, probably due to their main food source, the squids. The different increase rates of zinc with cadmium between liver and kidney may be useful as an "indicator" to show a level of cadmium exposure, and a higher increase of zinc with cadmium in liver may suggest a formation of other forms of metallothionein with a higher ratio of zinc to cadmium.

Age Trends of Cadmium Concentration

Age trends of cadmium concentration in various organs of striped dolphins are shown in Figure 3. Although the cadmium concentration of fetuses was very low, it markedly increased with age during the weaning stage (0–1.5 yr). With muscle, liver, and kidney, the cadmium concentration was unchanged up to approximately 15 yr of age; afterwards, it gradually increased with age. The cadmium concentration in the pancreas did not change much after the weaning stage and the cadmium concentration in brain increased gradually with age, while that in the blood sharply decreased during 1.5–15 yr and was constant after that age.

The rapid increase of cadmium concentration in the six tissues and organs during the periods of weaning implies higher absorption efficiency and accumulation of cadmium through the digestive tract of the pup dolphin compared with that of the adult dolphin. According to Miyazaki *et al.* (1974), the mean weaning periods of the striped dolphin is 0 to 1.5 yr and some dolphins, however, continue to take milk up to 2 to 3 yr of age. They also reported that the dolphin starts feeding on solid food such as fish, squid, and shrimp at 0.25 yr of age. Therefore, further studies are needed to estimate the uptake rates of cadmium through milk and solid food during the periods of weaning.

The plateau or decrease of cadmium concentration in various tissues and organs during 1.5 to 15 yr of age is explained by a dilution effect of the body weight increase during growth.

Although the similar age-trend of cadmium concentration was found in both the liver and kidney (Figure 3), the renal-hepatic ratio of cadmium concentration changed with age (Table 3). The mean ratio markedly increased at 0.5 yr of age and then slightly decreased after 15 yr. The change of the renal-hepatic ratio of cadmium with age has not been found in wild animals including their fetuses and pups. Kjellstrom (1979) reported that using the nine age groups of humans from Japan and Sweden, the renal-hepatic cadmium ratio increased with age up to about 40 yr and then decreased; the age trend is similar to our data.

The renal-hepatic ratio of the striped dolphin (mean: 4.25; range: 1.20–6.82) was lower than those

Table 3. Ratios between cadmium concentrations in kidney and liver of the striped dolphin, *Stenella coeruleoalba*, with age

Age	(N)[a]	Sexual maturity	Ratio (Kidney/liver) (Range)	Mean ± SD
0 – 0.50	(2)	Calf	1.20–1.50	1.35 ± 0.15
0.5 – 1.75	(3)	Calf	4.95–5.59	5.27 ± 0.26
1.75– 7.5	(4)	Immature	4.68–5.39	5.05 ± 0.27
7.5 –15	(8)	Mature	3.69–6.82	4.94 ± 1.10
15 –25	(7)	Mature	1.70–4.37	3.53 ± 0.85
25 –40	(2)	Mature	3.71–3.96	3.84 ± 0.13
Overall	(26)		1.20–6.82	4.25 ± 1.33

[a] Number of samples

of steller sea lions from the coast of Hokkaido, Japan (mean: 8.14; range: 4.23–16.59) reported by Hamanaka *et al.* (1982). The ratio between cadmium concentrations in the kidney and liver for marine mammals was calculated from data in the literature and was found to be in a wide range between animal species; pilot whales (Denton *et al.* 1980; Stoneburner 1978) and beluga whales (Harms *et al.* 1978) (3:1 to 5:1); and bottlenose dolphins (Denton *et al.* 1980) (10:1 to 15:1). Moreover, cadmium levels in the kidney and liver of striped dolphin, pilot whale, and beluga whale, which have the low renal-hepatic cadmium ratio, were one order higher compared with those of bottlenose dolphin with the high renal-hepatic cadmium ratio, and that of steller sea lion was in between. Therefore, the lower renal-hepatic ratio found both between age and between animal species may reflect a higher exposure levels. It is known from animal experiments and autopsy data from industrial workers that an increased proportion of the body burden of cadmium will be present in the liver at proportionately higher levels (Kjellstrom 1979).

An age-related cadmium increase in the kidney and liver has been reported for grey seals (Roberts *et al.* 1976), common seals (Heppleston and French 1973), and dugongs (Denton *et al.* 1980). However, they dealt with limited sample sizes, especially without fetus and newborn, and were also meager in biological information on the animals, such as age, growth of body weight and size, parturition, and lactation. This biological information is indispensable for the understanding of bioaccumulation phenomena of heavy metals. The age-related accumulation of cadmium may be responsible for the induction and biosynthesis of metallothionein in the kidney and liver and the absence of a well-defined excretory system as well as the long biological half-life of cadmium. Experimental studies (Kimura 1980) have suggested that different metals have different affinities for metallothionein protein, that there are complicated interactions among metals, and that metallothioneins can be organ- and species-specific. Although the mechanism leading to the age-related accumulation of cadmium in marine and terrestrial mammals is at present still unknown, the toxicological criteria of cadmium for animals must be given some consideration.

Age Trends of Zinc Concentration

Remarkable differences of zinc concentration were also found between the fetus and the pup; the zinc concentration in the muscle, blubber, and blood was higher in the former than the latter, and the remains were relatively higher in the latter (Table 1).

Figure 4 shows the zinc concentration in the various tissues and organs vs the age of striped dolphins. The zinc concentration characteristically changed with age during the periods of fetus, pup, and immaturity and was unchanged for mature dolphins. The zinc concentration in the muscle increased at the highest level until approximately 10 months during the pregnancy, and later rapidly decreased until soon after the birth. Both the liver and the kidney showed the same age trends of zinc concentration; the highest concentration was in the pup, the lowest in the fetus of approximately 10 months. The zinc concentration in the pancreas and brain in the fetus increased until birth; afterwards, there was little change with increased age. The mean zinc concentration in blood of the fetus was about three times higher than that of the mature dolphin and, after birth, decreased with age until about 8 yr of age. However, the zinc concentrations in blood of the pups sharply decreased in a very short time and such a peculiar curve of zinc concentration has never been found in other tissue and organs of the pups. The zinc concentrations in the muscle, liver and kidney of 8–25 yr of age varied more widely than those above 25 yr specimens, and it may probably reflect the reproductive activities, such as parturition and lactation during the periods.

Distinct age trends of zinc concentration in marine mammals have not been established. Denton *et al.* (1980) reported that the zinc concentration in liver and kidney of dugongs correlated positively with age. However, Drescher *et al.* (1977) did not find an age-specific increase of zinc concentration in harbor seals. Zinc distributes in a form of metallothionein and metalloenzyme such as carboxydehydrogenase and oxydoreductase, which are essential in animals, especially during the periods of fetus and newborn (Venugopal and Lucky 1978; Underwood 1975). The specific physiology of zinc in the

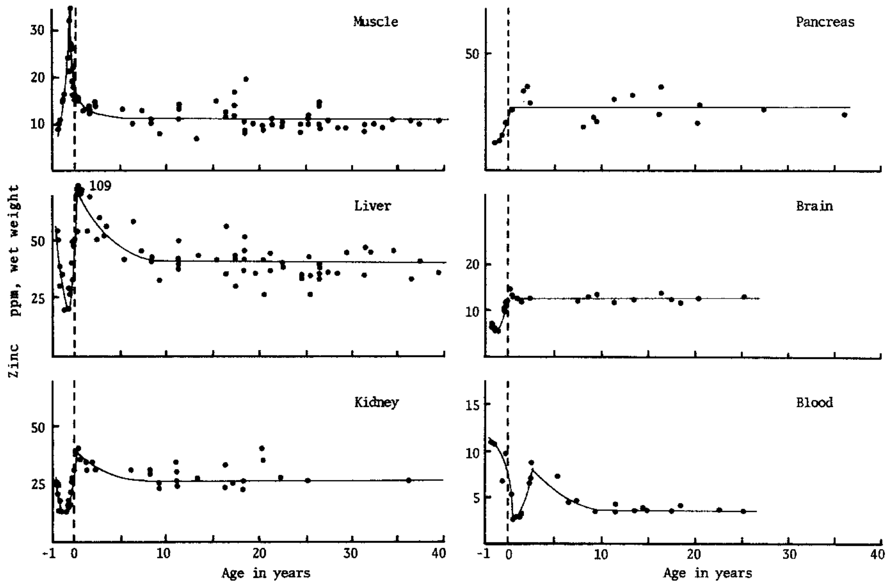

Fig. 4. Relationships between age and zinc concentrations (μg/wet g) in the muscle, liver, kidney, pancreas, brain, and blood of striped dolphin. The fetus age is shown in the periods of −1 to 0 year on the abscissa of the graphs

fetus and pup, therefore, may explain a fast change of zinc concentration during these periods.

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References

Anas, R. E.: Heavy metals in the northern fur seal, *Callorhinus ursinus* and harbor seal, *Phoca viturina richardi*. Fish. Bull. U. S. **72,** 133 (1974).

Arima, S., and K. Nagakura: Mercury and selenium content of *Odontocei*. Bull. Jap. Soc. Sci. Fish. **45,** 623 (1979).

Buhler, D. R., R. R. Claeys, and B. R. Mato: Heavy metal and chlorinated hydrocarbon residues in California sea lions. J. Fish. Res. Bd. Can. **32,** 2391 (1975).

Cousins, R. J., A. K. Barber, and J. R. Trout: Cadmium toxicity in growing swine. J. Nutr. **103,** 964 (1973).

Denton, G. R. W., H. Marsh, G. E. Heinsohn, and C. Bardon-Jones: The unusual metal status of the dugong *Dugong dugong*. Mar. Biol. **57,** 201 (1980).

Doyle, J. J., and W. H. Pfander: Interaction of cadmium with copper, iron, zinc, and manganese in ovine tissues. J. Nutr. **105,** 599 (1975).

Drescher, H. E., U. Harms, and E. Huschenbeth: Organochlorines and heavy metals in the harbor seal *Phoca viturina* from the German North Sea coast. Mar. Biol. **41,** 99 (1977).

Duinker, J. C., M. Th. J. Hillebrand, and R. F. Nolting: Organochlorines and metals in harbor seals (Dutch Wadden Sea). Mar. Pollut. Bull. **10,** 360 (1979).

Elinder, C. G., M. Piscator, and L. Linnman: Cadmium and zinc relationships in kidney cortex, liver, and pancreas. Environ. Res. **13,** 432 (1977).

Elinder, C. G., and M. Piscator: Cadmium and zinc relationships. Environ. Health Perspect. **25,** 129 (1978).

Gaskin, D. E., K. I. Stonefield, P. Suda, and R. Frank: Changes in mercury levels in harbor porpoises from the Bay of Fundy, Canada, and adjacent waters during 1969–1977. Arch. Environ. Contam. Toxicol. **8,** 733 (1979).

Hamanaka, T., T. Itoo, and S. Mishima: Age-related change and distribution of cadmium and zinc concentrations in the steller sea lion (*Eumetopias jubata*) from the coast of Hokkaido, Japan. Mar. Pollut. Bull. **13,** 57 (1982).

Hamanaka, T., H. Kato, and T. Tsujita: Cadmium and zinc in ribon seal, *Histriphoca fasciata,* in the Okhotsk Sea. Res. Inst. N. Pac. Fish., Hokkaido Univ., Spe. Vol. 547 (1977).

Harms, U., H. E. Drescher, and E. Huschenbeth: Further data on heavy metals and organochlorines in marine mammals from German coastal waters. Meeresforschung **26,** 153 (1978).

Heppleston, P. B., and M. C. French: Mercury and other metals in British seals. Nature **243,** 302 (1973).

Honda, K., R. Tatsukawa, and T. Fujiyama: Distribution characteristics of heavy metals in the organs and tissues of striped dolphin, *Stenella coeruleoalba*. Agric. Biol. Chem. **46,** 3011 (1982).

Jones, D., K. Ronard, D. M. Lavigne, R. Frank, K. Holdrint, and J. F. Uthe: Organochlorine and mercury residues in the harp seal (*Pagophilus groenlandius*). Sci. Total Environ. **5,** 181 (1976).

Kasuya, T., N. Miyazaki, and W. H. Dawbin: Growth and reproduction of *Stenella attenuata* in the Pacific coast of Japan. Sci. Rep. Whales Res. Inst. No. 26, 157 (1974).

Kimura, M.: Toxicological aspects of environmental pollutants—inorganic chemicals—. Kagaku no Ryoiki No. 126, 47 (1980) Japanese.

Kjellstrom, T.: Exposure and accumulation of cadmium in populations from Japan, the United States, and Sweden. Environ. Health Perspect. **28,** 169 (1979).

Koeman, J. H., W. H. M. Peeters, C. J. Smit, P. S. Tjioe, and J. J. M. De Goeij: Persistent chemicals in marine mammals. TNO-niews **27,** 570 (1972).

Koeman, J. H., W. S. M. van de Ven, J. J. M. De Goeij, P. S. Tjioe, and J. L. van Haaften: Mercury and selenium in marine mammals and birds. Sci. Total Environ. **3,** 279 (1975).

Martin, J. H., and A. P. Flegal: High copper concentrations in squids liver in association with elevated levels of silver, cadmium, and zinc. Mar. Biol. **30,** 51 (1975).

Miyazaki, N., T. Kasuya, and M. Nishiwaki: Food of *Stenella coeruleoalba*. Sci. Rep. Whales Res. Inst. No. 25, 265 (1973).

———: Distribution and migration of two species of *Stenella* in the Pacific coast of Japan. Sci. Rep. Whales Res. Inst. No. 26, 227 (1974).

———: Growth and reproduction of *Stenella coeruleoalba* off the Pacific coast of Japan. Sci. Rep. Whales Res. Inst. No. 29, 21 (1977).

Miyazaki, N., Y. Fujise, and T. Fujiyama: Body and organ weight of striped and spotted dolphins off the Pacific coast of Japan. Sci. Rep. Whales Res. Inst. No. 33, 27 (1981).

Nordberg, G. F.: Separation of two forms of rabbit metallothionein by isoelectric focusing. Biochem. J. **126,** 491 (1972).

Piscator, M.: Cadmium-zinc interaction. In Proceedings of recent advances in the assessment of health effects of environmental pollution. CEC-EPA-WHO Symposium, Paris, June 24–28, 1974.

Reijinders, P. J. H.: Organochlorine and heavy metal residues in harbor seals from the Wadden Sea and their possible effects on reproduction. Netherlands J. Sea Res. **14,** 30 (1980).

Roberts, T. M., P. B. Heppleston, and R. D. Roberts: Distribution of heavy metals in tissues of the common seal. Mar. Pollut. Bull. **7,** 194 (1976).

Schroeder, H. A., and A. P. Nason: Interaction of trace metals in rat tissues. Cadmium and nickel with zinc, chromium, copper and manganese. J. Nutr. **104,** 167 (1974).

Stoneburner, D. L.: Heavy metals in tissues of stranded short-finned pilot whales. Sci. Total Environ. **9,** 293 (1978).

Tanabe, S., R. Tatsukawa, K. Maruyama, and N. Miyazaki: Trans placental transfer of PCBs and chlorinated hydrocarbon pesticides from the pregnant striped dolphin (*Stenella coeruleoalba*) to her fetus. Agric. Biol. Chem. **46,** 1249 (1982).

Tanabe, S., R. Tatsukawa, H. Tanaka, K. Maruyama, N. Miyazaki, and T. Fujiyama: Distribution and total burdens of chlorinated hydrocarbons in bodies of striped dolphins (*Stenella coeruleoalba*). Agric. Biol. Chem. **45,** 2569 (1981).

Underwood, E. J.: Trace elements in human and animal nutrition. 3 ed. p. 491. Academic Press: Copyright 1975 by Maruzen Co., Ltd. (1975) Japanese.

Venugopal, B., and T. D. Luckey: Chemical toxicity of metals and metalloids. Vol. 2, p. 409. New York and London: Plenum Press (1978).

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