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Yearly trend of trace element accumulation in liver of Antarctic minke whale, *Balaenoptera bonaerensis*

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ABSTRACT

Concentrations of toxic elements (Hg, Cd, Pb and Ni) and essential elements (Cu, Zn, Fe and Mn) were determined in 1,056 livers of Antarctic minke whales (*Balaenoptera bonaerensis*) taken from Antarctic Areas IIIE, IV, V and VIW during 1988/89 and 2004/05. The ranges of concentrations for each element were, in μg/g wet wt: Hg, <0.005-0.43; Cd, 0.089-66; Pb, <0.3-0.7; Ni, <0.1-0.3; Cu, 2.8-14; Zn, 18-103; Fe, 1.6-11000; Mn, 1.4-7.4. Gender differences in Fe and Zn levels were observed in livers of Antarctic minke whales. A stepwise multiple regression analyses of Hg and Cd levels in males identified sampling years, age and sampling longitude as main effective factors. Although it has been known that essential element levels in animals are maintained constant due to homeostasis, essential elements were independent of sampling year (Cu, Zn), age (Cu, Fe, Mn), longitude (Cu, Zn , Fe, Mn) and latitude (Mn). Toxic element intake in young minke whales (1-15 years) significantly decreased with sampling years, while that of over 16 year individuals was stable. These results can be interpreted as changes of feeding environment in Antarctic minke whales in recent years. In the pollutant levels in Antarctic minke whales, toxic and essential element levels, except for Fe, in Antarctic minke whales were considerably lower than those of cetaceans from the Northern Hemisphere. These element levels detected in livers of Antarctic minke whales may not have any adverse effect on whale health.

KEY WORDS: ANTARCTIC MINKE WHALE; TRACE ELEMENT; BIOACCUMULATION, AGE TREND, FOOD AVAILABILITY

INTRODUCTION

In 1992, the International Whaling Commission (IWC) decided to establish a regular agenda item for research on effects of environmental change on cetaceans in the Scientific Committee (SC) of IWC (IWC, 1993). At the IWC/SC meeting in 1994, the Committee addressed: (1) global warming; (2) ozone depletion; (3) pollution; (4) direct and indirect fisheries; (5) noise; and (6) other human activities (e.g. tourism, coastal development) (IWC, 1995). However, because of difficulty to conduct all topics simultaneously, it agreed to initially focus on two specialized items, the relationships between chemical pollutants and cetaceans, and the potential ecological effects of climate change and ozone depletion on cetaceans (IWC, 1999). Then, the Committee decided to hold two workshops (IWC, 1999). The JARPA was designed to cover these items by collecting related samples and data from the beginning of the program, in order to respond to a growing concern over environmental changes. Some results on effects of environmental changes on cetaceans in JARPA surveys were reported in the JARPA review meeting in 1997 (Government of Japan, 1995; Fujise, 1997).

We have monitored pollutants, such as trace elements and organochlorine compounds, in Antarctic minke whales in the JARPA research. Trace elements include oxic elements, such as Hg, Cd, Pb and Ni (or nonessential element), and essential elements, such as Cu, Zn, Fe and Mn. Toxic elements induced adverse effects for animals and humans and indicate more persistence than essential elements. Essential elements are essential for survival and health of animals and humans.

Fujise (1997), Watanabe *et al.* (1998) and Honda *et al.* (2006) reported that 'yearly changes of age-accumulation patterns of hepatic Hg in Antarctic minke whales suggest possible environment changes such as changes of food availability.' This hypothesis was also supported by the studies on biological parameters (Zenitani *et al.*, 1997), body fatness and blubber thickness (Ohsumi *et al.*, 1997) of Antarctic minke whales.

The object of this report is to monitor levels and behaviour of trace elements, especially toxic elements, in Antarctic minke whales and to evaluate their health effects.

MATERIALS AND METHODS

Antarctic minke whales were collected from Areas IIIE (35-70E), IV (70-130E) and V (130E-170W), VIW (170W-145W), alternative years in JARPA. Liver samples of 1,056 (918 males and 138 females) Antarctic minke whales from Areas IIIE, IV, V and VIW sampled during 1988/89 and 2004/05 were excised form the medial region for trace element analysis (Table 1). All samples were stored in polyethylene bags at -20°C until analysis. Examined temporal trends of trace element levels in age organization, four age groups, 1-15, 16-25 and over 26 years, were selected at random in each year. Sex differences were examined only in 1988/89 and 1998/99.

For the analysis of Hg, Cd, Pb, Ni, Cu, Zn, Fe and Mn, the tissues were homogenized and digested in microwave (Milestone General: MLS 1200 mega) using nitric acid in a PTFE (Teflon) vessel (Okamoto, 1994). Cd, Pb, Ni, Cu, Zn, Fe and Mn were measured by inductively coupled plasma atomic emission spectrometry (Seiko Instruments Inc., SPS 1700R) and Hg was measured by cold vapour / atomic absorption spectrometry (Nippon Instruments Co. RA-2A) using external standard method. Concentrations of liver are given on wet weight basis. Accuracy and precision of the methods were confirmed using 'bovine liver' (BCR-CRM No. 185) and 'pig kidney' (BCR-CRM No. 186). Chemical analyses were performed by the Miura Institute of Environmental Science.

The differences between sexes and areas were assessed by Mann-Whitney U test and the relationships between concentrations of trace elements and age were assessed by Spearman rank correlation (Zar, 1999). To analyze factors for trace element levels in Antarctic minke whales, we used the stepwise multiple regression analysis. These statistical analyses were executed by SPSS ver.11 for Windows (SPSS Co. Ltd.).

RESULTS AND DISCUSSION

Cd, Cu, Zn, Fe and Mn were detected in almost all of the liver samples of Antarctic minke whales and Hg was detected, except for one animal. Pb and Ni concentrations in all the liver samples of Antarctic minke whales were almost less than the lower level of determination limit. The ranges of concentrations for each element were, inμg/g wet wt: Hg, <0.005-0.43; Cd, 0.089-66; Pb, <0.3-0.7; Ni, <0.1-0.3; Cu, 2.8-14; Zn, 18-103; Fe, 1.6- 11000; Mn, 1.4-7.4.

In general, no gender difference of most trace elements accumulation is observed in marine mammals (Law, 1995). Gender differences in trace element levels were confirmed using individuals taken from the Area V in 1988/89 and 1998/99 (Table 2). Hepatic Fe and Zn concentrations of Antarctic minke whales in 1988/89 were significantly different between sexes. Hepatic Fe concentrations of males clearly increased with age and those of females were not observed (Fig. 1a, 1b). In this paper, only male samples were used for the examinations to avoid sex difference.

Factors for trace element levels in minke whales

A multiple regression analysis was done to determine the extent of effect of individual factors of sampling years, age, sampling longitude and latitude (Table 3). For Hg and Cd, sampling year, age and longitude were significantly selected. Toxic element, such as Hg and Cd, levels are simply determined by food intake, food toxic element levels and their turn over (Honda 1985; Law, 1995). On the other hand, essential element levels in animals are maintained constant due to homeostasis and not relatively affected by several varying environments (Mertz, 1981). However, toxic and essential elements, except for Mn, were significantly selected with the sampling longitude, while not selected with the sampling latitude. It is suggested that longitude variation is more important than latitude for spatial trend of trace element in Antarctic minke whales.

Toxic elements

Age trend

Figures 2a, 2b, 3a and 3b represents plots of hepatic Hg and Cd concentrations in males of Antarctic minke whales taken from the Areas IV and V, versus their age. Table 4 shows significant correlation between hepatic Hg and Cd concentrations and age in males of Antarctic minke whales tested with Spearman rank test ($p<0.05$) in Areas IIIE-VIW. In general, positive correlation was not observed Hg/Cd and age until 1993/94 season, but it was observed since then.

It has been reported that hepatic Hg and Cd levels increase with age in whales (Denton *et al.*, 1980; Honda *et al.*, 1983; Mackey *et al.*, 1996; Law, 1995). However, Honda *et al.* (1987) reported that age-accumulation of hepatic Hg levels in Antarctic minke whales taken from the Antarctic during 1980 and 1985 was not observed, because food intake of the young minke whales rapidly increased. Furthermore, Fujise (1997) and Honda *et al.* (2006) reported that age-accumulation of the hepatic Hg concentrations in Antarctic minke whales were clearly observed during 1988/89 and 1998/99. Honda *et al.* (2006) suggested that hepatic Hg levels in the young minke whales decreased due to the decrease of the food stock since middle 1980's. Our result was consistent with the previous studies. And also, this hypothesis is supported by results in another study that Hg and Cd levels in Antarctic krill from the Areas III-IV and V-VI are stable during 1988/89 and 1997/98 (Yasunaga *et al.*, 2006).

Spatial trend

Plots of hepatic Hg and Cd concentrations in Antarctic minke whales (16-25 years) taken during 1995/96 and 2002/03 against their sampling latitude are shown in Fig.4. Mature males which were from 16 to 25 years old were used for statistical analysis to avoid influence of age and sex. Correlation between hepatic Hg ($r=0.205$, $p=0.028$) and Cd ($r=0.575$, $p<0.001$) levels with sampling latitude were significantly observed by Spearman rank test.

Toxic element levels in Antarctic minke whales are related to food intake and their toxic element levels. Geographical differences of Cd and Hg levels in Antarctic krill, the stomach contents of Antarctic minke whales, were not observed between Areas IIIE-IV and V-VIW (Yasunaga *et al.*, 2006). Then, food intake of minke whales taken from western (Area IIIE) would be lower than those from eastern (Area VIW). This is consistent with the report that blubber thickness, as obesity index, of Antarctic minke whales from Areas IV and V became thick toward East (Konishi *et al.,* 2006). These reports suggest that feeding environment in eastern area would be better than that in western area. On the other hand, Murase *et al.* (2006a, b) reported that biomass of Antarctic krill in Area IV was higher than Area V, while the magnitude of interspecies competition of baleen whales in Area IV was higher than the magnitude in Area V. This point should be investigated quantitatively in future to reveal those phenomena.

Temporal trend

Plots of hepatic Hg and Cd concentrations in Antarctic minke whales in each age group, 1-15, 16-25 and over 26 years old, against their sampling year are shown in Fig.5. Results of simple linear regression analysis identified the dependent variables as hepatic logarithm Hg and Cd concentrations and sampling year as independent variable as shown in Table 5. Hepatic Hg and Cd levels decreased significantly in the youngest age group (1-15 years) from Areas IV and V, hepatic Cd levels in middle age group (16-25 years) from Area IV and hepatic Hg levels in the oldest age class (over 26 years) form Area IV. This result would mean that food intake of minke whales in later stage of JARPA research would be lower than that in earlier stage from Areas IV and V. Furthermore, this trend was mainly observed in youngest age class. It can be interpreted as changes of feeding environment in Antarctic minke whales in recent years.

Essential elements

The Antarctic minke whale hepatic Mn and Fe shows correlation coefficient by Spearman rank test (Table 6). Figure 6 shows the relationships between the hepatic Mn and Fe levels and age. Hepatic Mn and Fe levels in Antarctic minke whales were affected with their age and sampling areas. Regression slopes of Mn with age among Areas IIIE, IV, V and VIW were not significantly different, while those of Fe were significantly different among Areas IIIE, IV, V and VIW, except for between Areas IV and VIW (ANCOVA, $p<0.05$). The difference is because hepatic Fe might be affected by food intake and physiological functions such as immunological system, and requirement of hepatic Mn level in infant is characteristically higher than that in the following stages.

Figure 7 shows a plot of average of Zn levels in Antarctic minke whales versus the sampling year. Hepatic Zn data from each sampling year were pooled as there were no age-accumulation observed. The temporal Zn curve has cyclic ups and downs each 3-5 years. In mammals, Zn is related to the activity and stability of more than 200 metallo-enzymes, so its physiological function is a complicated system. However, these functions were indistinguishable in this study.

Copper levels in Antarctic minke whales were affected by sampling year, age and longitude. In marine mammals, Cu levels in neonates and juvenile are higher than are those of mature individuals (Honda 1985; Fujise, 1987). Copper levels in animals are affected by metabolic interactions with other essential elements, such as Cd, Fe and Zn, further complicating the interpretation (Davis and Mertz, 1987).

Comparison of trace element levels in baleen whales

Table 7 and Fig. 8 show the trace element levels in livers of whales around the world as previously reported for comparison with our data.

Hepatic Hg levels of Antarctic minke whales were one order of magnitude lower than those of common minke, sei and Bryde's whales from the western North Pacific. In general, it is known that hepatic Hg levels of baleen whales are lower than those of tooth whales (Honda *et al.*, 1983; Law, 1995). Hepatic Cd levels are constant in baleen and tooth whales in the world and Cd levels of Antarctic minke whales are classified into higher categories in analogue with sei and sperm whales from the western North Pacific and narwhals from the near Greenland. Hepatic Pb and Ni levels of the whales, except for striped dolphins, were almost less than the lower limit of determination level or close to these.

Hepatic levels of essential elements, such as Mn, Cu and Zn, of Antarctic minke whales are comparable to those of other baleen and tooth whales in the Northern Hemisphere. However, hepatic Fe levels of Antarctic minke whales were one order of magnitude higher than those of other whales in the Northern Hemisphere. Higher Fe levels may be caused by their physiological functions, because dissolved iron is extremely low in the surface water of Antarctic Ocean (Martin *et al.,* 1991)

Therefore, trace element levels, except for Fe, in Antarctic minke whales were extremely or comparatively lower than those of cetaceans from Northern Hemisphere. Then, these element levels measured in livers of Antarctic minke whales may not have any adverse effect on whale health.

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Table 1 Description of Antarctic minke whales using for trace element analysis

Year	Area	*n* (sex)	Body length (m)
1988/89	Area V	68M	7.91
	Area V	76F	8.22
1989/90	Area IV	100M	8.40
1990/91	Area V	36M	8.47
1991/92	Area IV	36M	8.42
1992/93	Area V	36M	8.54
1993/94	Area IV	36M	8.44
1994/95	Area V	49M	8.12
1995/96	Areas IIIE, IV	100M	8.15
1996/97	Areas V, VIW	75M	7.89
1997/98	Areas IIIE, IV	75M	7.81
1998/99	Areas V, VIW	108M	7.58
	Areas V, VIW	62F	7.17
1999/00	Areas IIIE, IV	39M	7.93
2000/01	Areas V, VIW	40M	7.73
2001/02	Areas IIIE, IV	40M	7.86
2002/03	Areas V, VIW	40M	7.79
2003/04	Area V	20M	7.95
2004/05	Area V	20M	7.91

Table 2. Hepatic trace element concentrations (μg/g wet wt) and sex difference of Antarctic minke whales (over 16 years) in 1988/89 and 1998/99.

			Hg	Cd	Cu	Zn	Fe	Mn
1988/89	males	Ave.	0.078	16	5.2	40	2407	3.2
		Range	(0.023 - 0.23)	(5.3 - 32)	(4 - 7.4)	(31 - 52)	(798 - 6170)	(1.8 - 4.2)
		n	16	16	16	16	16	16
	females	Ave.	0.11	20	5.4	52	361	3.5
		Range	(0.044 - 0.27)	(8.3 - 63)	(4.4 - 9.3)	(37 - 103)	(41 - 2630)	(2.2 - 4.9)
		n	22	22	22	22	22	22
		p	0.060	0.162	0.356	0.001	<0.001	0.651
	Significant difference					**	***	
1998/99	males	Ave.	0.093	18	5.1	46	2550	3.1
		Range	(0.010 - 0.43)	(5.5 - 51)	(3.5 - 11)	(30 - 70)	(130 - 6800)	(1.7 - 4.6)
		n	40	40	40	40	40	40
	females	Ave.	0.082	20	5.2	54	608	2.8
		Range	(0.043 - 0.16)	(13 - 45)	(3.7 - 10)	(33 - 99)	(23 - 1900)	(2.0 - 4.9)
		n	13	13	13	13	13	13
		p	0.901	0.443	0.901	0.100	<0.001	0.181
	Significant difference						***	

*: p<0.05, **: p<0.01, ***: p<0.001

Table 3 The results of multiple regression cofficients.

		LN (Hg conc.)	LN (Cd conc.)	LN (Cu conc.)	LN (Zn conc.)	LN (Fe conc.)	LN (Mn conc.)
Constant	B±SE	**47.812±9.528**	**80.060±12.350**	**20.186±3.183**	**16.608±3.343**	-10.692±21.752	-0.156±3.905
	P value	**<0.001*** **	**<0.001*** **	**<0.001*** **	**<0.001*** **	0.623	0.968
Year (1988-2004)	B±SE	**-0.026±0.005**	**-0.039±0.006**	**-0.009±0.002**	**-0.006±0.002**	0.008±0.011	0.001±0.002
	P value	**<0.001*** **	**<0.001*** **	**<0.001*** **	**<0.001*** **	0.448	0.560
Age	B±SE	**0.025±0.002**	**0.040±0.002**	**-0.002±0.001**	-0.000001±0.001	**0.078±0.004**	**-0.006±0.001**
	P value	**<0.001*** **	**<0.001*** **	**0.009** **	0.999	**<0.001*** **	**<0.001*** **
Longitude (E+W)	B±SE	**0.002±0.000**	**0.004±0.001**	**0.0004±0.000**	**0.001±0.000**	**-0.005±0.001**	**0.0006±0.000**
	P value	**<0.001*** **	**<0.001*** **	**0.026* **	**<0.001*** **	**<0.001*** **	**<0.001*** **
Latitude (S)	B±SE	-0.003±0.008	-0.011±0.010	-0.006±0.003	-0.005±0.003	-0.002±0.018	**-0.013±0.003**
	P value	0.747	0.280	0.028	0.106	0.909	**<0.001*** **

*: *p* <0.05, **: *p* <0.01, ***: *p* <0.001

Table 4 Significant correlationships between age and hepatic Hg and Cd concentrations in Antarctic minke whales tested with Spearman rank test.

Year		Hg				Cd			
		Area III	Area IV	Area V	Area VI	Area III	Area IV	Area V	Area VI
1988/89	*r*			**0.410****				**0.565*****	
	p			**0.002**				**<0.001**	
1989/90	*r*		0.161				**0.222***		
	p		0.110				**0.026**		
1990/91	*r*			0.299				**0.533****	
	p			0.076				**0.001**	
1991/92	*r*		-0.056				0.306		
	p		0.7440				0.069		
1992/93	*r*			0.000				0.081	
	p			0.998				0.637	
1993/94	*r*		0.190				0.220		
	p		0.266				0.198		
1994/95	*r*			**0.489*****				**0.453****	
	p			**<0.001**				**0.001**	
1995/96	*r*	**0.468****	**0.438*****			**0.516****	**0.487*****		
	p	**0.009**	**<0.001**			**0.004**	**<0.001**		
1996/97	*r*			**0.466***	**0.430****			**0.623*****	**0.677*****
	p			**0.012**	**0.006**			**<0.001**	**<0.001**
1997/98	*r*	**0.647*****	**0.550****			**0.779*****	**0.610****		
	p	**<0.001**	**0.004**			**<0.001**	**0.0010**		
1998/99	*r*			**0.620*****	**0.386***			**0.737*****	**0.650*****
	p			**<0.001**	**0.018**			**<0.001**	**<0.001**
1999/00	*r*	**0.892*****	**0.532***			**0.789*****	**0.814*****		
	p	**<0.001**	**0.016**			**<0.001**	**<0.001**		
2000/01	*r*			**0.648****	0.365			**0.654****	**0.545***
	p			**0.002**	0.124			**0.002**	**0.016**
2001/02	*r*	**0.552***	**0.846*****			**0.644****	**0.497***		
	p	**0.014**	**<0.001**			**0.003**	**0.026**		
2002/03	*r*			**0.770*****	**0.715*****			**0.755*****	**0.543***
	p			**<0.001**	**<0.001**			**<0.001**	**0.013**
2003/04	*r*		**0.583****				**0.515***		
	p		**0.007**				**0.020**		
2004/05	*r*			**0.595****				**0.555***	
	p			**0.006**				**0.006**	

*: p <0.05, **: p <0.01, ***: p <0.001

Table 5 Simple linear regression analysis of logarithm Hg and Cd concentrations in Antarctic minke whales from Areas V and VI with their sampling year

		Area IV		Area V	
		LN_Hg	LN_Cd	LN_Hg	LN_Cd
1-15 years	*p*	**<0.001*** **	**<0.001*** **	**0.01***	**0.005** **
	Year	**-8.350**$\times 10^{-2}$	**-6.559**$\times 10^{-2}$	**-2.804**$\times 10^{-2}$	**-4.227**$\times 10^{-2}$
	Constant	**163.3670**	**132.812**	**52.917**	**86.308**
16-25 years	*p*	0.153	**0.016***	0.118	0.6580
	Year		**-3.823**$\times 10^{-2}$		
	Constant		**78.583**		
over 26 years	*p*	**0.049***	0.717	0.209	0.662
	Year	**-2.485**$\times 10^{-2}$			
	Constant	**46.7820**			

*: *p* <0.05, **: *p* <0.01, ***: *p* <0.001

Table 6 Correlationships between the hepatic trace element concentrations and age in Antarctic minke whales during 1988/89 and 2004/05 using Spearman rank correlation test.

		Area III	Area IV	Area V	Area VI
Mn	*r*	**-0.365**	**-0.246**	**-0.317**	**-0.290**
	p	**<0.001*** **	**<0.001*** **	**<0.001*** **	**0.001** **
	n	**106**	**327**	**316**	**117**
Fe	*r*	**0.804**	**0.642**	**0.522**	**0.801**
	p	**<0.001*** **	**<0.001*** **	**<0.001*** **	**<0.001*** **
	n	**106**	**327**	**316**	**117**

*: *p* <0.05, **: *p* <0.01, ***: *p* <0.001

Table 7. Trace element concentrations (μg/g wet wt) in the liver of cetaceans.

Species	*n*	Hg	Cd	Pb	Ni	Cu	Zn	Fe	Mn	year	Area	(References)
Baleen whales												
Antarctic minke whale	1056	0.068	12	0.4	0.2	5.2	43	1400	3.5	1988-2005	Antarctic	
		(<0.005 - 0.43)	(0.089 - 66)	(<0.3 - 0.7)	(<0.1 - 0.3)	(2.8 - 14)	(18 - 103)	(1.6 - 11000)	(1.4 - 7.4)			(This study)
Common minke whale	738	0.65	2.6	0.5	0.2	7.0	41	368	3.4	1994-2002	NW Pacific	
		(0.001 - 4.3)	(0.010 - 9.5)	(<0.3 - 2.0)	(<0.1 - 0.4)	(2.0 - 34)	(21 - 82)	(2.5 - 4108)	(1.1 - 9.5)			(In preparation)
Common minke whale	17	0.39*	0.90*				34.5*			1980	W Greenland	
		(0.14 - 2.68)	(0.50 - 1.45)	(-)	(-)	(-)	(26.4 - 48.0)	(-)	(-)			(Hansen *et al.* , 1990)
Bryde's whale	143	0.18	3.1	<0.3	<0.1	4.4	36	275	2.4	2000-2	NW Pacific	
		(0.011 - 1.1)	(0.030 - 9.0)	(-)	(-)	(2.6 - 11)	(21 - 54)	(2.6 - 2000)	(1.3 - 5.3)			(In preparation)
Sei whale	39	0.43	11	<0.3	<0.1	12	37	162	2.2	2002	NW Pacific	
		(0.07 - 1.6)	(3.1 - 25)	(-)	(-)	(5.6 - 50)	(22 - 68)	(31 - 500)	(1.5 - 3.2)			(In preparation)
fin whale	11	0.55								1983-4	Spain (Factory)	
		(0.16 - 1.4)	(-)	(-)	(-)	(-)	(-)	(-)	(-)			(Sanpera *et al.* , 1993)
fin whale	5	0.55								1986	Iceland (Factory)	
		(0.39 - 0.82)	(-)	(-)	(-)	(-)	(-)	(-)	(-)			(Sanpera *et al.* , 1993)
Bowhead whale	20	0.07		0.04		4.9	34	700	0.93	1994	Alaska (Barrow)	
		(0.02 - 0.11)	(-)	(<0.03 - 0.04)	(-)	(2.8 - 8.0)	(22 - 61)	(135 - 2740)	(0.4 - 2.0)			(Krone *et al.* , 1999)
Toothed whales												
Sperm whale	13	62	14	<0.3	<0.1	3.3	32	610	0.7	2000-2	NW Pacific	
		(3.2 - 250)	(4.0 - 31)	(-)	(-)	(2.1 - 5.1)	(25 - 39)	(33 - 1700)	(0.40 - 1.0)			(In preparation)
beluga	40	1.77*	2.21*				28.4*			1984-5	W Greenland	
		(0.07 - 30.8)	(<0.015 - 8.54)	(-)	(-)	(-)	(22 - 45.2)	(-)	(-)			(Hansen *et al.* , 1990)
Narwhal	48-90	5.26*	10.8*				35.9*			1984-5	W Greenland	
		(<0.005 - 42.8)	(<0.015 - 73.7)	(-)	(-)	(-)	(13.3 - 67.7)	(-)	(-)			(Hansen *et al.* , 1990)
Striped dolphin	37-46	169*	1.3*			6.3*	32*			1987-94	Italy	
		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)			(Monaci *et al.* , 1998)
Striped dolphin	20-30	205	6.26	0.22	0.22	8.09	44.5	215	3.18	1978-80	NW Pacific	
		(1.7 - 485)	(0.04 - 11.1)	(0.03 - 0.64)	(0.1 - 0.5)	(3.57 - 15.2)	(27 - 109)	(55.8 - 95.5)	(1.30 - 6.71)			(Honda *et al.* , 1998)
Dall's porpoise	26M	20.0	7.81			7.42	43.2	254	6.31	1982-84	NW Pacific	
		(6.52 - 48.7)	(2.62 - 17.8)	(-)	(-)	(1.29 - 17.4)	(32 - 53.5)	(106 - 456)	(4.03 - 7.70)			(Fujise, 1987)

*: Median

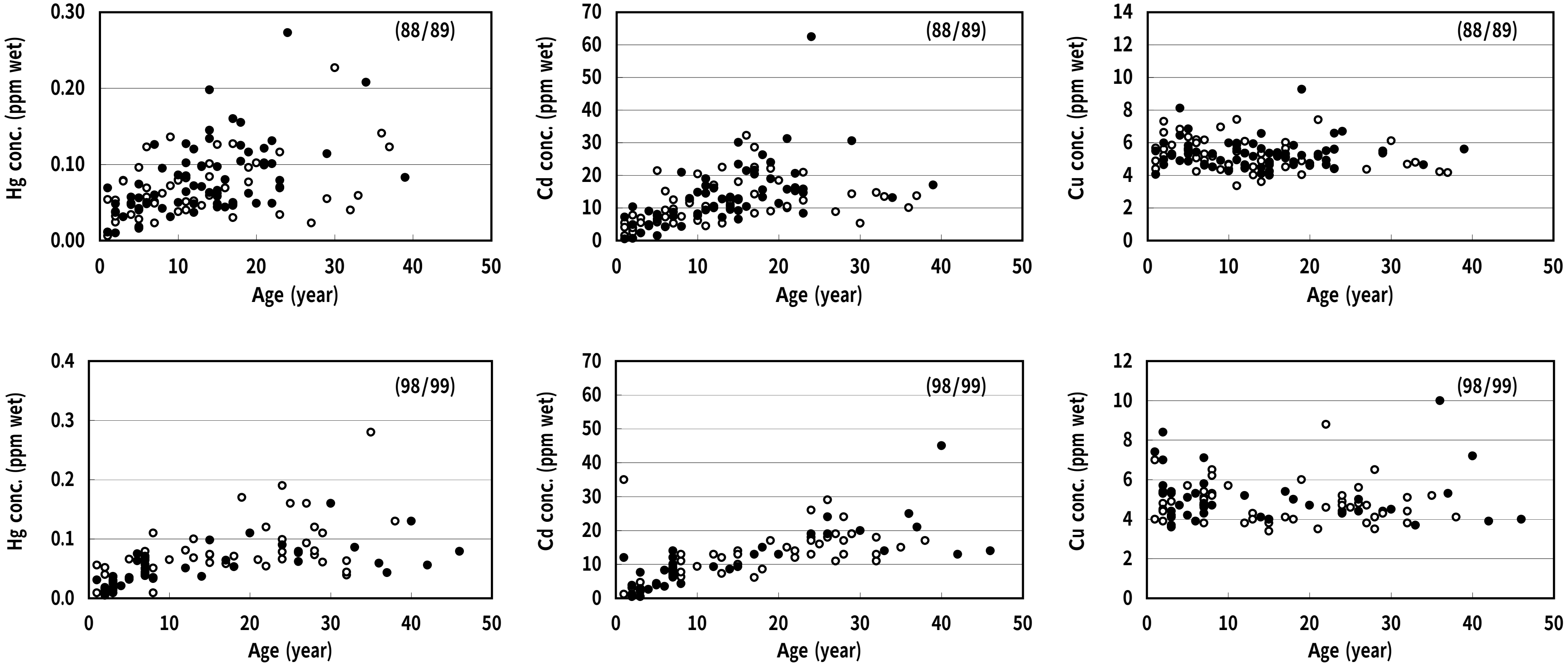


Fig. 1a. Relationships between age and trace element concentrations (μ g/g wet wt.) in the liver of Antarctic minke whales (male=○, female=●) from Antarctic Ocean Area V.

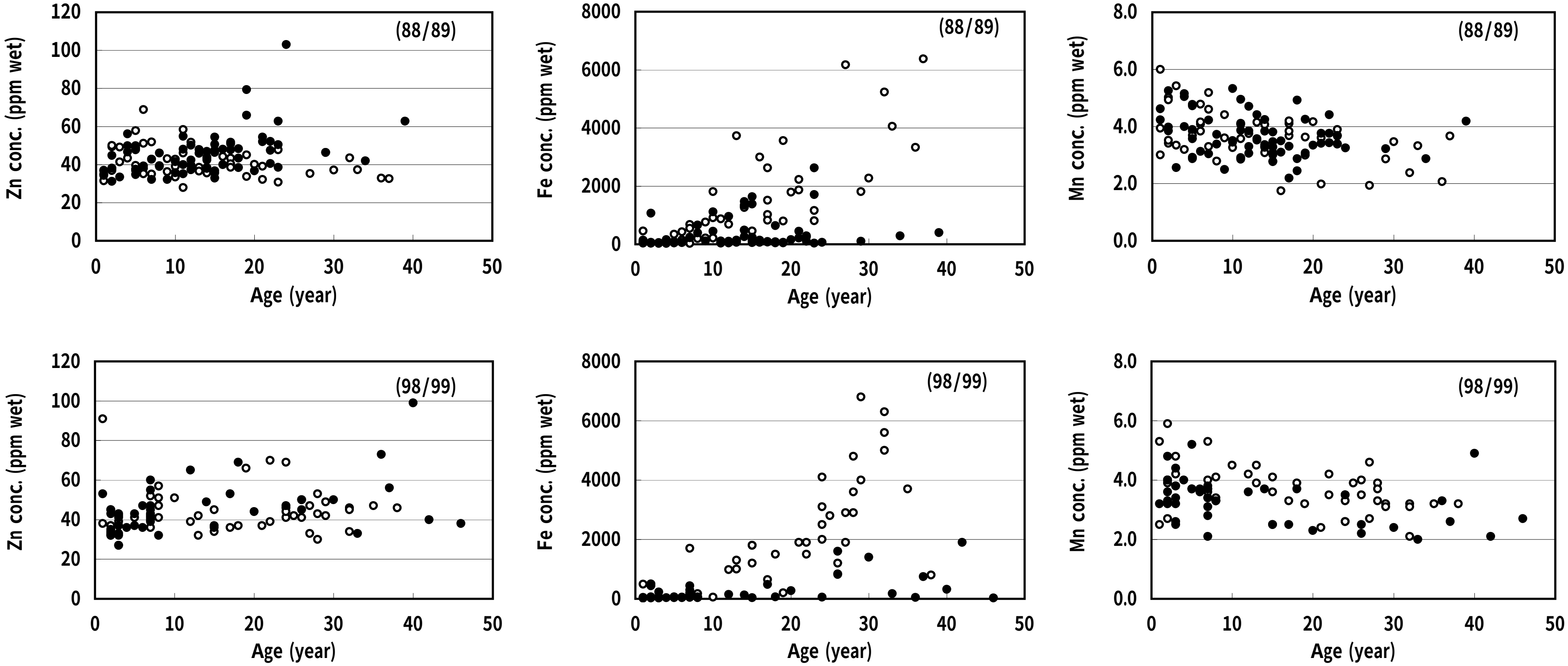


Fig. 1b. Relationships between age and trace element concentrations (μ g/g wet wt.) in the liver of Antarctic minke whales (male=○, female=●) from Antarctic Ocean Area V.

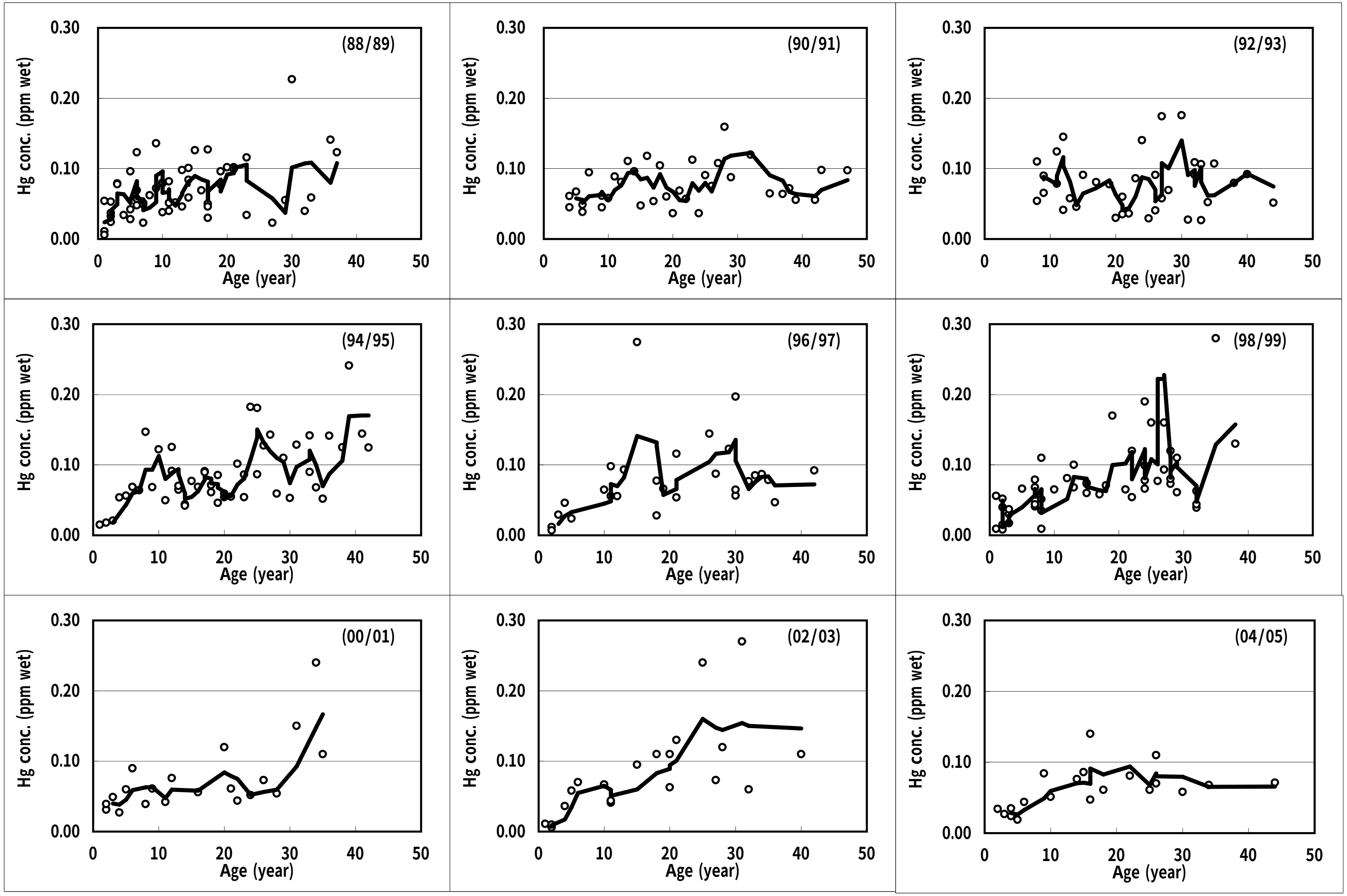


Fig. 2a Yearly Relationships between age and hepatic Hg concentrations of Antarctic minke whales (males) from the Antarctic Area V.

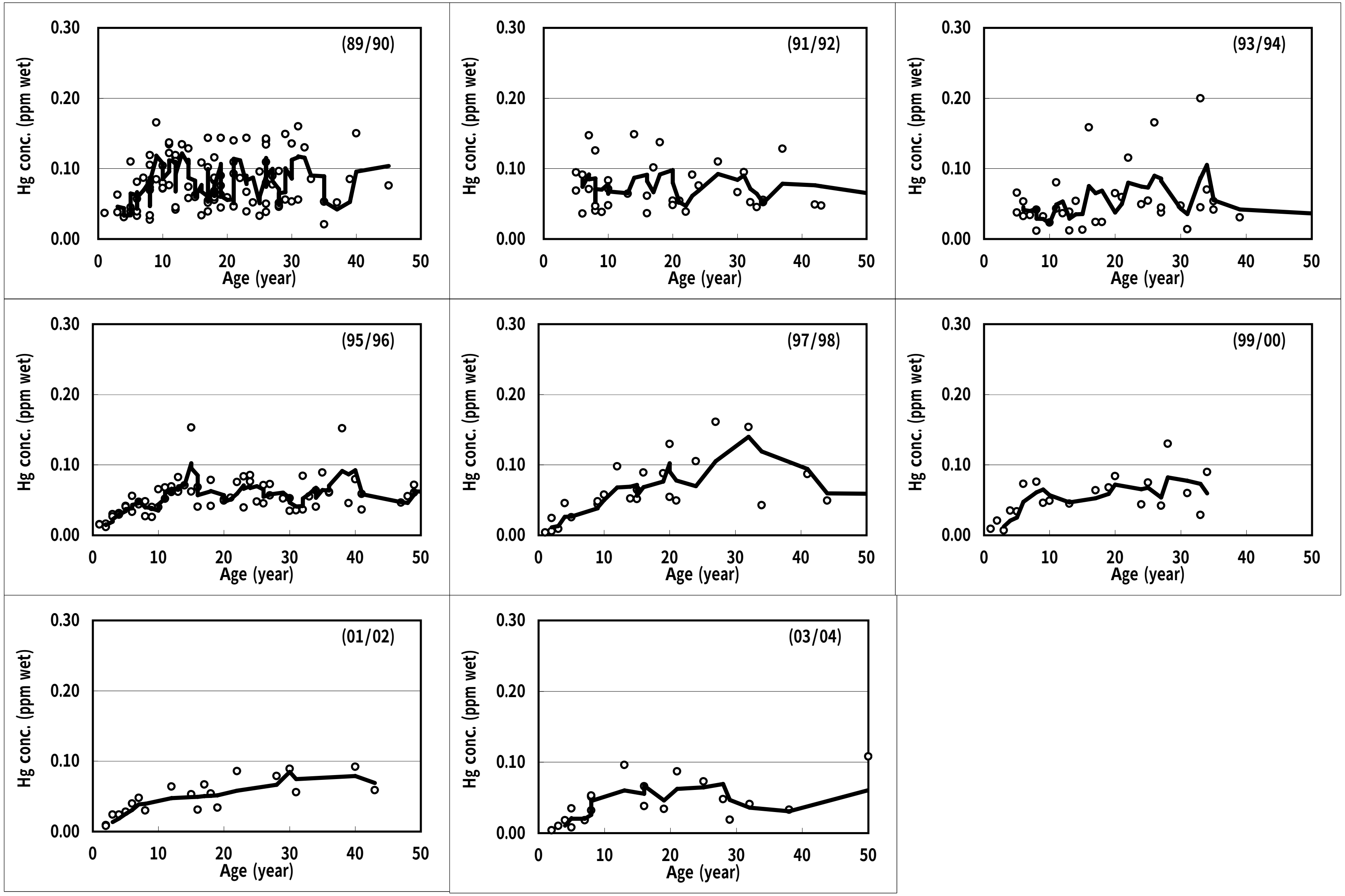


Fig. 2b Yearly relationships between age and hepatic Hg concentrations of Antarctic minke whales (males) from the Antarctic Area IV

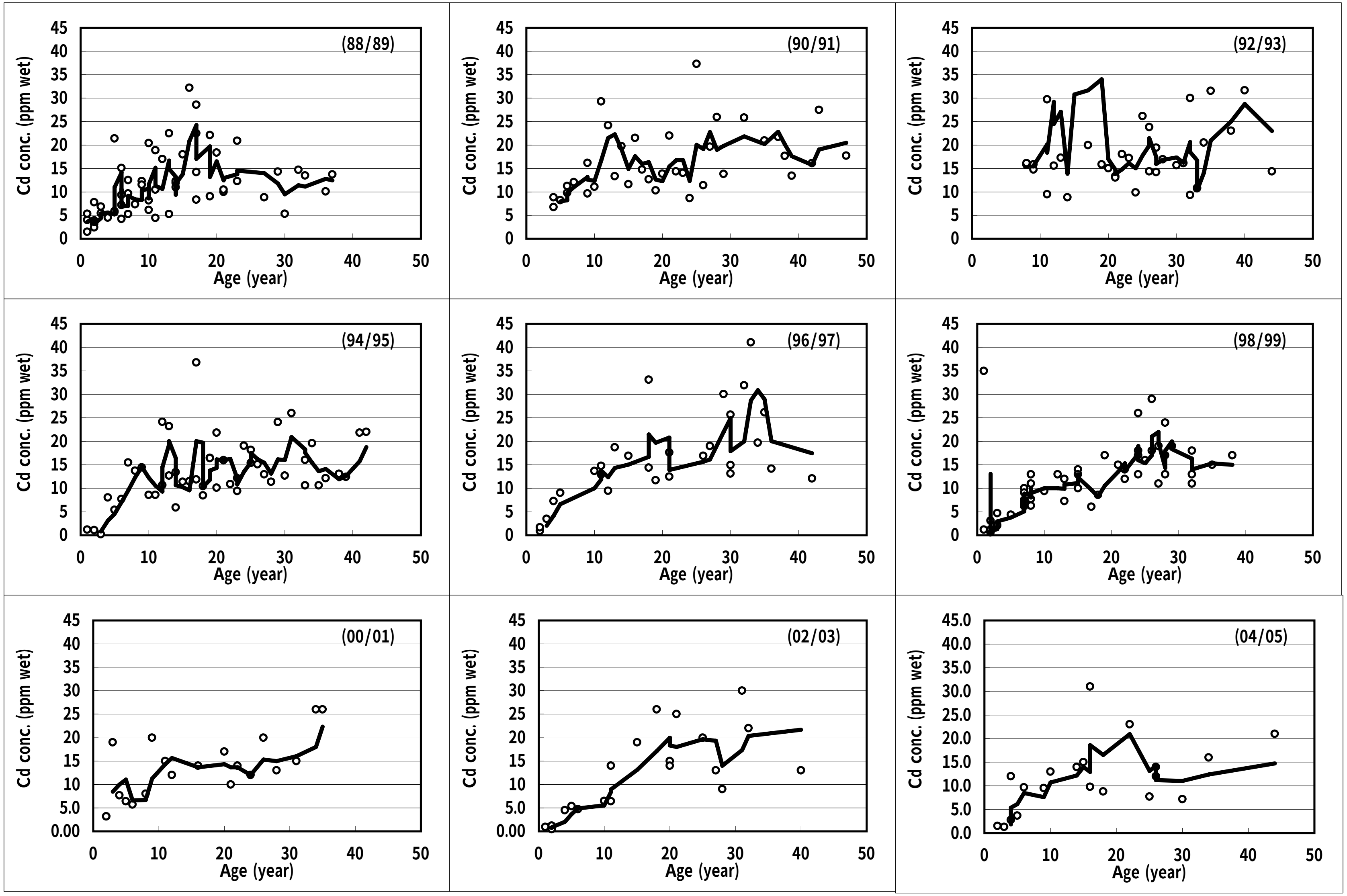


Fig. 3a Yearly relationships between age and hepatic Cd concentrations of Antarctic minke whales (males) from the Antarctic Area V.

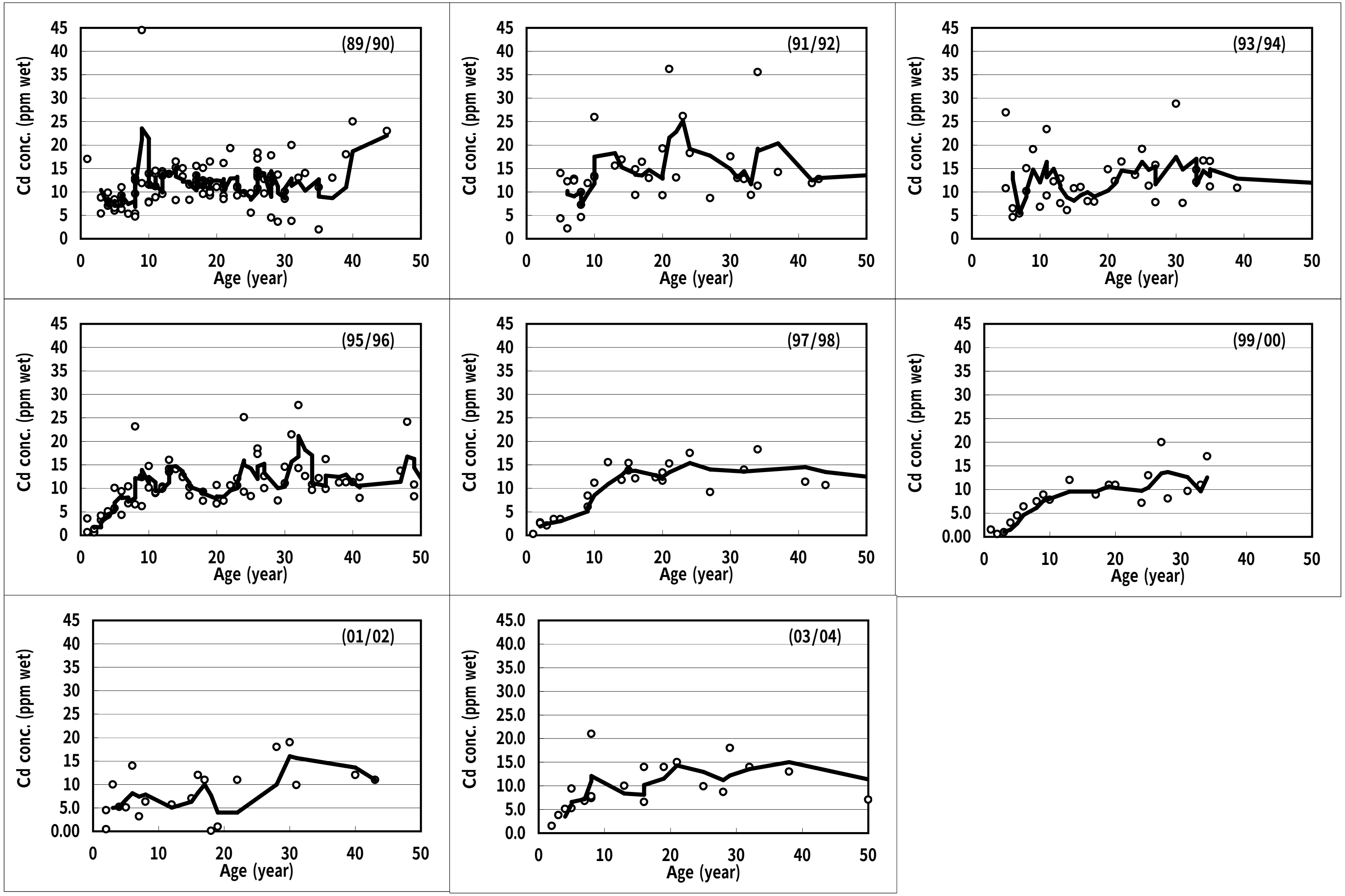
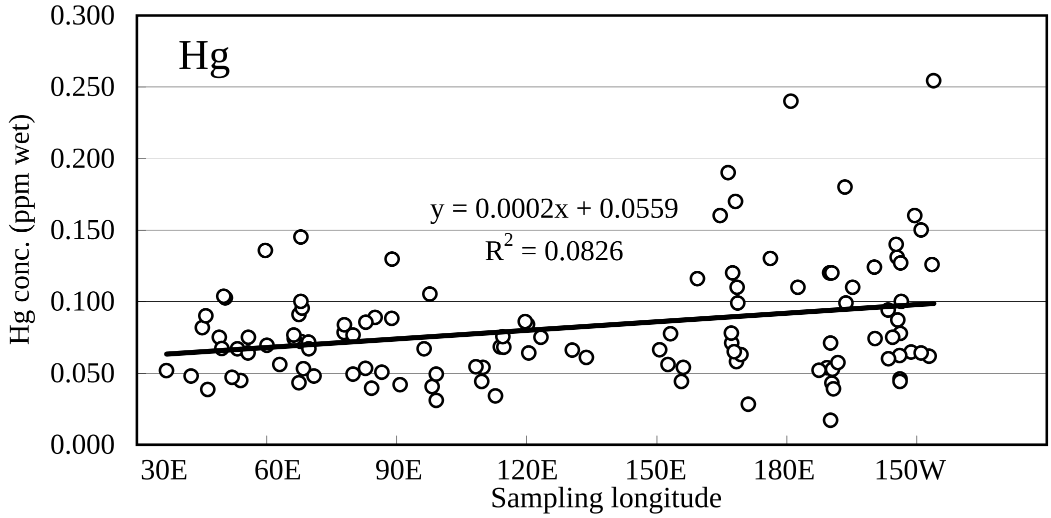


Fig. 3b Yearly relationships between age and hepatic Cd concentrations of Antarctic minke whales (males) from the Antarctic Area IV



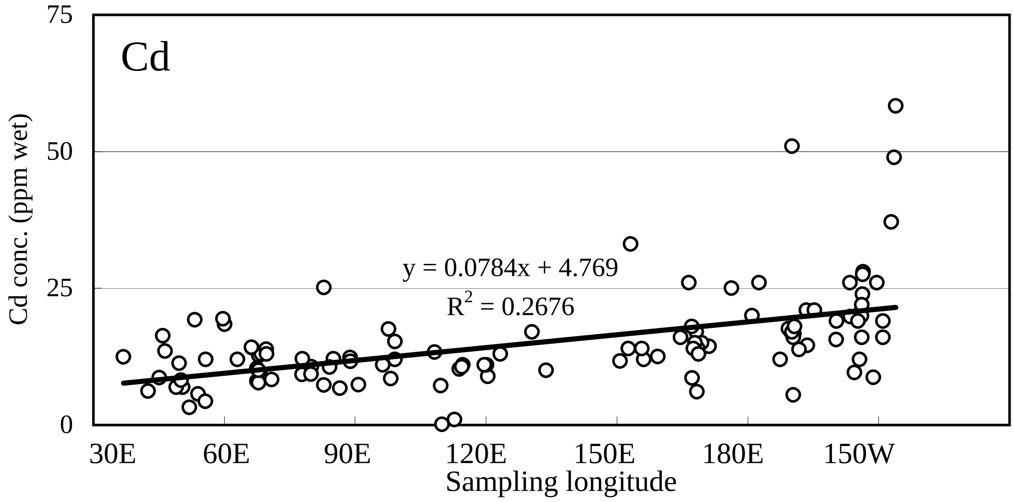
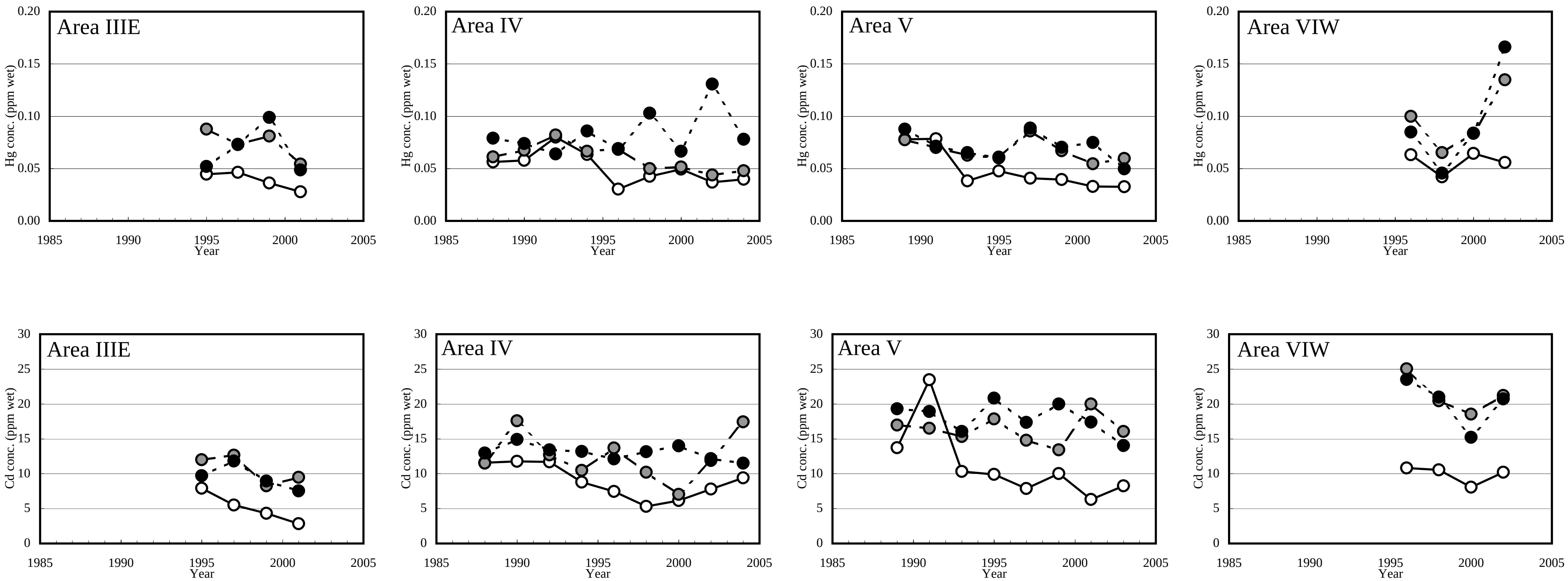


Fig. 4 Relatioships between hepatic Hg and Cd concentrations in Antarctic minke whales (16-25 years old) taken during 1995/96 and 2002/03 and their sampling longitude



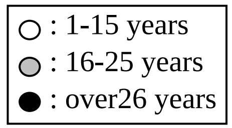


Fig. 5 Relationships between average concentrations of hepatic Hg and Cd in each year goup (1-15, 16-25, over 26 years) of Antarctic minke whalse from Area IIIE, IV, V and VIW and their sampling years

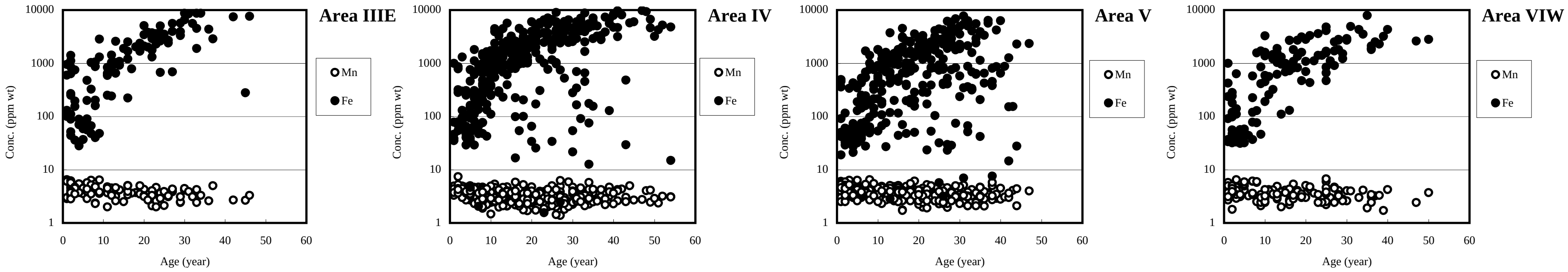


Fig. 6 Relationships between hepatic Mn and Fe concentrations and age of Antarctic minke whales from Areas IIIE, IV, V and VIW

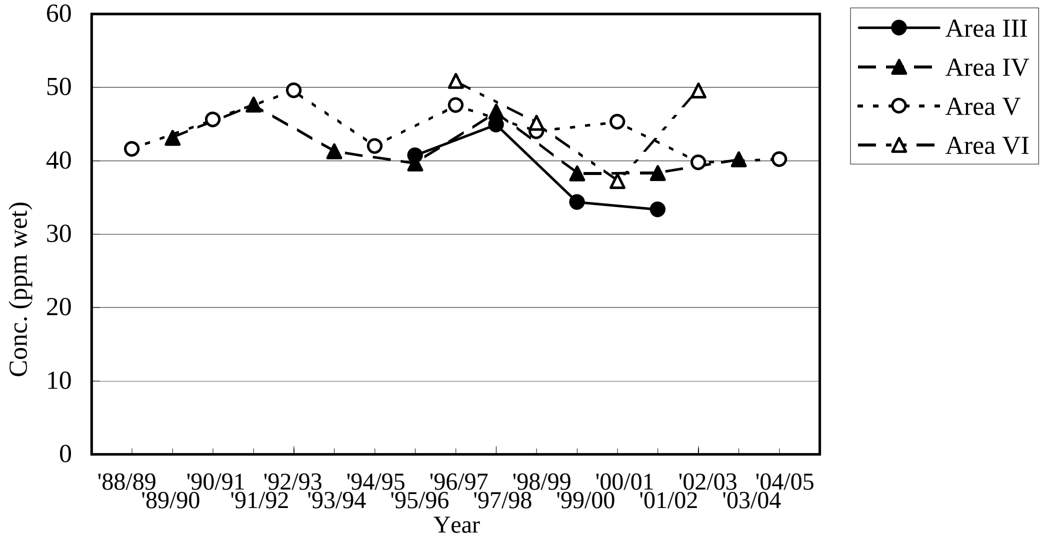


Fig. 7 Relationships between hepatic Zn levels and sampling year in Antarctic minke whales from Area IIIE, IV, V and VW

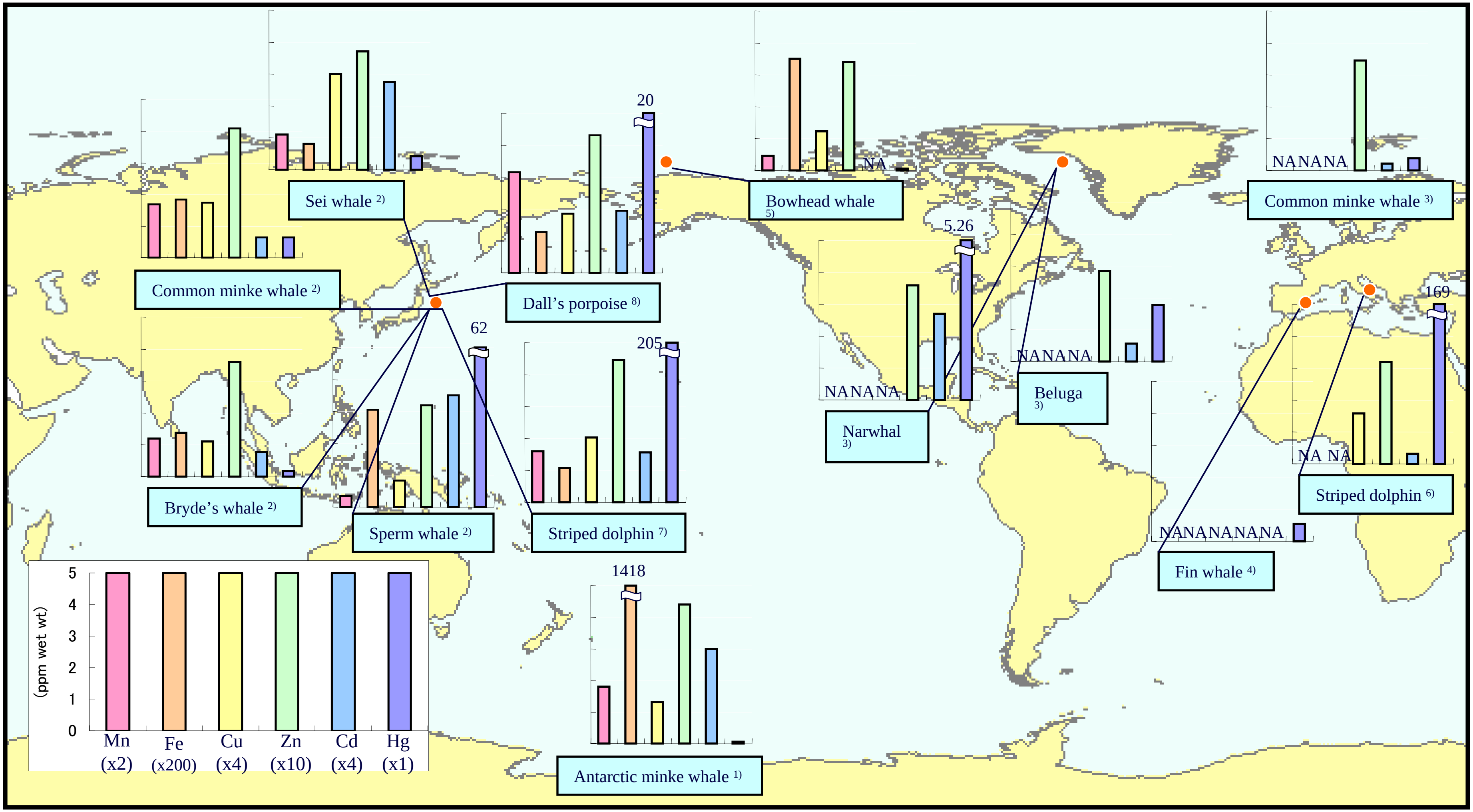


Fig. 8. Trace element levels in livers of Cetaceans.

1) This study (2006); 2) In preparation; 3) Hansen *et al.* (1990); 4) Sampera *et al.* (1993); 5) Krone *et al.* (1999) ; 6) Monaci *et al.* (1998); 7) Honda *et al.* (1983); 8) Fujise (1987)

NA: Not Analysis