Temporal trends and factors affecting mercury levels in common minke, Bryde's and sei whales and their prey species in the western North Pacific

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ABSTRACT

To examine accumulation features and yearly changes of total Hg in the western North Pacific, total Hg levels in samples from zooplankton (krill *Euphausia pacifica*; copepods *Neocalanus spp.* and *Calanus sp.*), pelagic fishes (Japanese anchovy *Engraulis japonicus*; Pacific saury *Cololabis saira*; walleye pollock *Theragra chalcogramma*; mackerels; Pacific pomfret) and baleen whales (common minke whales *Balaenoptera acutorostrata*; Bryde's whales *B. edeni*; sei whales *B. borealis*), were measured. Total Hg levels in krill and copepods were in the range <0.001-0.013 and 0.003-0.010 ppm dry wt., respectively. Total Hg levels in the pelagic fishes were in the order: Pacific pomfret (0.232±0.027 ppm wet wt.) > walleye pollock (0.045) ≥Pacific saury (0.039±0.016) ≒ Japanese anchovy (adult) (0.037±0.025) > Japanese anchovy (larval fish) (0.005±0.003). Total Hg levels in muscle samples of mature baleen whales were in the order: common minke whales (0.22±0.07) > sei whales (0.052 ±0.009) ≒ Bryde's whales (0.046±0.008). Yearly changes of total Hg levels in zooplankton and pelagic fishes were not observed in the period 1995-2007. Apart from common minke whales from sub-area 9, significant yearly changes of total Hg levels in whales, were not observed. Results of a multiple linear regression analysis showed that variation of Hg levels in common minke whales from sub-area 9 was affected by sampling year and sampling region. Some considerations with mercury levels in prey species and prey composition suggest that these changes of Hg levels in sub-area 9 reflect change in food habitat rather than the changes in accumulation levels of Hg in the environment in the period considered. Therefore changes in food habitat of whales are important for predicting changes of Hg levels in both baleen whales and their environment.

KEYWORDS: COMMON MINKE WHALE; BRYDE'S WHALE; SEI WHALE; NORTH PACIFIC; MERCURY; TEMPORAL TREND, SPATIAL TREND

INTRODUCTION

Pollutants accumulate through the food chain in a marine ecosystem. Because cetaceans are located at the top of the food chain they are frequently used for monitoring the pollutants in the marine environment (Sanpera *et al.*, 1993; Borrell and Reijnders, 1999). Further cetaceans are mobile and long-lived animals, and these characteristics mean that pollutants can be monitored in wide areas and integrated in some way over time..

In JARPN II, surveys were designed so that quantitative behaviour and fate of the pollutants in the marine environment can be monitored. The present study examines levels and temporal changes of total Hg in the western North Pacific, through the analysis of top predators such as whales and whale's prey species such as zooplankton and fishes collected from their stomachs. The analysis of this pollutant in both predators and prey species is important as the level of Hg in predators reflect in part their feeding habit. To understand the pattern of accumulation of Hg in whales it is important to consider some biological information such as sex and sexual maturity. Such information is considered in this study.

This study examines level and temporal changes of Hg levels in two zooplanktons, six pelagic fishes species and three baleen whale species. For the later group sex and sexual maturity information obtained during JARPN II surveys is considered to assist in the interpretation of factors affecting Hg levels

MATERIALS AND METHODS

Samples and sampling method

Zooplanktons (krill and copepods) were collected by JARPN II researchers from the forestomach of common minke, Bryde's and sei whales from sub-areas 7, 8 and 9 in the surveys conducted in the period from 1994 to 2007. Table 1 shows the sample sizes and moisture content of the planktons sampled, by species and survey. The plankton samples were frozen and shipped to the laboratory and stored at -20˚C until chemical analysis.

Pelagic fishes (Japanese anchovy; Pacific saury; walleye pollock; Mackerels; and Pacific pomfret) were collected by JARPN II researchers from the forestomach of common minke, Bryde's and sei whales from sub-areas 7, 8 and 9 in the surveys conducted in the period from 1994 to 2007. Table 2 shows the sample sizes and moisture content of the fishes sampled, by species and survey. The fish samples were frozen and shipped to the laboratory and stored at -20˚C until chemical analysis.

Muscle tissues from the common minke whales (Okhotsk Sea-West Pacific stock) from sub-areas 7, 8 and 9 (offshore component of JARPN II), off-Sanriku and off-Kushiro (coastal component of JARPN II), Bryde's whales from sub-areas 8 and 9 and sei whales from sub-area 9 were collected by JARPN II researchers in the surveys conducted in the period from 1994 to 2007. The muscle tissues were excised from the medial region part of the body. Tables 3 and 4 show the sample sizes, maturity stage and body length of male animals, by species, sub-area and survey. The muscle samples were frozen and shipped to the laboratory and stored at -20˚C until chemical analysis. In this study we considered information on the body length and maturity status of male whales. Males of minke, Bryde's and sei whales were defined as sexually mature by testis weight (larger side) of more than 290g, 560g and 1,090g, respectively (Bando *et al.*, unpublished data). Only minke whales from the Okhotsk Sea-West Pacific stock as identified by the microsatellite analysis (Kanda *et al.*, 2009), were used.

Laboratory analysis

In the laboratory the whole body of zooplanktons and fishes were rinsed with milli-Q water, weigthed, dried for 12 hr. at 80˚C and reweigthed. The samples were homogenized using electrical blender and an agate motar. The muscle samples were stripped externally to avoid contamination and then homogenized using electrical blender.

For total Hg analysis, the homogenate samples (100 to 150 mg) were set on a ceramic boat and were subjected to Cold-vapor atomic absorption spectrometry with Heat-vaporization, gold amalgamation method (Nippon Instruments Co., MA-2000). Accuracy and precision of the methods were confirmed using standard materials, DORM-2 (NRCC: muscle of dogfish).

Statistical analysis

The yearly trend of total Hg levels in zooplanktons, fishes and whales were assessed by Ordinal Regression test (Polytomous Universal Model: PLUM). Furthermore, in order to examine the yearly trend of total Hg levels in the context of other factors in whales, multiple linear regression analyses, were conducted (Zar, 1999). The following independent variables: "sampling year" , "sampling date (1 May = day 1)", "sampling latitude", "sampling longitude", "body length" and "blubber thickness", were allowed, and all parameters were normalized. Temporal differences between JARPN and JARPN II in muscular total Hg levels of immature common minke whales were tested by ANCOVA with body length as covariate, and all parameters were normalized. A p value of less than 0.05 was used as a criterion on statistical significance in all tests. These statistical analyses were executed by SPSS ver.11 for Windows (SPSS Co. Ltd.).

RESULTS AND DISCUSSION

Zooplankton

Total Hg levels in krill and copepods from the western North Pacific exhibited ranges from <0.001-0.013 and 0.003-0.010 ppm dry wt., respectively (Table 1). Total Hg levels in zooplanktons, krill and copepods fed by common minke, Bryde's and sei whales were similar. Plots of total Hg levels in krill during 1994 and 2006 against their sampling year were shown in Figure.1. No significant trend in total Hg levels in krill was observed for the period 1994-2006 (Table 5). The result suggests that total Hg level in low trophic organisms is stable.

Pelagic fish

Table 2 shows the total Hg levels in the Japanese anchovy (adult), Japanese anchovy (larval fish), Pacific saury, walleye pollock, mackerels and Pacific pomfret. The total Hg levels in fish were in the order: Pacific pomfret (0.232 ± 0.027 ppm wet wt.) > walleye pollock (0.045 ppm wet wt.) ≥ Pacific saury (0.039 ± 0.016) ≒Japanese anchovy (adult) (0.037 ± 0.025) > Japanese anchovy (larval fish) (0.005 ± 0.003). Total Hg levels in Japanese anchovy (larval fish) were similar to those of the zooplanktons. Plots of total Hg levels against the sampling years in the Japanese anchovy (adult) and Pacific saury for the period 1995-2007 were shown in Figures 2 and 3. No significant trend in total Hg levels in Japanese anchovy (adult) was observed for the period 1995-2007 (Table 6). However, The total Hg level in Pacific saury showed significant differences in the period from 1995 to 2007 (Table 7). Furthermore, a multiple regression analysis was done to determine the extent of effect of individual factors such as sampling year, body length, season and sampling location (longitude and latitude). Only body length were significantly selected (Table 8). This result suggest that total Hg levels in pelagic fishes from western North Pacific in the study period is stable.

Baleen whale

Tables 3 and 4 show the total Hg levels in common mike whales and Bryde's/sei whales, respectively. Total Hg levels were in the order: common minke whales (0.22±0.07 ppm wet wt.) > sei whales (0.052 ±0.009) ≒Bryde's whales (0.046±0.008). Differences in feeding habitat among whale species and trophic levels of preys might be one of the reasons for such differences. It is known that common minke whales selectively feed on relatively higher trophic organisms, mainly pelagic fish such as Pacific saury and Japanese anchovy (Tamura *et al.*, 2002), which are different from the prey items of Bryde's and sei whales, which feed mainly on krill and copepod (Tamura *et al.*, 2002; Tamura *et al.*, 2009).

Plots of total Hg levels against their sampling year is shown for common minke (Figures 4-8 for different sub-areas), Bryde's (Figure 9) and sei (Figure 10) whales during 1994 and 2007. Tables 9, 10 and 11, 12 and 13 show the results of the regression test for common minke whales in sub-areas 7, 8 and 9 (offshore component), Kushiro, Sanriku (coastal component), respectively. Tables 14 and 15 show these results for Bryde's (sub-areas 8 and 9) and sei (sub-area 9) whales, respectively.

In minke whales from sub-area 7 and Sanriku, Bryde's whales from sub-areas 8 and 9 and sei whales from sub-area 9 the Hg levels were not significantly correlated with sampling year. However Hg levels in minke whales from sub-areas 8 and 9 were correlated negatively with sampling year and those from Kushiro were correlated positively with sampling year.

To examine the factors affecting total Hg levels trends in common minke whales, multiple regression linear analyses were conducted. For minke whales in sub-areas 8 and 9 two periods were considered: 1994-2007 and 2000-2007. This was done because the trend of Hg levels appear to change around year 2000 (Figures 5 and 6).

The results for minke whales in sub-areas 8, 9 and Kushiro are shown in Tables 16, 17 and 18, respectively. In sub-area 8 (period 2000-2007) and Kushiro, no significant correlation with the parameters was found. However, in sub-areas 8 (period 1994-2007) and 9 (both periods) significant correlation was found for the following parameters: blubber for sub-area 8; year (-), date (-) and latitude (+) for sub-area 9 (1994-2007); year (+) and longitude (-) for sub-area 9 (2000-2007).

These results suggest that total Hg levels in muscles of three baleen whales in are stable except in the case of common minke whales from sub-area 9. In this case a decreasing trend was observed in a JARPN period (1994-1999) while that an increasing trend was observed in the JARPN II period (2000-2007).

The total Hg level in immature common minke whales from sub-areas7, 8 and 9 were compared between JARPN (1994-1999) and JARPN II (2000-2007). To take into account the age-related accumumulation, plots of total Hg concentrations and body length were made (Figure 11). The results of the ANCOVA for Hg levels in immature common minke whales between JARPN and JARPN II periods are shown in Table 19, for coastal (sub-area 7) and offshore (sub-areas 8 and 9) regions. The slopes of the linear regression curves were significant different in the case of sub-areas 8 and 9 ($p<0.05$, Fig. 11b). In the case of sub-area 7 not significant differences were found. This finding coincide with the results of mature minke whales that total Hg levels in offshore minke whales were significantly decreased between two periods, while those from coastal region did not showed any yearly trend.

Multiple regression analyses for mature common minke whales from sub-area 9 selected parameters, such as sampling latitude and longitude. It has been reported that common minke whales locally feed Pacific pomfret in sub-area 9 (Tamura *et al.*, 1998) and minimal armhook squid in north-eastern of sub-area 9 (Konishi and Tamura, 2007), while they considerably feed Japanese anchovy, Pacific saury and krill (Tamura *et al.*, 2009). Total Hg levels in these mesopelagic fishes, such as Pacific pomfret (Hg: 0.215 - 0.264 ppm wet wt.) were higher than those in pelagic fishes, such as Japanese anchovy (Hg: 0.009 - 0.064) and Pacific saury (Hg: 0.009 - 0.064), and zooplanktons (Hg: <0.001 - 0.013). Consequently, yearly change of total Hg levels in common minke whales from sub-area 9 might be affected by change of the food habitat rather than the difference in background levels of Hg in the western North Pacific in the period.

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Table 1. Total Hg concentrations, moisture contents and sampling data of krill and copepods in stomach contents of baleen whales taken from JARPN and JARPN II researches during a period from 1994 to 2007.

Species	Tissue	Year	*n**	Area	Hg (ppm wet wt)	Hg (ppm dry wt)	Moisture content (%)
Krill	whole	1994	2	9	0.008	0.048	84
	body		(2Mi)		(0.006 - 0.010)	(0.044 - 0.053)	(81 - 86)
		1996	5	7, 8	0.004 ± 0.003	0.032 ± 0.023	85 ± 3
			(5Mi)		(0.002 - 0.009)	(0.016 - 0.069)	(81 - 88)
		2002	4	9	0.004 ± 0.001	0.027 ± 0.009	85 ± 2
			(1Mi, 3Se)		(<0.001 - 0.005)	(<0.001 - 0.037)	(83 - 87)
		2005	3	7, 8	0.003 ± 0.003	0.017 ± 0.014	84 ± 2
			(2Se, 1Br)		(0.001 - 0.006)	(0.007 - 0.033)	(82 - 86)
		2006	5	9	0.007 ± 0.005	0.038 ± 0.022	84 ± 3
			(5Br)		(0.003 - 0.013)	(0.019 - 0.069)	(81 - 87)
		total	19	7, 8, 9	0.005 ± 0.003	0.030 ± 0.019	85 ± 2
			(8Mi, 5Se, 6Br)		(0.001 - 0.013)	(0.007 - 0.069)	(81 - 88)
Copepods	whole	2007	5	9	0.005 ± 0.003	0.047 ± 0.024	88 ± 2
	body		(5Se)		(0.003 - 0.010)	(0.021 - 0.081)	(87 - 91)

*: Whale species (Mi: common minke whale, Se: Sei whale, Br: Bryde's whale) and numbers are shown in parentheses.

Table 2. Hg concentrations, moisture contents and sampling data of Japanese anchovy, Pacific saury, walleye pollock, marckerels and Pacific pomfret and in stomach contents of baleen whales taken from JARPN and JARPN II researches during a period from 1994 to 2007.

Species	Tissue	Year	*n**	Area	Body length (mm)	Hg (ppm wet wt)	Hg (ppm dry wt)	Moisture content (%)
Japanese anchovy	whole	1995	3	9	139 ± 7	0.068 ± 0.008	±	±
(adult)	body		(3Mi)		(131 - 145)	(0.058 - 0.072)	(-)	(-)
		2003	4	8	121 ± 3	0.069 ± 0.015	0.233 ± 0.068	70 ± 3
			(4Mi)		(119 - 125)	(0.052 - 0.088)	(0.170 - 0.320)	(65 - 73)
		2004	3	9	119 ± 10	0.022 ± 0.005	0.070 ± 0.013	69 ± 2
			(1Se, 2Br)		(110 - 130)	(0.018 - 0.028)	(0.062 - 0.085)	(67 - 71)
		2006	5	9	108 ± 5	0.011 ± 0.002	0.034 ± 0.007	69 ± 4
			(4Se, 1Br)		(100 - 115)	(0.008 - 0.015)	(0.026 - 0.043)	(64 - 75)
		2007	5	7, 8	122 ± 13	0.045 ± 0.022	0.153 ± 0.067	72 ± 3
			(4Mi, 1Br)		(101 - 133)	(0.011 - 0.071)	(0.046 - 0.230)	(69 - 76)
		total	20	7, 8, 9	123 ± 11	0.037 ± 0.025	0.122 ± 0.091	70 ± 3
			(11Mi, 5Se, 4Br)		(100 - 145)	(0.008 - 0.088)	(0.026 - 0.320)	(64 - 76)
Japanese anchovy	whole	2002	4	7, 8	51 ± 8	0.004 ± 0.001	0.021 ± 0.004	79 ± 1
(larval fish)	body		(4Br)		(42 - 62)	(0.004 - 0.005)	(0.018 - 0.025)	(78 - 79)
		2004	2	9	53 ±	0.007 ±	0.032 ±	79 ±
			(1Se, 1Br)		(33 - 126)	(0.003 - 0.010)	(0.017 - 0.046)	(78 - 81)
		total	6	7, 8, 9	52 ± 15	0.005 ± 0.003	0.025 ± 0.011	79 ± 1
			(1Se, 5Br)		(33 - 74)	(0.003 - 0.010)	(0.017 - 0.046)	(78 - 81)
Pacific saury	whole	1995	9	9	270 ± 41	0.039 ± 0.015	±	±
	body		(9Mi)		(200 - 310)	(0.017 - 0.058)	(-)	(-)
		1996	4	8	248 ± 55	0.028 ± 0.020	±	±
			(4Mi)		(195 - 315)	(0.014 - 0.058)	(-)	(-)
		2002	5	9	279 ± 45	0.035 ± 0.014	0.075 ± 0.026	55 ± 10
			(4Mi, 1Se)		(200 - 310)	(0.011 - 0.045)	(0.037 - 0.100)	(42 - 70)
		2003	5	9	300 ± 11	0.050 ± 0.004	0.118 ± 0.021	57 ± 5
			(4Mi, 1Se)		(282 - 313)	(0.043 - 0.053)	(0.092 - 0.140)	(51 - 63)
		2004	5	9	285 ± 26	0.032 ± 0.014	0.071 ± 0.023	57 ± 6
			(5Mi)		(248 - 308)	(0.017 - 0.048)	(0.044 - 0.092)	(48 - 63)
		2005	5	8, 9	296 ± 9	0.054 ± 0.009	0.134 ± 0.033	59 ± 4
			(2Mi, 3Se)		(283 - 309)	(0.044 - 0.064)	(0.100 - 0.170)	(54 - 66)
		2006	5	9	290 ± 14	0.042 ± 0.013	0.096 ± 0.036	55 ± 6
			(5Mi)		(272 - 307)	(0.023 - 0.055)	(0.057 - 0.150)	(48 - 63)
		2007	3	9	272 ± 36	0.028 ± 0.026	0.082 ± 0.077	67 ± 1
			(1Mi, 2Se)		(231 - 300)	(0.009 - 0.058)	(0.027 - 0.170)	(66 - 67)
		total	41	8, 9	282 ± 33	0.038 ± 0.015	0.097 ± 0.039	58 ± 7
			(34Mi, 7Se)		(195 - 325)	(0.009 - 0.064)	(0.027 - 0.170)	(42 - 70)
Mackerels	whole	1996	5	7	192 ± 16	0.020 ± 0.002	±	±
	body		(5Mi)		(170 - 215)	(0.018 - 0.023)	(-)	(-)
Pacific pomfret	whole	1994	3	9	420 ± 18	0.232 ± 0.027	±	±
	body		(3Mi)		(405 - 440)	(0.215 - 0.264)	(-)	(-)
Walleye pollock	whole	1996	2	7	504 ±	0.045 ±	±	±
	body		(2Mi)		(485 - 522)	(0.038 - 0.051)	(-)	(-)

*: Whale species (Mi: common minke whale, Se: Sei whale, Br: Bryde's whale) and numbers are shown in parentheses.

Table 3. Biological data and musclar mercury levels of common minke whales (males) from western North Pacific during a period from 1994 to 2007.

subarea	year	matuarity	*n*	body length (m)	blubber thickness (cm)	musclar Hg (ppm wet wt.)
7	1996	mature	18	(7.34 ± 0.31)	(3.1 ± 0.4)	(0.22 ± 0.05)
	1998	mature	39	(7.45 ± 0.34)	(2.6 ± 0.4)	(0.20 ± 0.05)
	1999	mature	32	(7.38 ± 0.29)	(3.6 ± 0.8)	(0.19 ± 0.04)
	2000	mature	5	(7.19 ± 0.23)	(3.1 ± 0.3)	(0.23 ± 0.02)
	2001	mature	27	(7.44 ± 0.32)	(2.4 ± 0.5)	(0.21 ± 0.04)
	2002	mature	34	(7.52 ± 0.27)	(3.7 ± 0.7)	(0.22 ± 0.03)
	2003	mature	11	(7.41 ± 0.39)	(2.4 ± 0.5)	(0.19 ± 0.08)
	2004	mature	7	(7.46 ± 0.32)	(4.0 ± 0.6)	(0.22 ± 0.02)
	2005	mature	19	(7.50 ± 0.31)	(3.2 ± 0.9)	(0.27 ± 0.04)
	2006	mature	15	(7.40 ± 0.40)	(2.3 ± 0.4)	(0.22 ± 0.05)
	2007	mature	44	(7.48 ± 0.26)	(3.0 ± 0.7)	(0.23 ± 0.04)
8	1996	mature	10	(7.40 ± 0.45)	(2.7 ± 0.5)	(0.24 ± 0.06)
	1997	mature	26	(7.44 ± 0.36)	(3.5 ± 0.6)	(0.27 ± 0.06)
	1998	mature	30	(7.53 ± 0.25)	(2.6 ± 0.4)	(0.23 ± 0.05)
	2001	mature	14	(7.74 ± 0.36)	(2.4 ± 0.3)	(0.21 ± 0.04)
	2002	mature	5	(7.71 ± 0.21)	(3.2 ± 0.6)	(0.20 ± 0.11)
	2003	mature	25	(7.52 ± 0.23)	(2.4 ± 0.4)	(0.18 ± 0.06)
	2006	mature	27	(7.52 ± 0.24)	(2.8 ± 0.6)	(0.21 ± 0.05)
	2007	mature	12	(7.55 ± 0.35)	(2.3 ± 0.5)	(0.22 ± 0.05)
9	1994	mature	17	(7.46 ± 0.31)	(3.5 ± 0.7)	(0.35 ± 0.17)
	1995	mature	74	(7.43 ± 0.34)	(3.1 ± 0.5)	(0.27 ± 0.06)
	1997	mature	40	(7.38 ± 0.37)	(3.1 ± 0.5)	(0.24 ± 0.11)
	2000	mature	11	(7.47 ± 0.26)	(2.6 ± 0.5)	(0.16 ± 0.03)
	2001	mature	19	(7.68 ± 0.30)	(2.5 ± 0.4)	(0.19 ± 0.05)
	2002	mature	20	(7.54 ± 0.21)	(3.0 ± 0.6)	(0.21 ± 0.05)
	2003	mature	28	(7.50 ± 0.32)	(2.9 ± 0.6)	(0.18 ± 0.05)
	2004	mature	50	(7.47 ± 0.21)	(3.9 ± 0.7)	(0.20 ± 0.07)
	2005	mature	28	(7.48 ± 0.32)	(3.4 ± 0.6)	(0.17 ± 0.05)
	2006	mature	16	(7.56 ± 0.30)	(3.4 ± 0.6)	(0.28 ± 0.08)
	2007	mature	4	(7.56 ± 0.20)	(2.2 ± 0.3)	(0.18 ± 0.09)
Kushiro	2002	mature	14	(7.22 ± 0.34)	(±)	(0.21 ± 0.06)
	2004	mature	24	(7.40 ± 0.28)	(±)	(0.19 ± 0.03)
	2005	mature	25	(7.44 ± 0.32)	(±)	(0.25 ± 0.05)
	2006	mature	10	(7.50 ± 0.30)	(±)	(0.22 ± 0.03)
	2007	mature	11	(7.45 ± 0.25)	(±)	(0.23 ± 0.04)
Sanriku	2003	mature	7	(7.15 ± 0.35)	(±)	(0.18 ± 0.04)
	2005	mature	3	(7.27 ± 0.13)	(±)	(0.29 ± 0.02)
	2006	mature	8	(7.22 ± 0.32)	(±)	(0.20 ± 0.05)
	2007	mature	9	(7.44 ± 0.24)	(±)	(0.23 ± 0.05)
total	1994-2007	mature	821	(7.46 ± 0.31)	(3.0 ± 0.7)	(0.22 ± 0.07)
7	1996-1999	immature	17	(5.64 ± 0.49)	(2.8 ± 0.8)	(0.15 ± 0.03)
	2000-2007	immature	51	(5.72 ± 0.76)	(2.6 ± 0.5)	(0.14 ± 0.07)
8	1996-1998	immature	8	(6.21 ± 0.71)	(2.5 ± 0.3)	(0.18 ± 0.06)
	2003-2007	immature	12	(5.74 ± 0.72)	(2.4 ± 0.6)	(0.08 ± 0.05)
9	1994-1997	immature	13	(6.05 ± 0.52)	(2.9 ± 0.6)	(0.17 ± 0.07)
	2000-2007	immature	14	(5.56 ± 0.87)	(2.7 ± 0.5)	(0.10 ± 0.09)
Kushiro	2002-2007	immature	46	(5.65 ± 0.64)	(±)	(0.12 ± 0.06)
Sanriku	2003-2007	immature	29	(5.56 ± 0.72)	(±)	(0.11 ± 0.05)
total	1994-2007	immature	190	(5.71 ± 0.70)	(2.7 ± 0.6)	(0.13 ± 0.07)

Table 4 Biological data and musclar mercury levels of Bryde's and sei whales (males) from western North Pacific during a period from 2002 to2007.

species	subarea	year	matuarity	*n*	body length (m)	musclar Hg (ppm wet wt.)
Bryde's whale	8	2002	mature	5	(12.67 ± 0.43)	(0.051 ± 0.008)
	8, 9	2004	mature	5	(12.59 ± 0.36)	(0.045 ± 0.008)
	8	2006	mature	5	(12.36 ± 0.47)	(0.040 ± 0.009)
	8, 9	2007	mature	5	(12.63 ± 0.35)	(0.049 ± 0.008)
	total	2002-2007	mature	20	(12.56 ± 0.39)	(0.046 ± 0.008)
Sei whale	9	2002	mature	5	(13.60 ± 0.16)	(0.050 ± 0.012)
	9	2003	mature	5	(13.80 ± 0.43)	(0.057 ± 0.007)
	9	2004	mature	5	(13.61 ± 0.04)	(0.050 ± 0.009)
	9	2005	mature	5	(13.54 ± 0.38)	(0.049 ± 0.011)
	9	2006	mature	5	(13.84 ± 0.51)	(0.052 ± 0.006)
	9	2007	mature	5	(13.92 ± 0.08)	(0.058 ± 0.010)
	total	2002-2007	mature	30	(13.72 ± 0.33)	(0.052 ± 0.009)

Table 5. Results of Yealy trend of total Hg levels in krill during 1994 and 2006 from western North Pacific by the PLUM - Ordinal regression test.

	Chi-Square	df	Sig.
Pearson	39.37	45	**0.709**
Deviance	36.11	45	0.825

Table 6. Results of Yealy trend of total Hg levels in Japanese anchovy during 1995 and 2007 from western North Pacific by the PLUM - Ordinal regression test.

	Chi-Square	df	Sig.
Pearson	47.39	64	**0.94**
Deviance	32.06	64	1.000

Table 7. Results of Yealy trend of total Hg levels in Pacific saury during 1995 and 2007 from western North Pacific by the PLUM - Ordinal regression test.

	Chi-Square	df	Sig.
Pearson	226.42	182	**0.014**
Deviance	108.44	182	1.000

Table 8 Results of multiple linear regression analyses with "total Hg levels in Pacific saury" as the dependent variable.

a) Model of regression

Model	R	R2	R2'
1	0.800	0.640	0.589

b) Analysis of Variance Table

Model	Sum of Squares	DF	Mean Square	F value	P value
Regression	26.998	5	5.400	12.442	**0.000**
Residual	15.189	35	0.434		
Total	42.188	40			

c) Variables

Model	B	SE	B'	T	P value
Constant	-2.63E-03	0.104		-0.025	0.980
year	-9.41E-02	0.125	-0.088	-0.075	0.455
date	-0.203	0.252	-0.187	-0.804	0.427
latitude	-7.64E-02	0.257	-0.070	-0.297	0.768
longitude	7.95E-02	0.118	0.075	0.675	0.504
body length	0.730	0.113	0.735	6.467	**0.000**

Table 9. Results of Yealy trend of total Hg levels in common minke whales (mature, O stock) during 1996 and 2007 from western North Pacific sub-area 7 by the PLUM - Ordinal regression test.

	Chi-Square	df	Sig.
Pearson	810.35	820	**0.588**
Deviance	508.68	820	1.000

Table 10. Results of Yealy trend of total Hg levels in common minke whales (mature, O stock) during 1996 and 2007 from western North Pacific sub-area 8 by the PLUM - Ordinal regression test.

	Chi-Square	df	Sig.
Pearson	693.21	630	**0.041**
Deviance	404.36	630	1.000

Table 11. Results of Yealy trend of total Hg levels in common minke whales (mature, O stock) during 1994 and 2007 from western North Pacific sub-area 9 by the PLUM - Ordinal regression test.

	Chi-Square	df	Sig.
Pearson	1994.78	1590	**0.000**
Deviance	748.83	1590	1.000

Table 12. Results of Yealy trend of total Hg levels in common minke whales (mature, O stock) during 2002 and 2007 from off Kushiro by the PLUM - Ordinal regression test.

	Chi-Square	df	Sig.
Pearson	184.20	124	**0.000**
Deviance	119.73	124	0.592

Table 13. Results of Yealy trend of total Hg levels in common minke whales (mature, O stock) during 2003 and 2007 from off Sanriku by the PLUM - Ordinal regression test.

	Chi-Square	df	Sig.
Pearson	29.73	42	**0.922**
Deviance	30.17	42	0.913

Table 14. Results of Yealy trend of total Hg levels in Bryde's whales (mature) during 2002 and 2007 from western North Pacific sub-area 8, 9 by the PLUM - Ordinal regression test.

	Chi-Square	df	Sig.
Pearson	50.64	39	**0.100**
Deviance	46.196	39	0.199

Table 15. Results of Yealy trend of total Hg levels in sei whales (mature) during 2002 and 2007 from western North Pacific sub-area 9 by the PLUM - Ordinal regression test.

	Chi-Square	df	Sig.
Pearson	123.18	100	**0.058**
Deviance	88.98	100	0.777

Table 16 Results of multiple linear regression analyses with "total Hg levels in muscles of common minke whales from sub-areas 8" as the dependent variable.

a) 1994-2007

Model of regression

Model	R	R2	R2'
1	0.386	0.149	0.113

Analysis of Variance Table

Model	Sum of Squares	DF	Mean Square	F value	P value
Regression	22.029	6	3.672	4.139	**0.001**
Residual	125.971	142	0.887		
Total	148.000	148			

Variables

Model	B	SE	B'	T	P value
Constant	-7.324E-10	0.077		0.000	1.000
year	-0.195	0.107	-0.195	-1.822	0.071
date	-5.031E-02	0.217	-0.050	-0.232	0.817
latitude	7.348E-02	0.221	0.073	0.332	0.740
longitude	-8.814E-02	0.104	-0.088	-0.851	0.396
body length	0.132	0.080	0.132	1.645	0.102
blubber thickness	0.245	0.086	0.245	2.867	**0.005**

b) 2000-2007

Model of regression

Model	R	R2	R2'
1	0.369	0.136	0.068

Analysis of Variance Table

Model	Sum of Squares	DF	Mean Square	F value	P value
Regression	10.148	6	1.691	2	**0.076**
Residual	64.256	76	0.845		
Total	74.404	82			

Table 17 Results of multiple linear regression analyses with "total Hg levels in muscles of common minke whales from sub-areas 9" as the dependent variable.

a) 1994-2007

Model of regression

Model	R	R2	R2'
1	0.444	0.197	0.181

Analysis of Variance Table

Model	Sum of Squares	DF	Mean Square	F value	P value
Regression	60.315	6	10.053	12.275	**0.000**
Residual	245.685	300	0.819		
Total	306.000	306			

Variables

Model	B	SE	B'	T	P value
Constant	2.92E-03	0.052		0.057	0.955
year	-0.399	0.053	-0.399	-7.482	**0.000**
date	-0.363	0.112	363050	-3.252	**0.001**
latitude	3.450E-01	0.112	0.345	3.088	**0.002**
longitude	-6.219E-02	0.054	-0.062	-1.160	0.247
body length	6.905E-02	0.053	0.069	1.310	0.191
blubber thickness	9.920E-02	0.053	0.105	1.882	0.061

b) 2000-2007

Model of regression

Model	R	R2	R2'
1	0.350	0.122	0.091

Analysis of Variance Table

Model	Sum of Squares	DF	Mean Square	F value	P value
Regression	11.052	6	1.842	3.921	**0.001**
Residual	79.395	169	0.470		
Total	90.447	175			

Variables

Model	B	SE	B'	T	P value
Constant	-0.835	0.147		-5.681	0.000
year	0.535	0.153	0.307	3.486	**0.001**
date	-8.517E-04	0.118	-0.001	-0.007	0.994
latitude	8.750E-02	0.118	0.092	0.743	0.458
longitude	-0.203	0.053	-0.302	-3.817	**0.000**
body length	2.528E-02	0.059	0.031	0.428	0.669
blubber thickness	2.179E-03	0.053	0.004	0.041	0.967

Table 18 Results of multiple linear regression analyses with "total Hg levels in muscles of common minke whales from off-Kushiro" as the dependent variable.

a) 2002-2007

Model of regression

Model	R	R2	R2'
1	0.357	0.127	0.059

Analysis of Variance Table

Model	Sum of Squares	DF	Mean Square	F value	P value
Regression	10.547	6	1.758	1.869	**0.097**
Residual	72.419	77	0.941		
Total	82.966	83			

Table 18 Results of ANCOVA comparisons of musclar total Hg levels in immature of common minke whales between JARPN (1994-1999) and JARPN II (2000-2007) from sub-area 7 and sub-areas 8 and 9.

a) sub-are 7 *N* : 1994-1999 (*17*), 2000-2007 (*51*)

Test of effects between subjects

	Sum of square (Type III)	DF	Mean Square	F value	P value	Noncentral parameter	Observed Statystical
Modified model	37.505	3	12.502	27.126	0.000	81.379	1.000
Constant	0.175	1	0.175	0.381	0.539	0.381	0.093
Research period	0.930	1	0.930	2.018	**0.16**	2.018	0.288
Body length	9.254	1	9.254	20.079	0.000	20.079	0.993
Error	29.495	64	0.461				
Sum	67.000	68					
Sum'	67.000	67					

b) sub-are 8 & 9 *N* : 1994-1999 (*21*), 2000-2007 (*26*)

Test of effects between subjects

	Sum of square (Type III)	DF	Mean Square	F value	P value	Noncentral parameter	Observed Statystical
Modified model	31.53	3	10.51	33.551	0.000	100.653	1.000
Constant	6.53E-03	1	6.53E-03	0.021	0.886	0.021	0.052
Research period	3.946	1	3.946	12.596	**0.001**	12.596	0.934
Body length	16.537	1	16.537	52.790	**0.000**	52.790	1.000
Error	13.47	43	0.313				
Sum	45.000	47					
Sum'	45.000	46					

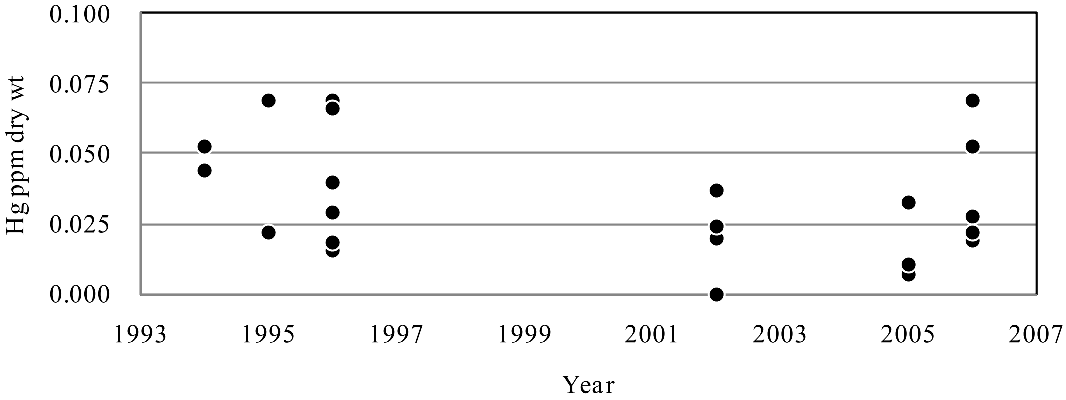

Fig. 1 Hg concentration (ppm dry wt) of krill (whole body)

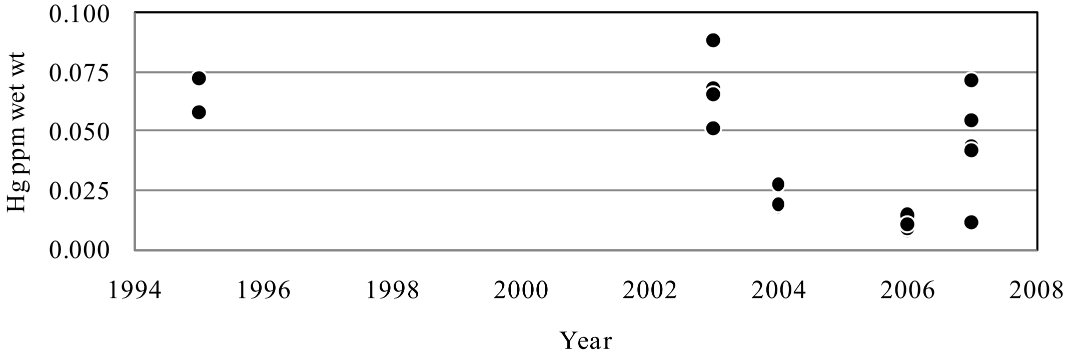

Fig. 2 Hg concentration (ppm wet wt) of Japanese anchovy (mature, whole body

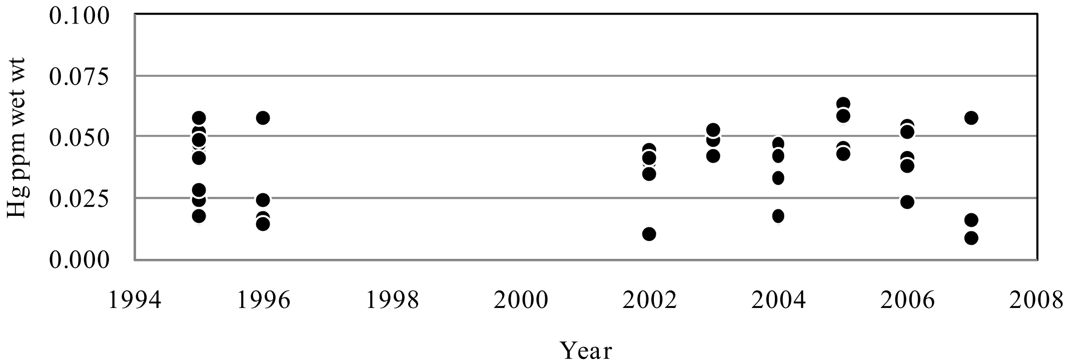

Fig. 3 Hg concentration (ppm wet wt) of Pacific saury (whole body)

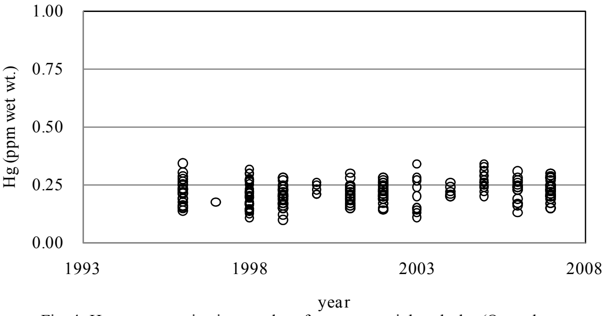

Fig. 4. Hg concentration in muscles of common minke whales (O stock, mature male) taken from sub-area 7 on western North Pacific.

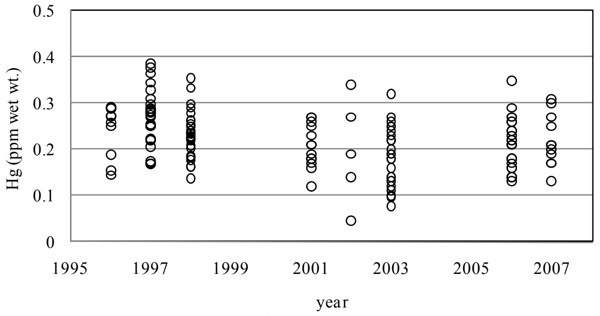

Fig. 5. Hg concentration in muscles of common minke whales (O stock, mature male) taken from sub-area 8 on western North Pacific.

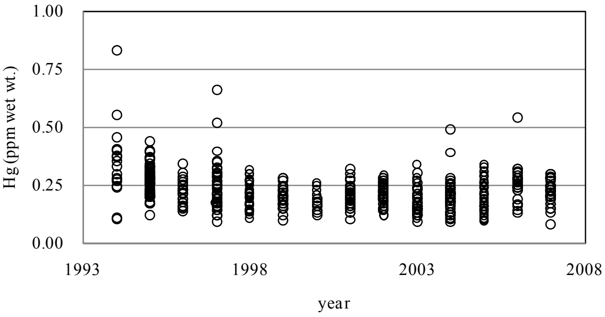

Fig. 6. Hg concentration in muscles of common minke whales (O stock, mature male) taken from sub-area 9 on western North Pacific.

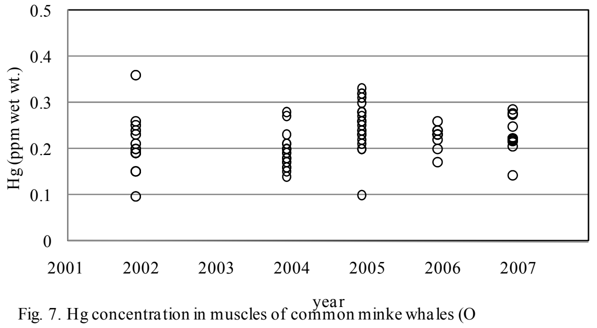

Fig. 7. Hg concentration in muscles of common minke whales (O stock, mature male) taken from off Kushiro on western North Pacific.

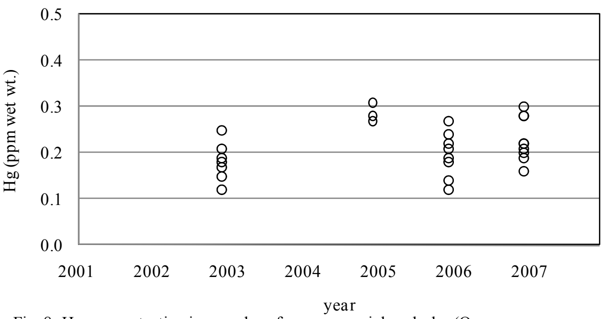

Fig. 8. Hg concentration in muscles of common minke whales (O stock, mature male) taken from off Sanriku in western North Pacific.

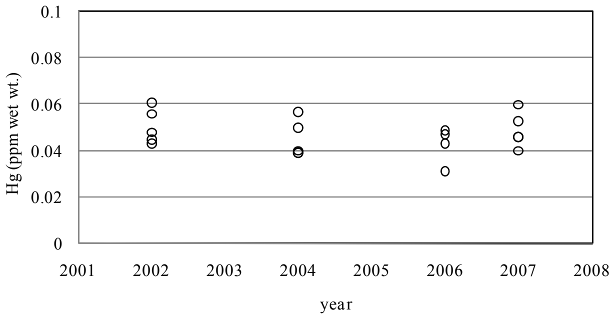

Fig. 9. Hg concentration in muscles of Bryde's whales (mature male) taken from sab-areas 8 and 9 in the western North Pacific.

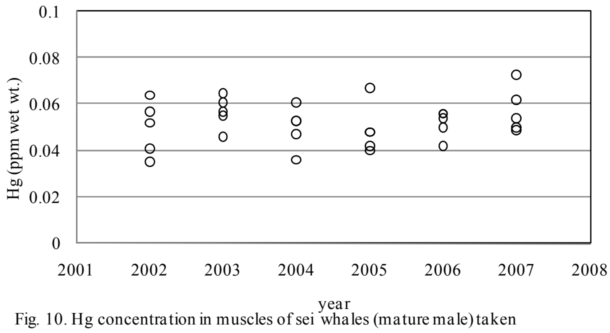

Fig. 10. Hg concentration in muscles of sei whales (mature male) taken from sab-area 9 in the western North Pacific.

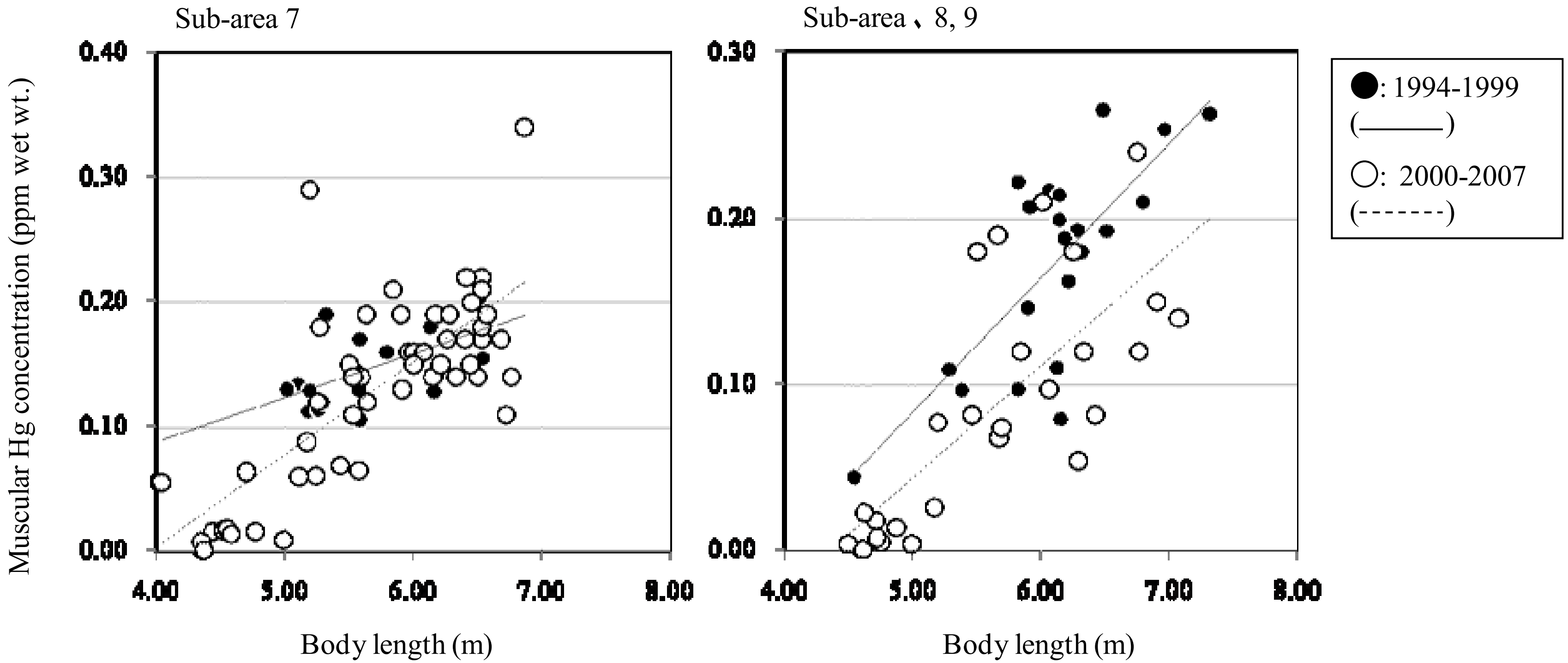

Fig.11 Relationships between muscular Hg concentrations (ppm wet wt.)and body length (m) in common minke whales in sub-areas 7 and 9 during 1994 and 2007.