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

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ABSTRACT

Concentrations of Mn, Fe, Ni, Cu, Zn, Cd, Hg, and Pb were determined in 750 livers of Antarctic minke whales (*Balaenoptera bonaerensis*) taken from the Antarctic Areas IV and V during 1988/89 and 2002/03 seasons and in 100 prey species (krill) from the Antarctic Areas III, IV, V and VI during 1989/90 and 1998/99 seasons. The ranges of concentrations for each element were, in μg/g wet wt: Mn, 1.4-7.4; Fe, 1.6-10591; Ni, <0.1-0.1; Cu, 3.1-10; Zn, 18-103; Cd, 0.10-66; Hg, 0.004-0.43, Pb, <0.3-0.5. Essential element, such as Mn, Cu and Zn, levels of Antarctic minke whales were comparable to those of other baleen and tooth whales in the Northern Hemisphere. Hepatic Hg levels of Antarctic minke whales were one order of magnitude lower than other baleen whales in the Northern Hemisphere, while their Fe levels were one order of magnitude higher than the other whales in the world. Hepatic Pb and Ni levels were almost less than the lower limit of determination levels or close to these. There were remarkably gender differences in hepatic Fe levels of Antarctic minke whales. Before 1995/96 season, positive correlation with age was not observed for Fe, Cd and Hg concentrations in livers and age. However, in recent years, these concentrations increased with age. Small changes of accumulation in Antarctic minke whales could be detected in early 1990's.

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

INTRODUCTION

In 1992, the International Whaling Commission (IWC) decided to established 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 developments) (IWC, 1995). However, because of difficulty to conduct all topics simultaneously, it agreed that initially two specialized items, a relationships between chemical pollutants and cetaceans, and the potential ecological effects on cetacean of climate change and ozone depletion were focussed (IWC, 1999). Then, the Committee decided to hold two workshops (IWC, 1999). The JARPA has 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 (Government of Japan, 1995). Some results on effects of environmental changes on cetacean in JARPA surveys were reported in the JARPA review meeting in 1997 (Fujise, 1997).

In that meeting, Fujise (1997) reported that although the organochlorine levels accumulated in livers of Antarctic minke whales are lower than those of other cetaceans in the Northern Hemisphere, a series of these studies suggested an increasing trend of accumulation levels of PCB's in the Antarctic minke whales in the Antarctic. Heavy metal studies suggest that yearly changes of accumulation levels 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, body fatness and blubber thickness of Antarctic minke whales (Zenitani *et al.*, 1997; Ohsumi *et al.*, 1997).

This paper reports trace element accumulation features, especially yearly changes, of livers of Antarctic minke whales from the Antarctic Areas IV and V during 1988/89 and 2002/03 seasons, and Antarctic krill, stomach contents of Antarctic minke whales, from the Areas III, IV, V and VI during 1989/90 and 1998/99 seasons. From viewpoint of age-related accumulation of trace elements, food availability changes in Antarctic minke whales were discussed.

MATERIALS AND METHODS

In order to this study, concentrations of Mn, Fe, Ni, Cu, Zn, Cd, Hg and Pb were determined for liver samples of 750 Antarctic minke whales taken from the Antarctic Areas IV and V during 1988/89 and 2002/03 seasons (Table 1) and stomach content samples (Antarctic krill: *Euphausia superba*) of 100 Antarctic minke whales taken from the Antarctic Areas III, IV, V and VI during 1989/90 and 1998/99 seasons (Table 2).

Liver and krill samples were digested in microwave (Milestone General: MLS1200mega) using nitric acid in a PTFE (Teflon) vessel (Okamoto, 1994). Mn, Fe, Ni, Cu, Zn, Cd and Pb were measured by inductively coupled plasma atomic emission spectrometry (Seiko Instruments Inc., SPS 1700R) and Hg were measured by cold vapor / atomic absorption spectrometry (Nippon Instruments Co. RA-2A) using external standard method. Concentrations of liver were given on wet weight basis and concentrations of krill were given on dry weight basis. Accuracy and precision of the methods were confirmed using bovine liver (BCR-CRM No. 185). Chemical analyses were performed by the Miura Institute of Environmental Science.

The differences between sexes and areas were assessed by Mann-Whitney U test, the relationships between concentrations of trace elements and age were assessed by Spearman rank correlation and temporal trend of trace element concentrations were assessed by simple linear regression analysis (Zar, 1999). These statistical analyses were executed by SPSS ver.11 for windows (SPSS Co. Ltd.).

RESULTS AND DISCUSSION

Accumulation levels

Table 3 shows the concentrations of trace elements in livers of Antarctic minke whales. While, Table 4 and Fig. 1 show the concentrations of trace elements in livers of baleen whales in the world as previously reported for comparison with our data. Mn, Fe, Cu, Zn, Cd and Hg were detected in almost the liver samples of Antarctic minke whales. Ni and Pb concentrations in all the liver samples of Antarctic minke whales were almost less than the lower limit of determination level. The ranges of concentrations for each element were, in μg/g wet wt: Mn, 1.4-7.4; Fe, 1.6-10591; Ni, <0.1-0.1; Cu, 3.1-10; Zn, 18-103; Cd, 0.10-66; Hg, 0.004-0.43, Pb, <0.3-0.5.

Hepatic essential element, such as Mn, Cu and Zn, levels of Antarctic minke whales were comparable to those of other cetaceans in the Northern Hemisphere. Hepatic Fe levels of Antarctic minke whales were one order of magnitude higher than those of other cetaceans in the Northern Hemisphere. Hepatic Pb and Ni levels of the baleen and tooth whales, except for striped whales, were almost less than the lower limit of determination level or close to these.

Hepatic Cd levels were constant in baleen and tooth whales in the world and Cd levels of Antarctic minke whales were classified into higher categories in analogue with sei and sperm whales from the western North Pacific and narwhals from the near Greenland. In general, it is known that hepatic Hg levels of baleen whales are lower than those of tooth whales (Honda *et al.*, 1983; Law, 1996). 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 and fin whales from the Mediterranean, and were similar to those of bowhead whales from Arctic. Therefore, accumulation feature of trace elements in Antarctic minke whales is comparatively higher Fe level and lower Hg level in the liver.

Temporal and spatial trends of trace element concentrations in stomach contents

Table 5 shows the concentrations of trace elements in Antarctic krill contained in a first stomach of Antarctic minke whales from the Antarctic Areas III, IV, V and VI during 1989/90 and 1998/99 seasons. Mn, Fe, Ni, Cu, Zn, Cd and Hg were detected in almost the krill samples. Pb concentrations in all the krill samples were almost less than the lower limit of determination level.

The concentrations of Ni, Cu and Cd in Antarctic krill were higher than those of krill in the North Pacific (in preparation), however the concentrations in the Mn, Fe, Zn and Hg were reverse (Tables 5 and 6). Mn and Zn concentrations of Antarctic krill in the Areas III and IV were significantly higher than those in the Areas V and VI ($p<0.01$), and no geographical deference was observed for other elements.

Figures. 2a and 2b show the relationships between research years and trace element concentrations in Antarctic krill from the Areas III, IV, V and VI. Mn, Ni, Zn and Cd levels in Antarctic krill from the Areas III and IV were significantly decreased with years, while Hg levels were reverse (Table 7). Cu levels in Antarctic krill from the Areas V and VI were significantly increased with years, while Hg levels were reveres (Table 7). It is unclear that these yearly trends were inconsistent between both areas during the research period.

Gender differences

Gender differences in hepatic concentrations of trace elements were examined in the present study using Antarctic minke whales taken from the Area V in 1988/89 and 1998/99 seasons. Hepatic Fe, Zn, Cd and Hg concentrations of Antarctic minke whales in 1988/89 seasons were significantly difference between sexes and Fe and Hg concentrations of Antarctic minke whales in 1998/99 seasons were significantly difference between sexes ($p<0.05$, Table 8, Figs. 3a and 3b). Hepatic Fe concentrations of males were clearly increased with age, while the relationships between that of females and age were unclear. Age trends of Zn and Cd concentrations in each sex were similar.

In general, gender differences of most trace element levels in wildlife are few compared with lipophilic compounds, such as PCBs and DDTs, due to the small transit of those between mother and calf. However, hepatic Fe levels in males of Antarctic minke whales are about 4 to 5 times those in females. The results were consistent in previous report of Antarctic minke whales (Honda *et al.*, 1987) Studies of human and rodents showed Fe level in the body is decreased by pregnancy, lactation, Fe deprivation in the food and some disease (Wada, 1985; Bacon, 1998). Temporal and spatial differences of Fe level in Antarctic krill were not observed and critical disease related with Fe toxicity has not observed in JARPA surveys. Consequently, gender difference of their Fe levels may be attributable to the biological process.

Temporal trend

Due to the gender differences among some hepatic trace elements of Antarctic minke whales, the relationships between those of only mature males and research years are plotted in Fig. 4. All the trace element levels in livers of Antarctic minke whales were less varied during research years. It is necessary to carefully examine the yearly changes of the relationships between the trace element levels and age in each year in order to some trace elements, such as Fe, Hg and Cd, levels in which whales have age-related accumulation.

Age trend

Figure 5 represents the relationships between hepatic trace element concentrations and age in males of Antarctic minke whales taken from the Areas IV and V. Table 9 shows significant correlation between hepatic trace element concentrations and age in males of Antarctic minke whales taken from the Areas IV and V ($p<0.05$). Significant negative correlations were observed in cases of hepatic Mn concentrations of Antarctic minke whales in the Areas IV (1989/90, 1995/96 and 1999/00 seasons) and V (1988/89, 1994/95, 1998/99 and 2000/01 seasons). Significant negative correlations between hepatic Cu (1988/89 and 1989/90 seasons) and Zn (1989/90 season) concentrations, and their age of Antarctic minke whales were observed, while significant positive correlation between hepatic Zn concentrations and their age in 1996/97 season from the Area V. And also, significant positive correlation between hepatic Fe (1988/89, 1989/90 and 1995/96-2002/03 seasons), Cd (1988/89-1990/91, 1994/95-2002/03 seasons) and Hg (1988/89, 1994/95-2002/03 seasons), and their age of Antarctic minke whales were observed.

It has been reported that Fe, Cd and Hg levels increase with age in cetaceans (Denton *et al.*, 1980; Honda *et al.*, 1983; Mackey *et al.*, 1996; Law, 1996). However, in the case of Antarctic minke whales there are no evidences that Hg increased with their age, while it was suggested that the increase of Hg intake is perhaps due to the increase of food intake (Honda *et al.*, 1987). Furthermore, Fujise (1997) reported that it was found that hepatic Hg levels of Antarctic minke whales taken from JARPA surveys until 1994/95 season increased with their age and suggested that possible environmental changes such as changes of food availability. This hypothesis is supported by results in this study that temporal trends of trace element levels in Antarctic krill from the Areas IV and V are not observed.

Figures 6a-d represent plots between hepatic concentrations of age-related elements, Fe, Cd, and Hg, of Antarctic minke whales from the Areas IV and V, and their age. Hepatic Cd levels of Antarctic minke whales below 10 years during 1989/90 and 1993/94 seasons were higher than those during 1995/96 and 2001/02 seasons in the Area IV. Hepatic Hg levels of Antarctic minke whales below 10 years from 1989/90 to 1993/94 seasons were higher than those in later years in the Area IV, and those from 1988/89 to 1992/93 seasons were higher than those in later years in the Area V. Their slopes are gradually moderate with research year after the middle 1990's in both areas.

Fujise (1997) suggested that a possibility that Hg intake started to decrease in early 1980's with JARPA data until 1994/95 season. We conform these hypotheses. Furthermore, Antarctic minke whales taken in 1992/93, 1993/94 and 1994/95 seasons indicated interesting features, as follows; a) Hepatic Fe levels of all age individuals into this period were very lower than those of the other individuals, and b) Hepatic Cd and Hg levels of individuals below 10 years into this period were higher than those during the other periods. Gender difference was observed in hepatic Fe level, suggested biological process such as breeding. It is reported that hepatic Fe levels of Adelie penguins are increased into starvation (Honda *et al.*, 1986). These results could suggest that there were some events related other biological and ecological process in this period.

CONCLUSION

Yearly changes of trace element levels in Antarctic krill were constant in the Areas III, IV, V and VI. Essential element, such as Mn, Cu, Zn, and Cd levels in livers of Antarctic minke are similar to the other cetaceans in the Northern Hemisphere. However, hepatic Hg level in Antarctic minke whales was extremely lower than those in the other cetaceans, while Fe level was reverse. Accumulation pattern of Cd and Hg with age are consistent with previous JARPA works for the most cases. These phenomenons reflect decreasing of food availability in recent years. Small changes could be observed in accumulation pattern of Fe in Antarctic minke whales with age in early 1990's. This phenomenon may reflect changes of some biological and ecological process, such as specific metabolism and food intake. Further monitoring is required to examine this phenomenon. We should continuously monitor the trace element levels in krill, as well as in the cetacean bodies, to understand the effects of environmental changes on Antarctic minke whales.

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Table 1. Sample list of Antarctic minke whales from the Antarctic Areas IV and V.

Year	Area	*n* (sex)	Mean body length (m)
1988/89	Area V	68M	7.91
		76F	8.22
1989/90	Area IV	100M	8.40
		8F	8.53
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
		1F	9.06
1995/96	Area IV	50M	8.17
1996/97	Area V	30M	7.95
1997/98	Area IV	30M	7.84
1998/99	Area V	68M	7.74
		46F	7.57
1999/00	Area IV	20M	7.94
2000/01	Area V	20M	7.78
2001/02	Area IV	20M	7.91
2002/03	Area V	20M	7.84

Table 2. Sample list of prey species (Antarctic krill) from the stomach contents of Antarctic minke whales in the Antarctic Areas III, IV, V and V.

Year	Area	*n* (sex)	Mean body length (m)
1989/90	IV	9M	7.69
		1F	9.70
1990/91	V	3M	8.57
		7F	8.80
1991/92	IV	7M	8.55
		3F	9.00
1992/93	V	6M	8.61
		4F	8.70
1993/94	IV	4M	8.17
		6F	9.01
1994/95	V	7M	8.45
		3F	8.73
1995/96	III	10M	8.09
1996/97	V	2M	7.91
		1F	7.01
	VI	6M	8.18
		1F	8.56
1997/98	III	2M	8.23
		3F	9.25
	IV	4M	7.87
		1F	8.57
1998/99	V	7M	8.58
		3F	9.25

Table 3. Trace element concentrations (μg/g wet wt.) in the liver of Antarctic minke whales from Antarctic Areas IV and V during 1988 and 2003 seasons.

Area	Year	*n*	Mn	Fe	Ni	Cu	Zn	Cd	Hg	Pb
IV	1989/90	108	2.8	2394	<0.1	5.0	45	13	0.080	<0.3
			(1.4 - 4.4)	(29 - 7900)	(-)	(3.1 - 8.8)	(30 - 92)	(2.0 - 45)	(0.012 - 0.17)	(-)
	1991/92	36	3.8	1383	<0.1	5.8	48	14	0.074	<0.3
			(2.2 - 5.0)	(1.6 - 8097)	(-)	(3.6 - 8.6)	(33 - 69)	(2.2 - 36)	(0.036 - 0.15)	(-)
	1993/94	36	3.6	794	<0.1	5.0	41	13	0.054	<0.3
			(2.2 - 6.2)	(2.5 - 6111)	(-)	(3.4 - 8.1)	(28 - 59)	(4.6 - 29)	(0.012 - 0.20)	(-)
	1995/96	70	3.4	3077	0.1	5.1	40	11	0.055	0.4
			(2.0 - 4.9)	(50 - 9797)	(<0.1 - 0.1)	(3.2 - 8.3)	(25 - 64)	(0.60 - 28)	(0.012 - 0.15)	(<0.3 - 0.5)
	1997/98	30	4.3	2054	<0.1	6.0	46	9.4	0.059	<0.3
			(2.7 - 7.4)	(40 - 10591)	(-)	(4.6 - 8.3)	(30 - 67)	(0.29 - 18)	(0.004 - 0.16)	(-)
	1999/00	20	3.1	1624	<0.1	4.5	38	8.5	0.054	<0.3
			(2.1 - 5.2)	(35 - 5100)	(-)	(3.5 - 6.2)	(28 - 65)	(0.58 - 20)	(0.007 - 0.13)	(-)
	2001/02	20	3.3	1096	<0.1	4.8	38	8.3	0.049	<0.3
			(2.3 - 5.2)	(39 - 4700)	(-)	(3.7 - 7.2)	(28 - 63)	(0.10 - 19)	(0.008 - 0.092)	(-)
	total	320	3.3	2089	0.1	5.1	43	12	0.065	0.4
			(1.4 - 7.4)	(1.6 - 10591)	(<0.1 - 0.1)	(3.1 - 8.8)	(25 - 92)	(0.10 - 45)	(0.004 - 0.20)	(<0.3 - 0.5)
V	1988/89	144	3.6	760		5.3	43	13	0.077	
			(1.8 - 6.0)	(26 - 6380)	(-)	(3.4 - 9.3)	(24 - 103)	(0.30 - 63)	(0.006 - 0.35)	(-)
	1990/91	36	3.8	1047	<0.1	5.5	46	16	0.076	<0.3
			(2.7 - 6.1)	(32 - 5665)	(-)	(4.1 - 7.4)	(29 - 80)	(6.8 - 37)	(0.036 - 0.16)	(-)
	1992/93	36	3.8	520	<0.1	5.8	50	20	0.079	<0.3
			(2.5 - 5.7)	(2.8 - 2652)	(-)	(4.1 - 8.0)	(33 - 95)	(8.8 - 66)	(0.027 - 0.18)	(-)
	1994/95	50	3.6	699	<0.1	4.7	42	14	0.088	<0.3
			(2.2 - 6.5)	(51 - 2524)	(-)	(3.6 - 7.4)	(28 - 68)	(0.22 - 37)	(0.015 - 0.24)	(-)
	1996/97	30	4.2	1312	<0.1	5.9	47	16	0.079	<0.3
			(2.9 - 6.3)	(15 - 5505)	(-)	(4.3 - 7.9)	(18 - 71)	(0.92 - 41)	(0.007 - 0.27)	(-)
	1998/99	114	3.5	901	<0.1	4.9	44	10	0.062	<0.3
			(2.0 - 5.9)	(3.7 - 6800)	(-)	(3.4 - 10)	(27 - 99)	(0.49 - 45)	(0.005 - 0.43)	(-)
	2000/01	20	3.7	1205	<0.1	4.3	37	12	0.074	<0.3
			(2.4 - 6.5)	(41 - 4300)	(-)	(3.3 - 5.3)	(27 - 64)	(0.10 - 26)	(0.010 - 0.22)	(-)
	2002/03	20	3.3	1712	<0.1	4.1	40	13	0.086	<0.3
			(2.1 - 4.6)	(32 - 7700)	(-)	(3.1 - 8.0)	(32 - 51)	(0.43 - 30)	(0.006 - 0.27)	(-)
	total	450	3.6	892	<0.1	5.1	44	13	0.075	<0.3
			(1.8 - 6.5)	(3 - 7700)	(-)	(3.1 - 10)	(18 - 103)	(0.10 - 66)	(0.005 - 0.43)	(-)

Table 4. Trace element concentrations (μg/g wet wt) in the liver of cetaceans.

Species	*n*	Mn	Fe	Ni	Cu	Zn	Cd	Hg	Pb	year	Area (Ref.)
Baleen whales											
Antarctic minke whale	1025	3.6	1418	0.2	5.2	44	12	0.069	0.4	1988-2003	Antarctic
		(1.4 - 7.4)	(1.6 - 10591)	(<0.1 - 0.3)	(2.8 - 14)	(18 - 103)	(0.089 - 66)	(0.004 - 0.46)	(<0.3 - 0.7)		(This study)
Common minke whale	738	3.4	368	0.2	7.0	41	2.6	0.65	0.5	1994-2002	NW Pacific
		(1.1 - 9.5)	(2.5 - 4108)	(<0.1 - 0.4)	(2.0 - 34)	(21 - 82)	(0.010 - 9.5)	(0.001 - 4.3)	(<0.3 - 2.0)		(In preparation)
Common minke whale	17					34.5*	0.90*	0.39*		1980	W Greenland
		(-)	(-)	(-)	(-)	(26.4 - 48.0)	(0.50 - 1.45)	(0.14 - 2.68)	(-)		(Hansen *et al.*, 1990)
Bryde's whale	143	2.4	275	<0.1	4.4	36	3.1	0.18	<0.3	2000-2	NW Pacific
		(1.3 - 5.3)	(2.6 - 2000)	(-)	(2.6 - 11)	(21 - 54)	(0.030 - 9.0)	(0.011 - 1.1)	(-)		(In preparation)
Sei whale	39	2.2	162	<0.1	12	37	11	0.43	<0.3	2002	NW Pacific
		(1.5 - 3.2)	(31 - 500)	(-)	(5.6 - 50)	(22 - 68)	(3.1 - 25)	(0.07 - 1.6)	(-)		(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 - 0.8)	(-)		(Sanpera *et al.*, 1993)
Bowhead whale	20	0.93	700		4.9	34		0.07	0.04	1994	Alaska (Barrow)
		(0.4 - 2.0)	(135 - 2740)	(-)	(2.8 - 8.0)	(22 - 61)	(-)	(0.02 - 0.11)	(<0.03 - 0.04)		(Krone *et al.*, 1999)
Toothed whales											
Sperm whale	13	0.7	610	<0.1	3.3	32	14	62	<0.3	2000-2	NW Pacific
		(0.40 - 1.0)	(33 - 1700)	(-)	(2.1 - 5.1)	(25 - 39)	(4.0 - 31)	(3.2 - 250)	(-)		(In preparation)
beluga	40					28.4*	2.21*	1.77*		1984-5	W Greenland
		(-)	(-)	(-)	(-)	(22 - 45)	(<0.015 - 8.54)	(0.07 - 30.8)	(-)		(Hansen *et al.*, 1990)
Narwhal	48-90					35.9*	10.8*	5.26*		1984-5	W Greenland
		(-)	(-)	(-)	(-)	(13.3 - 67.7)	(<0.015 - 73.7)	(<0.005 - 42.8)	(-)		(Hansen *et al.*, 1990)
Striped dolphin	37-46				6.3*	32*	1.3*	169*		1987-94	Italy
		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)		(Monaci *et al.*, 1998)
Striped dolphin	20-30	3.18	215	0.22	8.09	44.5	6.26	205	0.22	1978-80	NW Pacific
		(1.30 - 6.71)	(55.8 - 95.5)	(0.1 - 0.5)	(3.57 - 15.2)	(27 - 109)	(0.04 - 11.1)	(1.7 - 485)	(0.03 - 0.64)		(Honda *et al.*, 1983)
Dall's porpoise	26M	6.31	254		7.42	43.2	7.81	20.0		1982-84	NW Pacific
		(4.03 - 7.70)	(106 - 456)	(-)	(1.29 - 17.4)	(32 - 54)	(2.62 - 17.8)	(6.52 - 49)	(-)		(Fujise, 1987)

*: Median

Table 5. Trace element concentrations (μg/g dry wt) of Antarctic krill in Areas III, IV, V and VI during1989 and 1999 sesons.

Area	year	Mn	Fe	Ni	Cu	Zn	Cd	Hg	Pb
Areas III	1989/90	3.5	28	1.5	47	54	3.2	0.029	<2.1
IV		(2.5 - 4.6)	(11 - 100)	(0.8 - 2.3)	(16 - 85)	(44 - 60)	(1.4 - 8.3)	(0.018 - 0.051)	(-)
	1991/92	3.2	72	1.3	43	49	3.0	0.020	<2.1
		(1.9 - 4.3)	(4.9 - 420)	(0.9 - 2.2)	(25 - 58)	(38 - 58)	(0.42 - 5.5)	(0.01 - 0.031)	(-)
	1993/94	2.8	21	1.4	51	47	1.6	0.025	<2.1
		(1.9 - 4.5)	(7.6 - 89)	(1.0 - 2.1)	(26 - 77)	(36 - 56)	(0.51 - 2.7)	(0.014 - 0.048)	(-)
	1995/96	2.8	11	0.74	50	46	0.62	0.028	<2.1
		(2.5 - 3.3)	(8.5 - 18)	(0.6 - 0.9)	(20 - 76)	(39 - 50)	(0.32 - 1.6)	(0.021 - 0.037)	(-)
	1997/98	2.8	18	0.96	60	48	1.7	0.037	<2.1
		(2.4 - 3.3)	(9.0 - 31)	(0.6 - 1.3)	(46 - 82)	(40 - 65)	(0.71 - 4.4)	(0.026 - 0.054)	(-)
	total	3.0	30	1.2	50	49	2.0	0.028	<2.1
		(1.9 - 4.6)	(4.9 - 420)	(0.6 - 2.3)	(16 - 85)	(36 - 65)	(0.32 - 8.3)	(0.010 - 0.054)	(-)
Areas V	1990/91	2.5	25	1.4	39	48	2.5	0.037	<2.1
VI		(1.3 - 3.4)	(11 - 73)	(<0.5 - 2.4)	(1.6 - 63)	(40 - 74)	(0.20 - 7.1)	(0.018 - 0.066)	(-)
	1992/93	2.8	31	1.0	42	44	2.2	0.029	<2.1
		(2.1 - 3.7)	(9.6 - 79)	(0.7 - 1.5)	(23 - 55)	(38 - 52)	(0.47 - 7.5)	(0.02 - 0.043)	(-)
	1994/95	2.2	26	0.9	35	42	1.1	0.027	<2.1
		(1.5 - 2.9)	(5.2 - 100)	(<0.5 - 1.4)	(12 - 86)	(28 - 49)	(0.15 - 2.6)	(0.018 - 0.041)	(-)
	1996/97	2.5	17	1.3	42	45	1.6	0.026	<2.1
		(1.8 - 2.9)	(5.5 - 64)	(0.7 - 2.0)	(22 - 83)	(34 - 55)	(0.30 - 4.2)	(0.017 - 0.045)	(-)
	1998/99	2.8	17	1.4	66	45	2.1	0.025	<2.1
		(2.4 - 3.7)	(7.9 - 43)	(0.8 - 2.3)	(20 - 98)	(37 - 54)	(0.78 - 4.3)	(0.014 - 0.046)	(-)
	total	2.6	23	1.2	45	45	1.9	0.029	<2.1
		(1.3 - 3.7)	(5.2 - 100)	(0.25 - 2.4)	(1.6 - 98)	(28 - 74)	(0.15 - 7.5)	(0.014 - 0.066)	(-)

Table 6. Trace element concentrations (μg/g dry wt) of krill from the western North Pacific during 1994 and 1996 JARPN surveys (in preparation).

	Mn	Fe	Ni	Cu	Zn	Cd	Hg	Pb
Ave.±S.D.	4.0 ± 1.2	43 ± 55	0.8	28 ± 12	83 ± 21	0.64 ± 0.26	0.05 ± 0.017	3
(Range)	(2.2 - 6.0)	(8.6 - 200)	(<0.7 - 0.8)	(12 - 51)	(49 - 120)	(0.26 - 0.90)	(0.03 - 0.084)	(<2 - 3)
n	11	11	1	11	11	11	11	1

Table 7 Simple linear correlation coffecients and provability between research years and trace element concentrations in the krills involved the stomach contents of Antarctic minke whales.

	Mn	Fe	Ni	Cu	Zn	Cd	Hg
Areas III and IV	**(-)		***(-)		*(-)	**(-)	*(+)
Areas V and VI				*(+)			*(-)

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

+: positive correlation, -: negative correlation

Table 8. Hepatic trace element concentrations (μg/g wet wt.) and gender difference of mature Antarctic minke whales in 1988/89 and 1998/99 seasons.

			Mn	Fe	Cu	Zn	Cd	Hg
1988/89	mature male	Ave.	3.5	1418	5.1	41	13	0.077
		Range	(1.8 - 5.2)	(28 - 6170)	(3.4 - 7.4)	(26 - 60)	(4.2 - 32)	(0.023 - 0.35)
		n	44	44	44	44	44	44
	mature female	Ave.	3.5	378	5.3	48	17	0.095
		Range	(2.2 - 5.0)	(26 - 2630)	(4.0 - 9.3)	(35 - 103)	(7.6 - 63)	(0.016 - 0.27)
		n	51	51	51	51	51	51
	Significant difference			***		**	*	*
1998/99	mature male	Ave.	3.6	1343	4.8	43	11	0.072
		Range	(2.1 - 5.9)	(3.7 - 6800)	(3.4 - 8.8)	(29 - 91)	(0.60 - 35)	(0.008 - 0.43)
		n	68	68	68	68	68	68
	mature female	Ave.	3.3	242	5.2	45	9.3	0.048
		Range	(2.0 - 5.2)	(23 - 1900)	(3.6 - 10)	(27 - 99)	(0.49 - 45)	(0.005 - 0.16)
		n	47	47	47	47	47	47
	Significant difference			***				*

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

Table 9 Significant correlationships between age and hepatic trace element concentrations in Antarctic minke whales.

Area	Year	Mn	Fe	Cu	Zn	Cd	Hg
IV	1989/90	**(-)	***(+)	**(-)	**(-)	*(+)	
	1991/92						
	1993/94						
	1995/96	**(-)	***(+)			***(+)	***(+)
	1997/98		***(+)			**(+)	**(+)
	1999/00	*(-)	***(+)			***(+)	*(+)
	2001/02		*(+)			*(+)	***(+)
V	1988/89	**(-)	***(+)	*(-)		***(+)	**(+)
	1990/91					**(+)	
	1992/93						
	1994/95	***(-)				**(+)	***(+)
	1996/97		*(+)		*(+)	***(+)	*(+)
	1998/99	**(-)	***(+)			***(+)	***(+)
	2000/01	**(-)	***(+)			**(+)	**(+)
	2002/03		***(+)			***(+)	***(+)

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

+: positive correlation, -: negative correlation

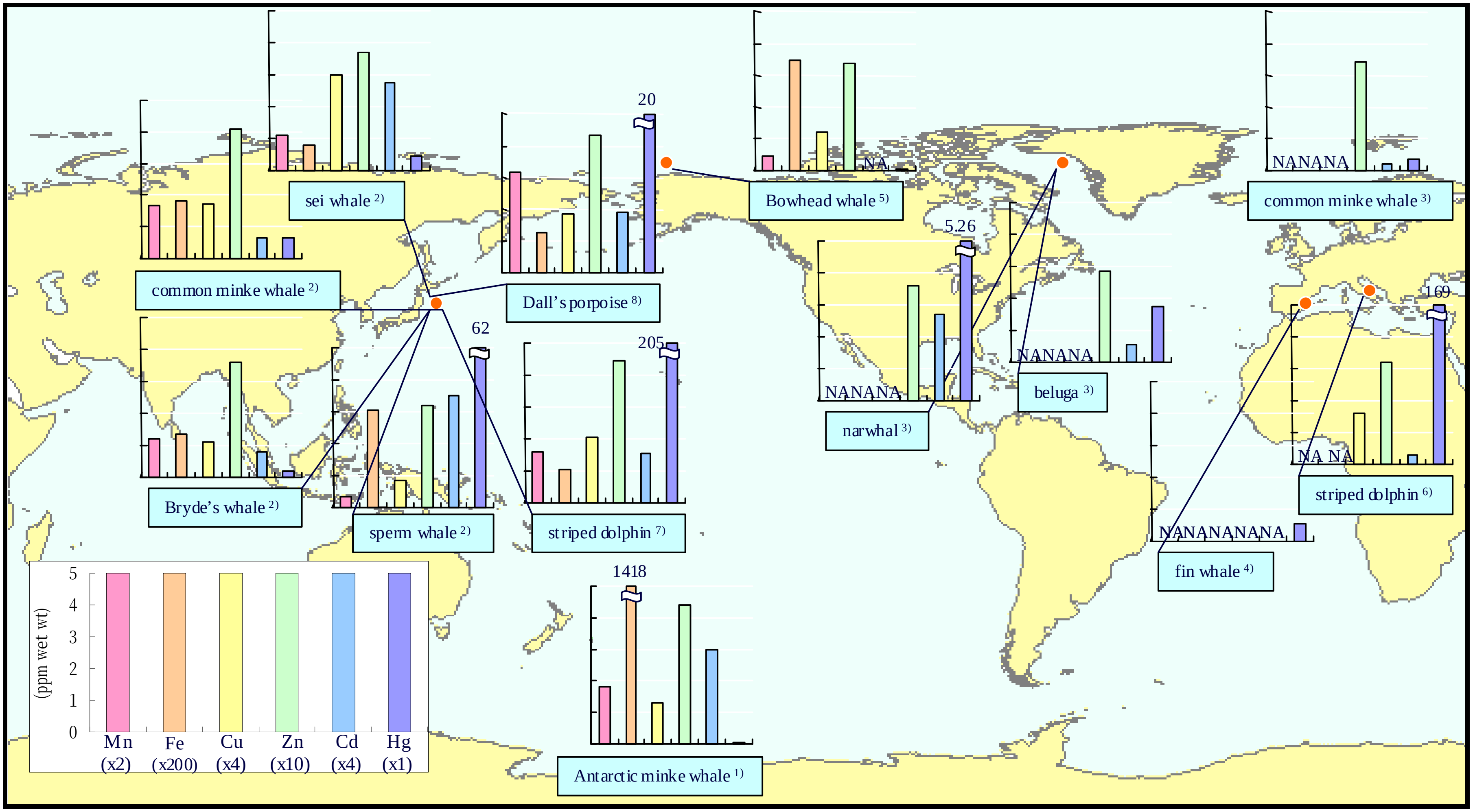

Fig. 1. Trace element Levels in Livers of Cetaceans.

1) This study (2005); 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

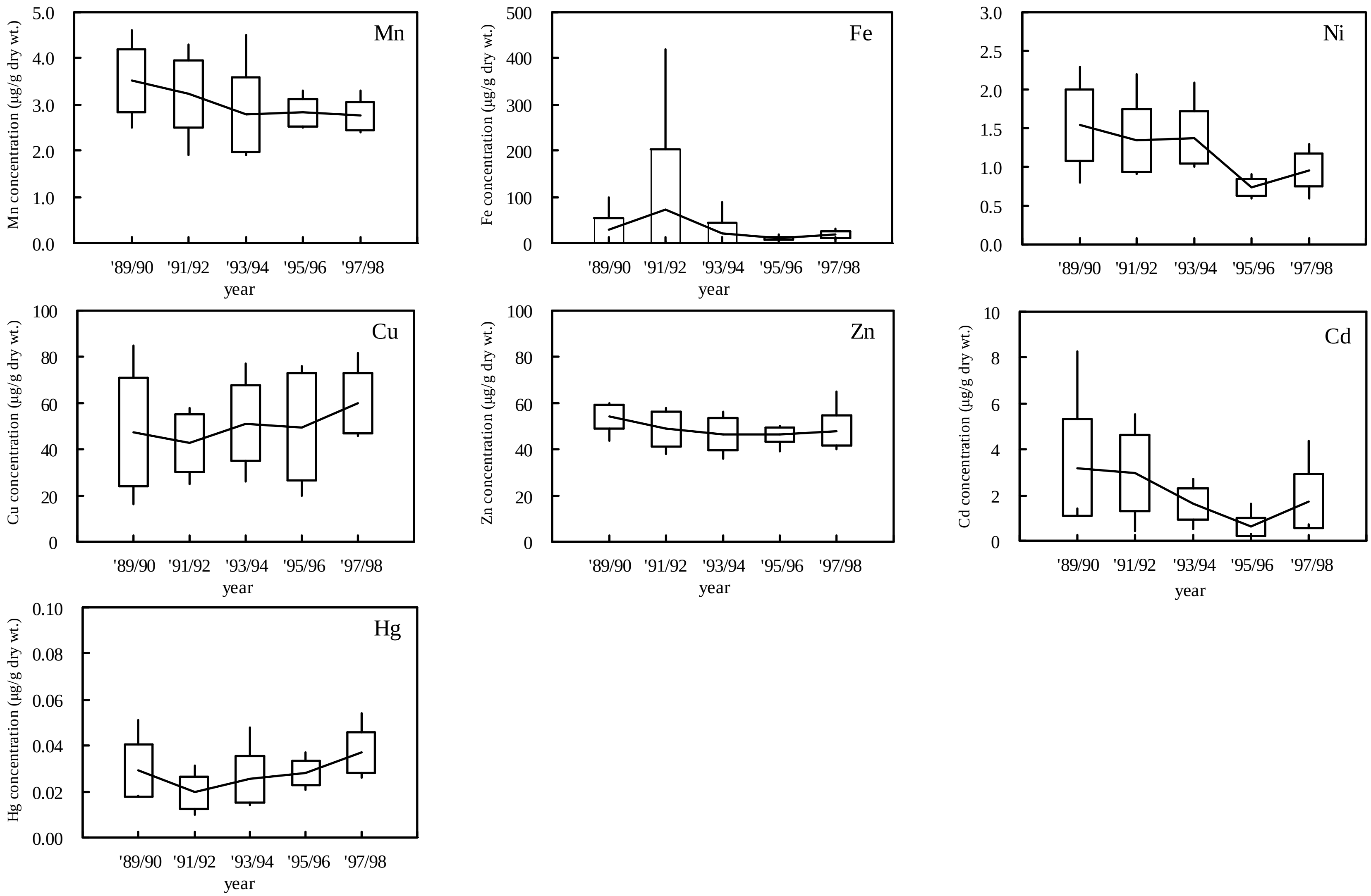

Fig. 2a. Temporal trend of trace element concentrations (µg/g dry wt.) of Antarctic krill from Areas III and IV during 1989/90 and 1997/98 seasons.
*: Siginificantly different ($p<0.05$)

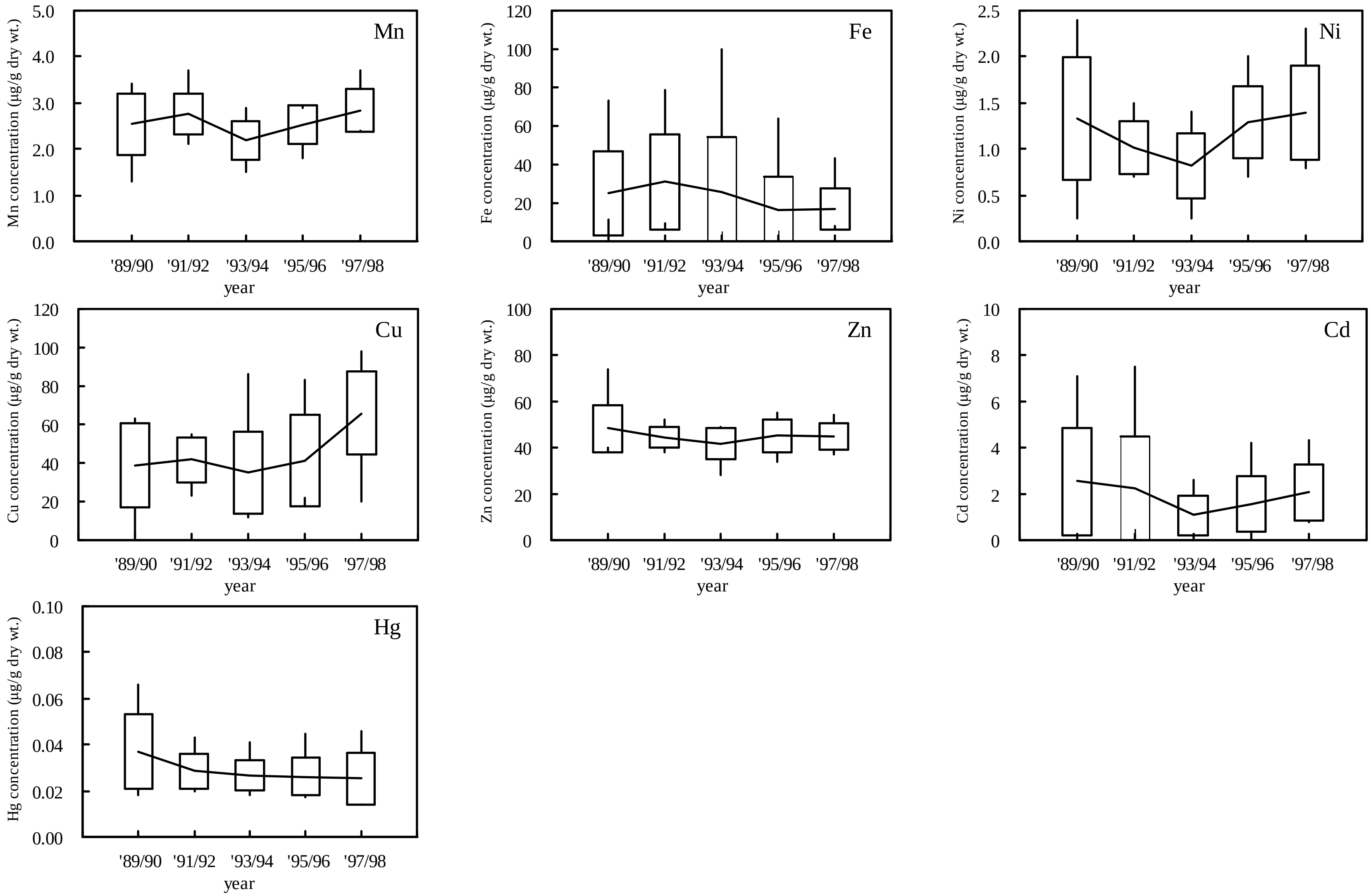

Fig. 2b. Temporal trend of trace element concentrations (μg/g dry wt.) of Antarctic krill from Areas V and VI during 1989/90 and 1997/98 seasons.
*: Siginificantly different ($p<0.05$)

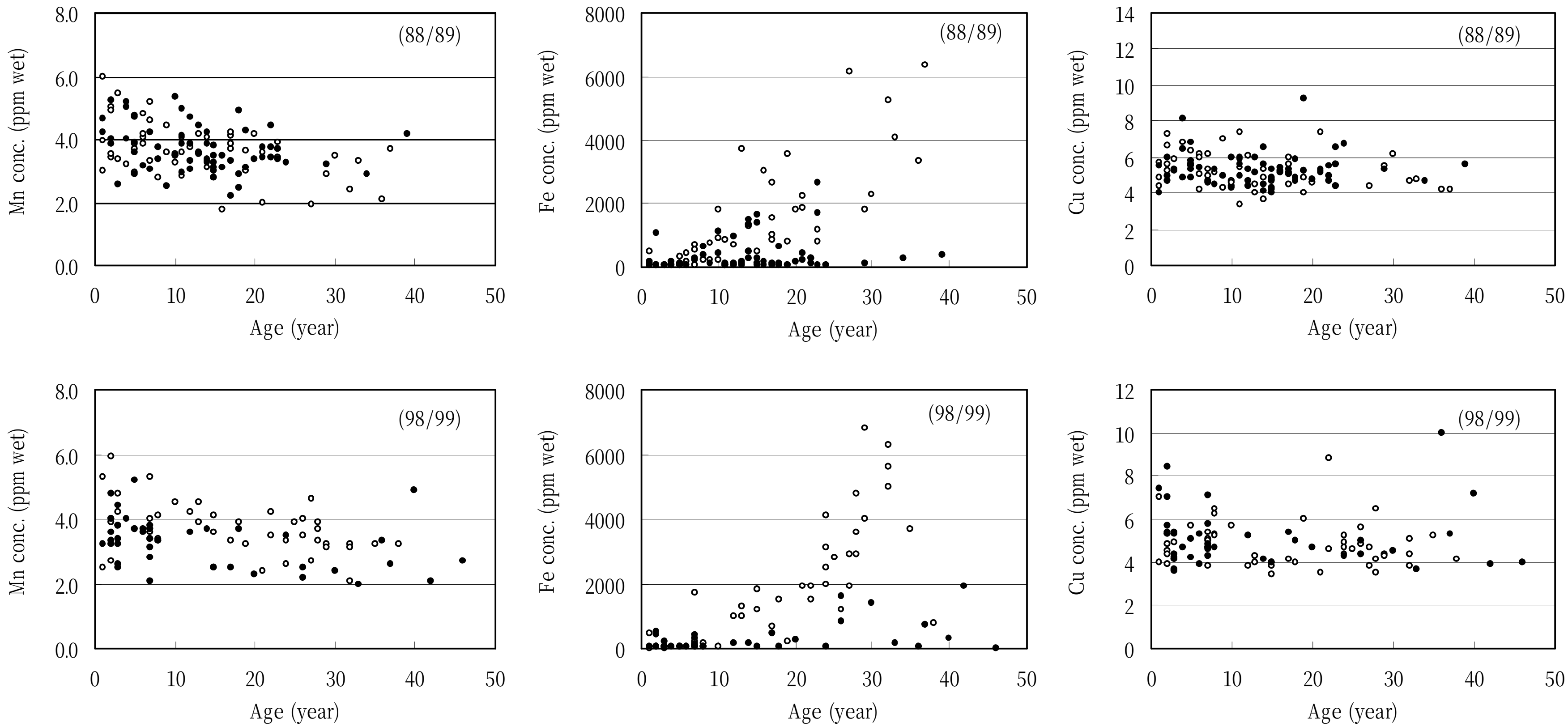

Fig. 3a. Relationships between age and Mn, Fe and Cu concentrations (μ g/g wet wt.) in the liver of Antarctic minke whales (male=○, female=●) from the Antarctic Area V.

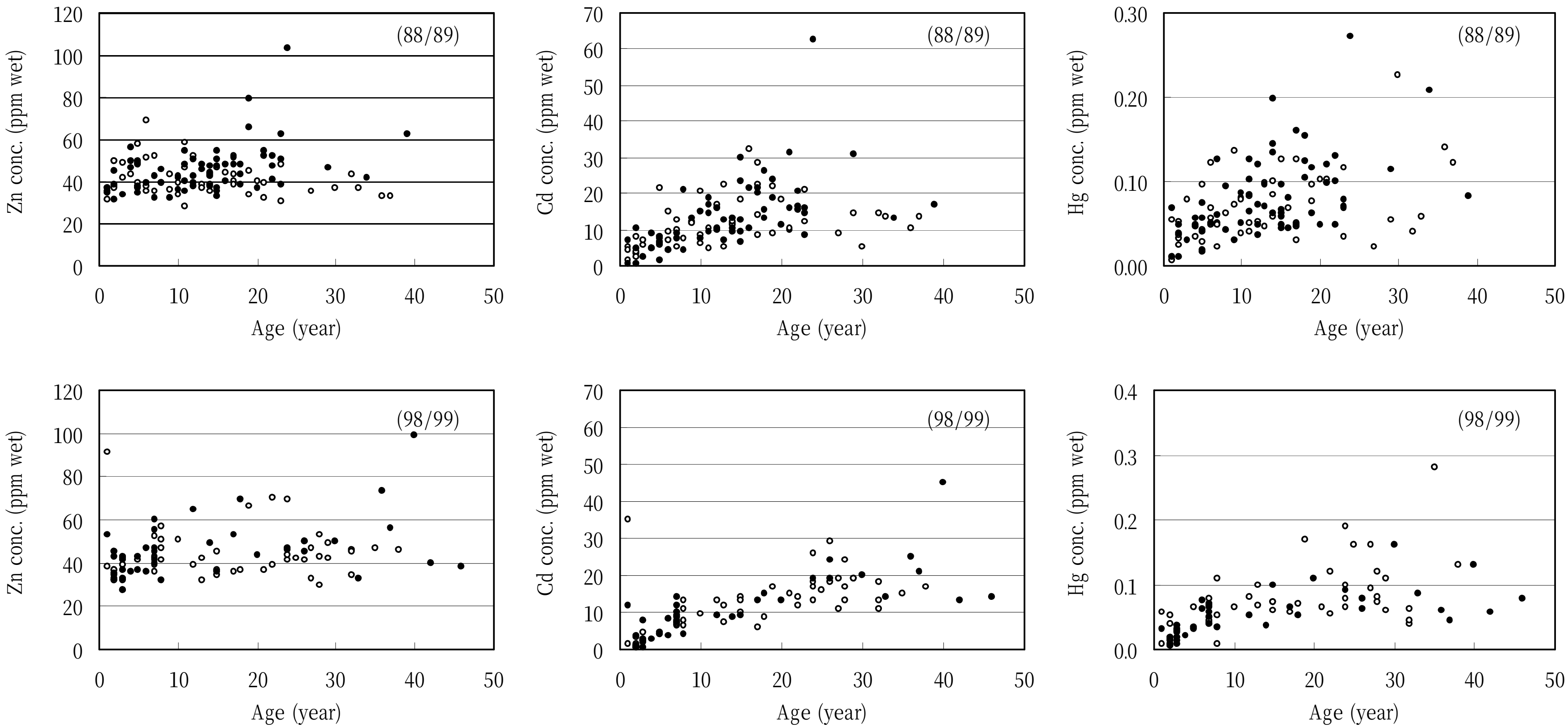

Fig. 3b. Relationships between age and Zn, Cd and Hg concentrations (μ g/g wet wt.) in the liver of Antarctic minke whales (male=○, female=●) from the Antarctic Area V.

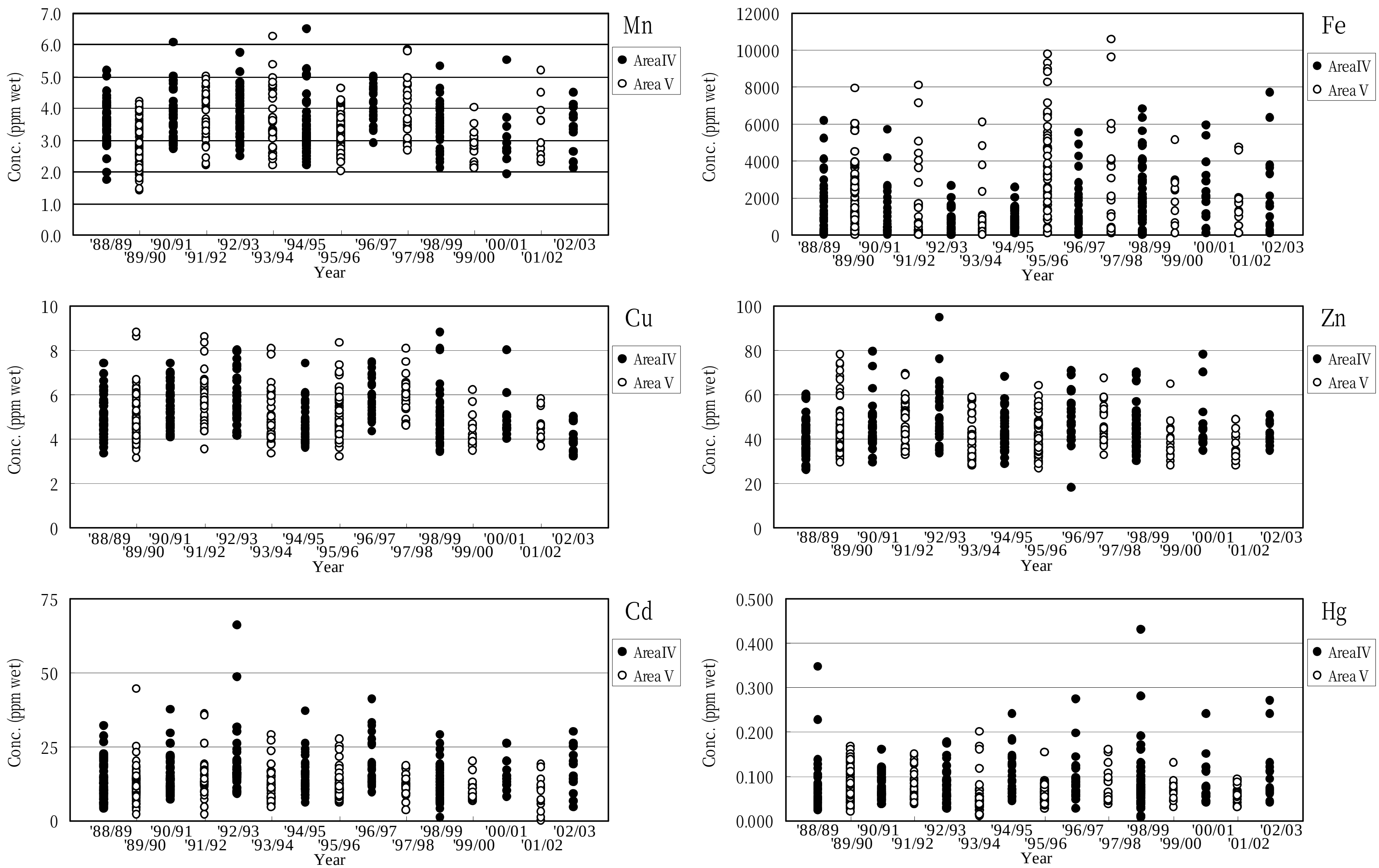

Fig. 4. Temporal trend of trace element concentrations (ppm wet wt.) in the liver of Antarctic minke whale (mature males) from the Antarctic Areas IV and V.

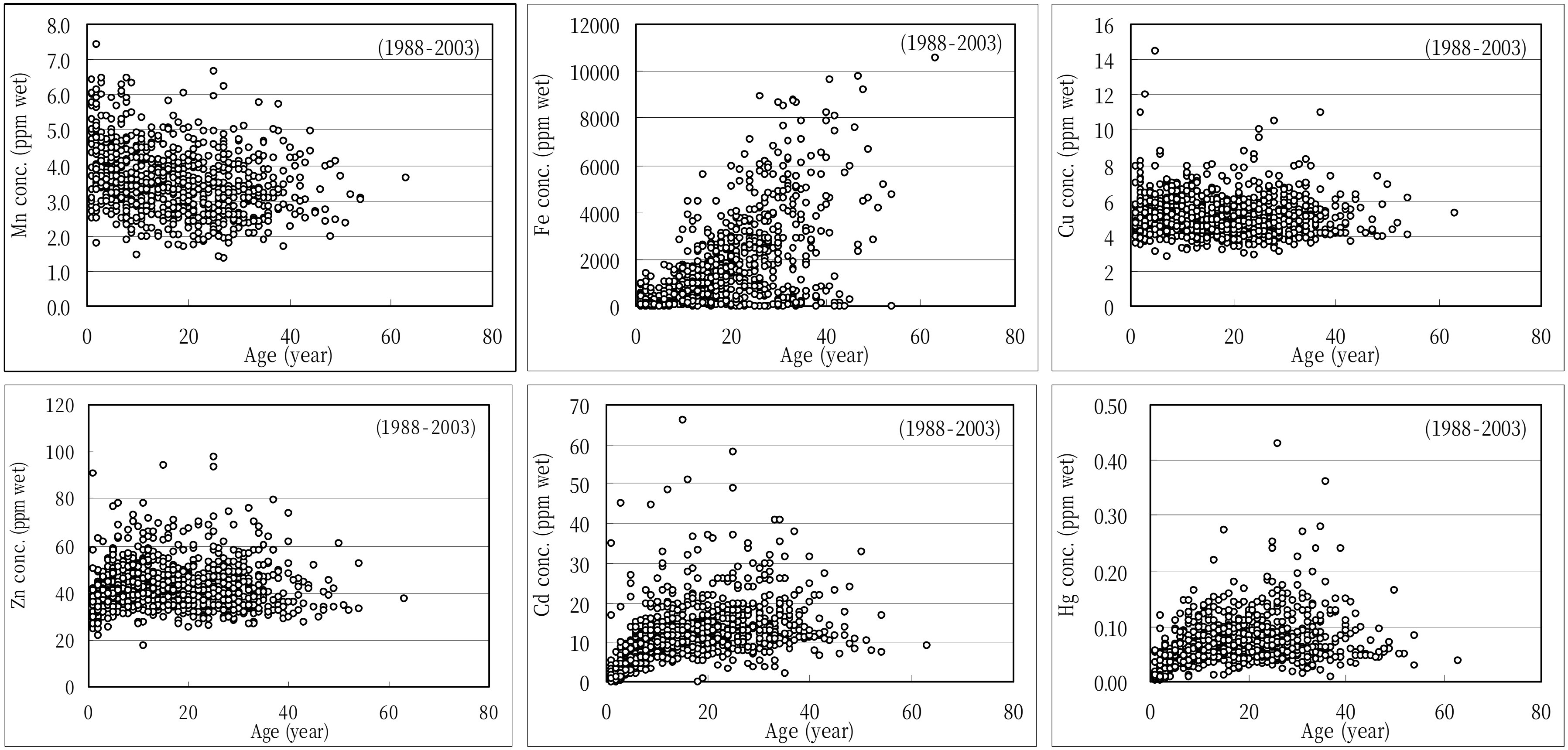

Fig. 5 Relationships between age and hepatic trace element concentrations of Antarctic minke whales (males) from the Antarctic Areas VI and V.

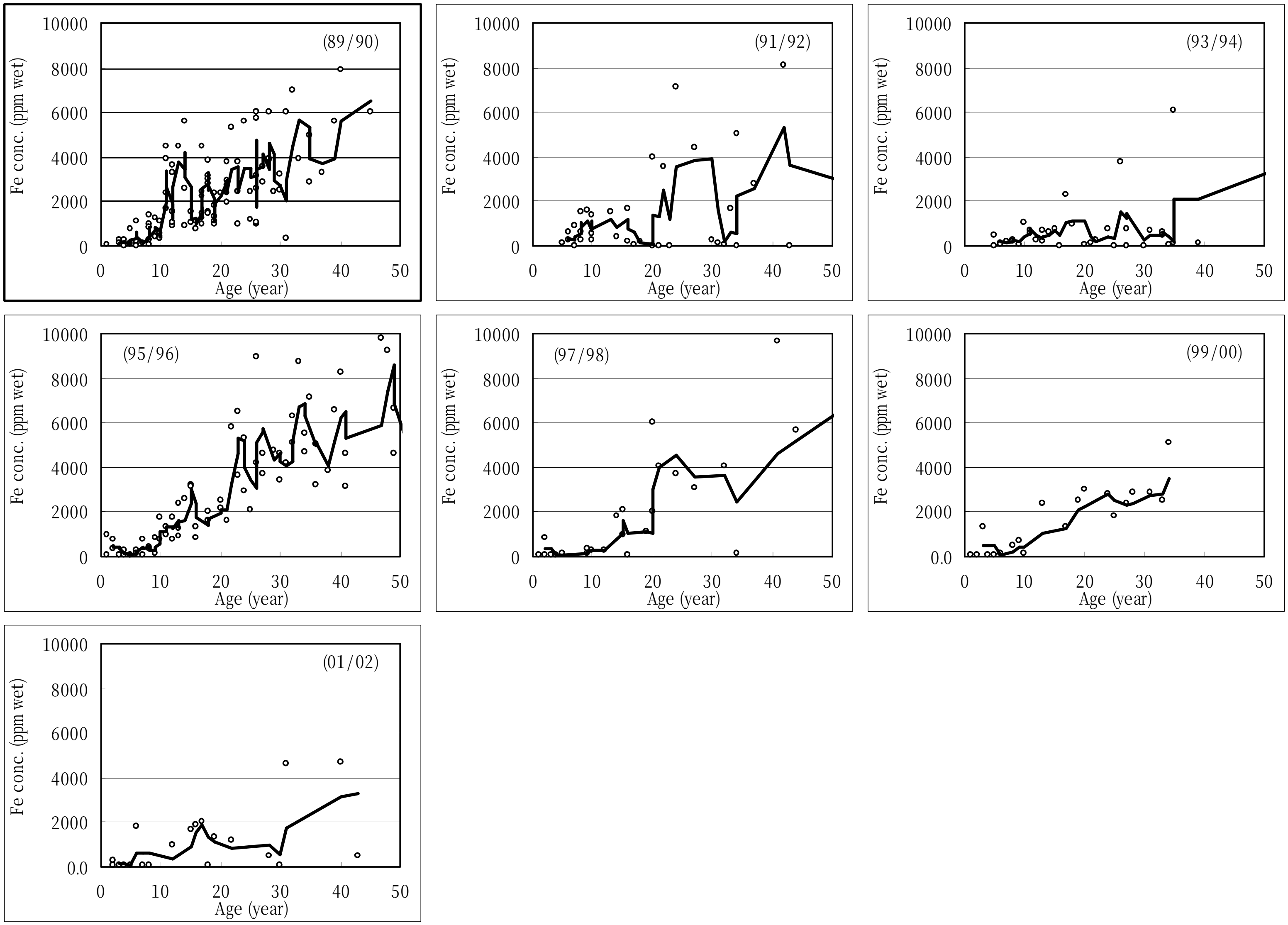

Fig. 6a Yearly relationships between age and hepatic Fe concentrations of Antarctic minke whales (males) from the Antarctic Area IV.

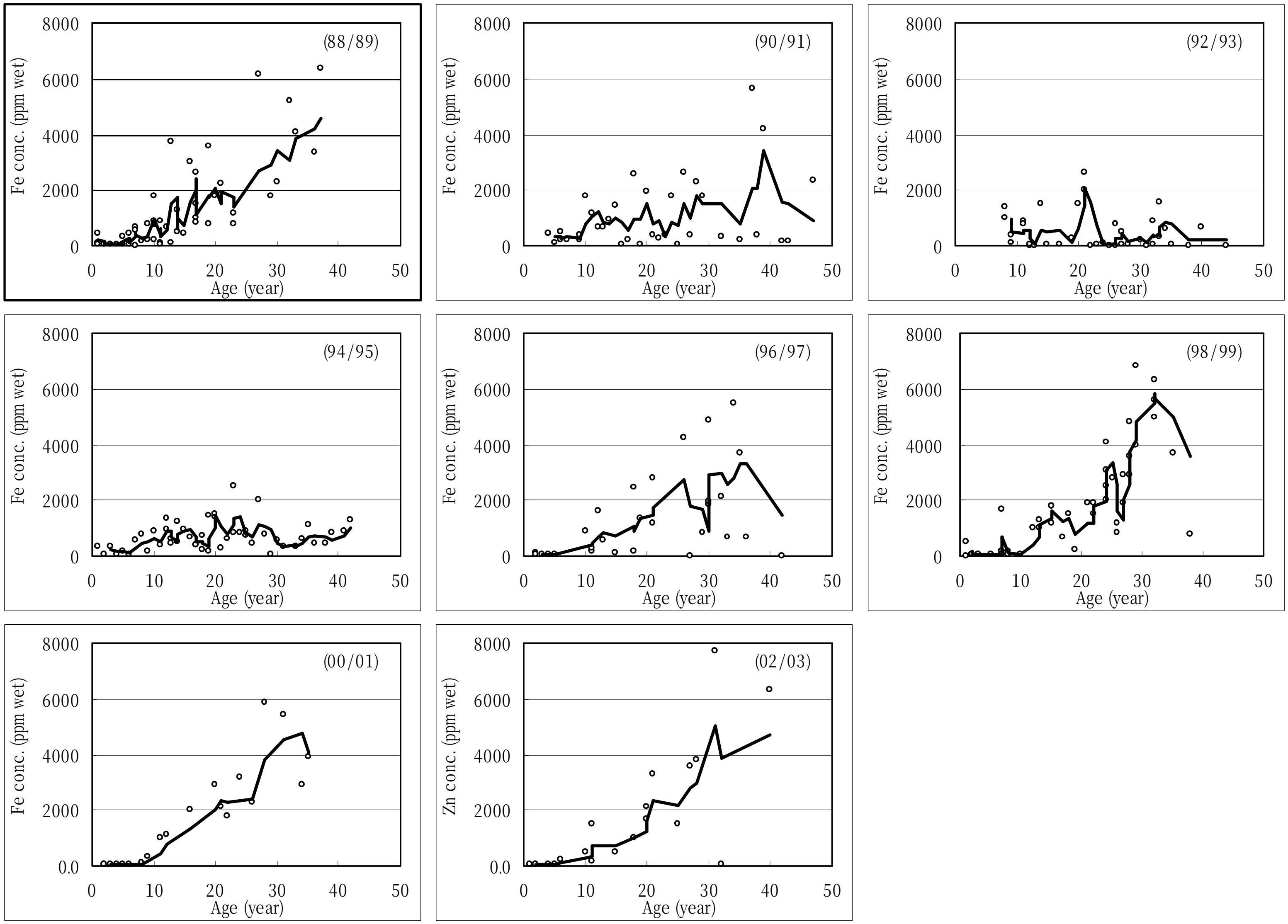

Fig. 6b Yearly relationships between age and hepatic Fe concentrations of Antarctic minke whales (males) from the Antarctic Area V.

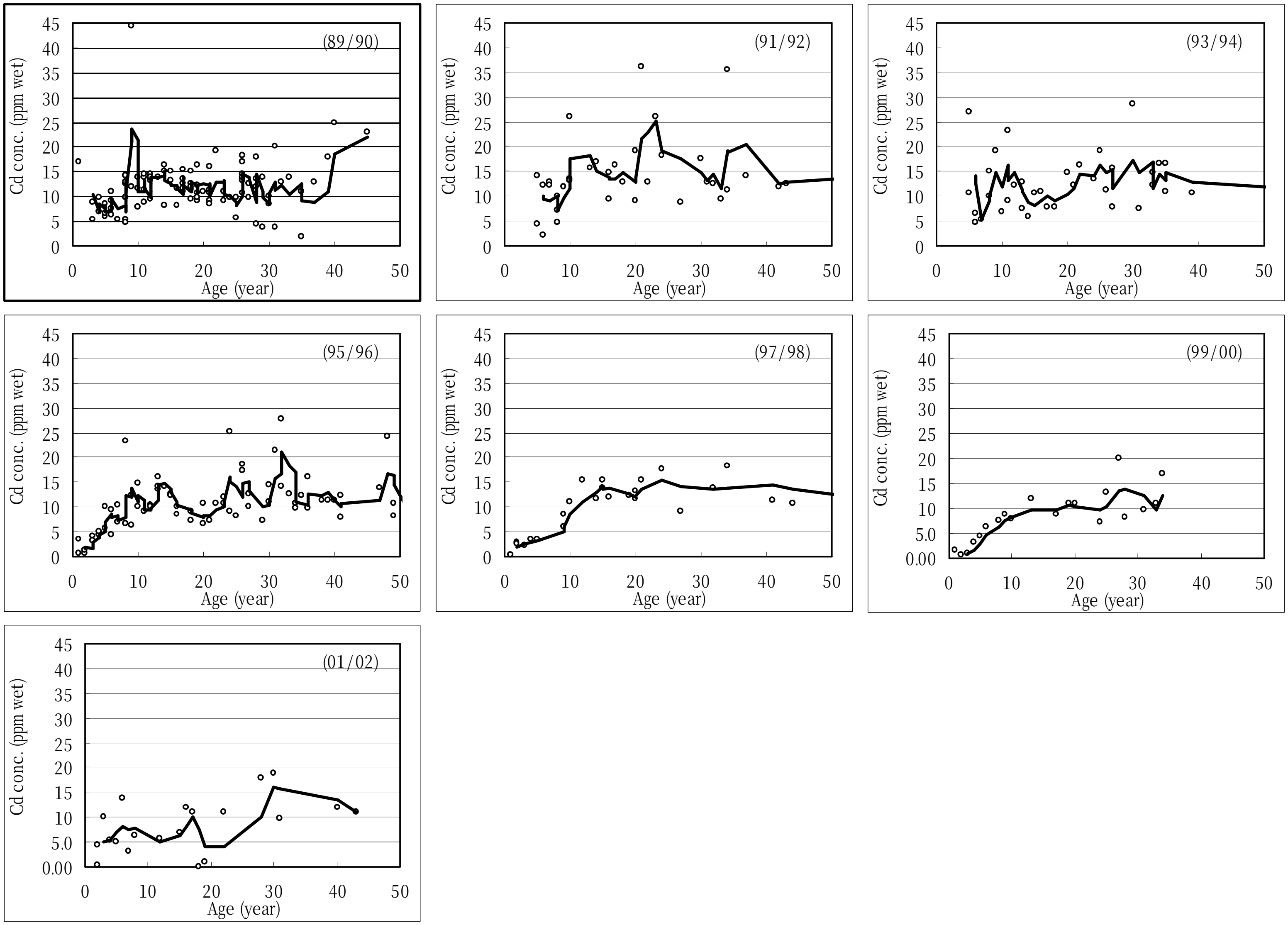

Fig. 6c Yearly relationships between age and hepatic Cd concentrations of Antarctic minke whales (males) from the Antarctic Area IV.

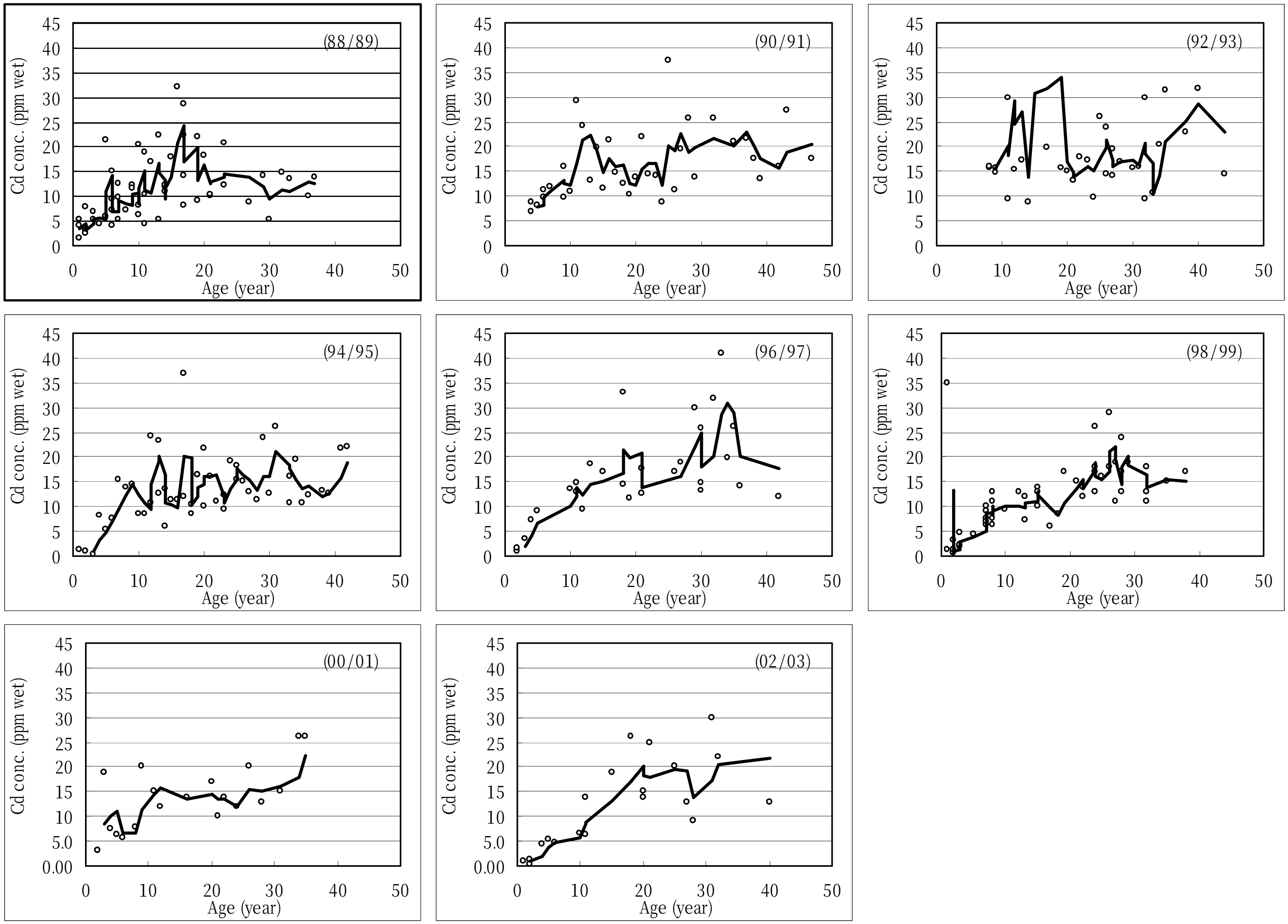

Fig. 6d Yearly relationships between age and hepatic Cd concentrations of Antarctic minke whales (males) from the Antarctic Area V.

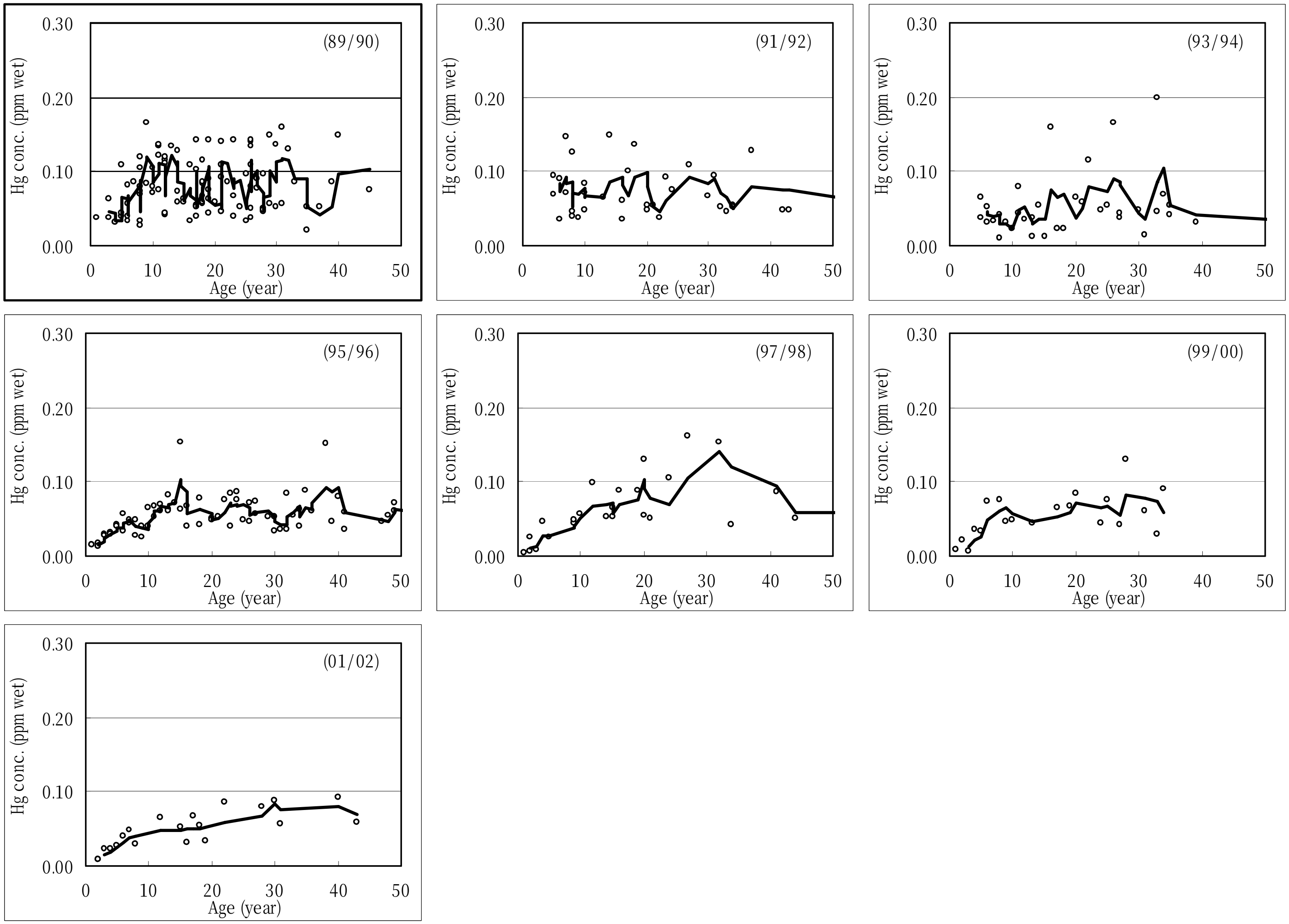

Fig. 6e Yearly relationships between age and hepatic Hg concentrations of Antarctic minke whales (males) from the Antarctic Area IV.

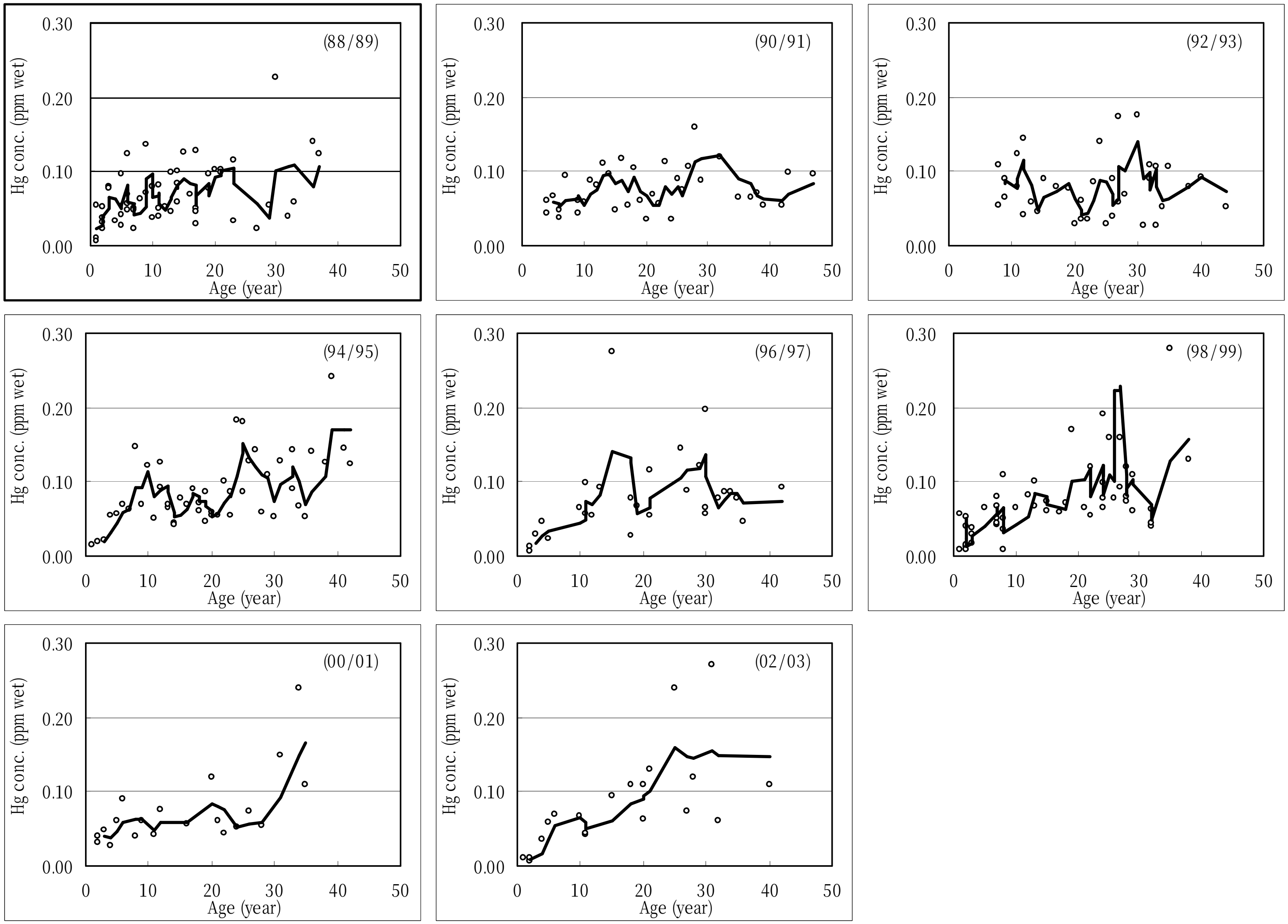

Fig. 6f Yearly Relationships between age and hepatic Hg concentrations of Antarctic minke whales (males) from the Antarctic Area V.