Temporal trend of Total Hg levels in three baleen whale species based on JARPNII data for the period 1994-2014

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ABSTRACT

To examine yearly changes of total mercury (Hg) in the western North Pacific, total Hg concentrations in muscle from common minke whale (*Balaenoptera acutorostrata*), sei (*B. borealis*) and Bryde's (*B. edeni*) whales, were measured. Averages and standard deviations of total Hg concentrations in samples of mature males of O stock of common minke whales from sub-area 7, off Kushiro, off Sanriku, subareas 8 and 9 were 0.22±0.05, 0.22±0.05, 0.22±0.06, 0.22±0.06 and 0.24±0.10, ppm wet wt., respectively. And those of sei whales from sub-area 9 and Bryde's whales from sub-areas 8 and 9 were 0.044±0.013 and 0.044±0.013 ppm wet wt., respectively. Multiple linear regression analysis was carried out and included adjustment for confounders, sampling years, sampling longitude, sampling latitude, sampling date, body length, blubber thickness and main prey item. Total Hg concentrations in the common minke whales from sub-area 7 were significantly associated with deficits in sampling year and main prey item, and those from sub-area 9 were significantly associated with deficits in sampling year, latitude and main prey item. Main prey items would have an effect on total Hg concentrations in the common minke whales from sub-areas 7 and 9. These findings suggest that yearly changes of total Hg in common minke whales from the western North Pacific could be affected by changes of their pray items.

KEYWORDS: COMMON MINKE WHALE; SEI WHALE; BRYDE'S WHALE; NORTH PACIFIC; TOTAL MERCURY; MONITORING

INTRODUCTION

Pollutants accumulate through the food chain in the 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 JARPNII, surveys were designed so that quantitative behavior and fate of the pollutants in the marine environment can be monitored. The present study examines three concentrations and temporal changes of total Hg in three top predator species (baleen whales) in the western North Pacific. The analysis of this pollutant in both predators and prey species is important as the concentration of Hg in predators reflect in part their feeding habits. 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.

In the 2009 review workshop, Yasunaga and Fujise (2009) presented a study on yearly changes of mercury concentrations in muscle samples of common minke (*Balaenoptera acutorostrata*), sei (*B. borealis*) and Bryde's (*B. edeni*) whales and their prey items from the western North Pacific using JARPN and JARPNII samples during 1994-2007. Yearly changes of total Hg concentrations in zooplankton and pelagic fishes were not observed in the period 1994-2007. Apart from minke whales from sub-area 9, significant yearly changes of concentrations in whales were not observed. For minke whales in sub-area 9, total Hg concentrations decreased from 1994 to 1999 but increased from 2000 to 2007. Results of a multiple linear regression analysis suggested that changes of Hg concentrations in sub-area 9 reflect changes in food habitats of minke whale rather than changes in accumulation concentrations in the environment.

This study examines concentrations and temporal changes of Hg concentrations in mature males of three baleen whale species. Body length, blubber thickness, stomach content and sexual maturity information obtained during JARPN and JARPNII surveys is considered to assist in the interpretation of factors affecting total Hg concentrations.

MATERIALS AND METHODS

Samples

Muscle tissues from the minke whales (Okhotsk Sea-West Pacific stock) from sub-area 7, off Kushiro, off Sanriku, subareas 8 and 9, sei whales from sub-area 9 and Bryde's whales from sub-areas 8 and 9 were collected by JARPNII researchers in the surveys conducted in the period from 1994 to 2014 (Fig. 1). Biological data such as body length and blubber thickness and tissue samples were collected on board the *Nisshin Maru* (Table 1). The muscle tissues were excised from the medial region part of the body, frozen and shipped to the laboratory and stored at -20˚C until chemical analysis. The forestomach contents have proved sufficient for determination of the common minke whale diet in the Northeast Atlantic (Lindstrøm *et al.*, 1997). The prey composition between forestomach and fundus were very similar in this study. Therefore, this study was based on contents from forestomach.

Tables 3 and 4 show the sample sizes, maturity stage and body length of male animals, by species, sub-area and survey. 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 (O-stock) as identified by the microsatellite analysis (Kanda *et al.*, 2009), were used.

Laboratory analysis

The muscle samples were stripped externally to avoid contamination. For total Hg analysis, the samples 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-3000). Triplicate analysis was performed on each sample, to increase the accuracy of the determination. Accuracy and precision of the methods were confirmed using standard materials, DORM-3 (NRCC, muscle of dogfish).

Total Hg concentrations in prey items in SC/J09/JR23 of the 2007 JARPNII review (Yasunaga and Fujsie, 2007), were used because most of the samples for this study until 2011 were lost after the 2011 earthquake and tsunami (see IWC, 2012).

Statistical analysis

The yearly changes of total Hg concentrations in whales were assessed by multiple linear regression in the context of other factors (R Development Core Team, 2006). The following independent variables: "sampling year", "sampling date", "sampling latitude", "sampling longitude", "body length", "blubber thickness" and "main prey item" were allowed, and all parameters except for main prey item were logarithmic transformed. Categorical parameters of main prey items used in the analyses were the following: sub-area 7 of minke whale (Japanese anchovy: *Engraulis japonicus*, Euphausiids, Japanese flying squid: *Todarodes pacificus*, mackerel: *Scomber japonicus*, Japanese sardine: *Sardinops melanostictus*, Pacific saury: *Cololabis saira* and Walleye Pollock: *Theragra chalcogramma*); off Kushiro and off Sanriku of common minke whale (None); sub-area 8 of minke whale (anchovy, Copepods, Euphausiids, Japanese flying squid, mackerel and Pacific saury); sub-area 9 of minke whale (anchovy, Atka mackerel: *Pleurogrammus monopterygius*, Copepods, Euphausiids, mackerel, armhook squid: *Berryteuthis anonychus*, oceanic lightfish: *Vinciguerria nimbaria*, Pacific pomfret: *Brama japonica*, Salomonids, Pacific saury); sub-area 9 of sei whale (Japanese anchovy, Copepods, Euphausiids, mackerel, armhook squid, Japanese sardine and Pacific saury); sub-areas 8 and 9 of Bryde's whale (Japanese anchovy, Euphausiids and mackerel). A p value of less than 0.05 was considered to indicate statistical significance in all tests. The statistical analyses were performed using the free software R, version 3.2.0.

RESULTS

Tables 1-3 show the total Hg concentrations in minke, sei and Bryde's whales, respectively. Averages and standard deviations of total Hg concentrations in muscle samples of mature males of O stock-minke whales from sub-area 7, off Kushiro, off Sanriku, subareas 8 and 9, sei whales from sub-area 9 were 0.22±0.05, 0.22±0.05, 0.22±0.06 and 0.22±0.06, 0.24±0.10, ppm wet wt., respectively. And those of sei whales from sub-area 9 and Bryde's whales from sub-areas 8 and 9 were 0.044±0.013 and 0.044±0.013 ppm wet wt., respectively. Plots of total Hg concentrations against their sampling year are shown for common minke (Figs. 2a-2e for different sub-areas), sei (Fig. 2f) and Bryde's (Fig. 2g) whales during 1994 and 2014.

To examine the factors affecting total Hg concentrations in minke, sei and Bryde's whales, multiple linear regression analyses were conducted. The results for minke whales in sub-area 7, off Kushiro, off Sanriku, subareas 8 and 9, sei whales in sub-area 9 and Bryde's whales in sub-areas 8 and 9 are shown in Tables 4, 5, 6, 7, 8, 9 and 10, respectively. Regression models were significant for all cases. In minke whales from sub-areas 7 and 9, and sei whales from sub-area 9, total Hg concentrations were significantly associated with sampling year (Tables 4, 6 and 9).

DISCUSSION

In sub-area 7, total Hg concentrations in minke whales (period 1996-2012), a significant association was found for year (+) and main prey items (Table 4). Total Hg concentrations in muscle of minke whale observed from each main prey item in stomach and total Hg concentrations in whole body of the prey items from the same areas are shown in Table 11. Total Hg concentrations in minke whales having mackerel in stomach were the highest and those having sardine in stomach were the lowest among minke whales from sub-area 7, whereas those for other prey items had similar concentrations. The number of minke whales having mackerel and sardine in their stomach were only one and two whales, respectively. These results indicate that total Hg concentrations of minke whales from sub-area 7 may be less affected by total Hg in the food items.

In sub-area 9, total Hg concentrations in minke whales (period 1996-2012), significant association was found for year (-), latitude (+) and main pray items (Table 6). Total Hg concentrations in muscle of minke whale for each main prey item in stomach and total Hg concentrations in the prey items from sub-area 9 are shown in Table 12. Total Hg concentrations in minke whales having Pacific pomfret in stomach were the highest among minke whales from sub-area 9, and total Hg concentrations in Pacific pomfret were one or two orders of magnitude higher than those in the other prey items. Also total Hg concentrations in minke whales having zooplankton such as copepods and euphausiids were lower than the others. Total Hg concentrations in the zooplankton were one or two orders of magnitude lower than those in the other prey items. Furthermore, yearly changes were observed in food items of the minke whales in the same period (Konishi *et al.*, 2016). These results indicate that changes of Hg concentrations in sub-area 9 reflect changes in food habitat of minke whale rather than changes of background levels of total Hg in the marine environment.

In sub-area 9, total Hg concentrations in sei whales (period 2002-2014), a significant association was found for year (-), body length (+) and main prey items (Table 9). Total Hg concentrations in muscle of each sei whale having the same main prey items in stomach and total Hg concentrations in the prey items from the same areas are compared in Table 13. Total Hg concentrations in minke whales having anchovy and sardine in stomach were slightly higher than the other two whale species from sub-area 9. These results indicate that Total Hg concentrations of sei whales from sub-area 9 may be less affected by Total Hg in the food items.

The Hg concentrations observed in muscle of minke whales in off Kushiro and off Sanriku, sub-area 8 and Bryde's whales in sub-areas 8 and 9 were relatively stable in the western North Pacific during the research periods. On the other hand, yearly changes of total Hg in muscle of minke whales from sub-areas 7 and 9, and sei whales from sub-area 9 were observed in order to change of their food items. Total Hg concentrations in surface water of the North Pacific have not changed since the 1980's (Laurier *et al.*, 2004; Sunderland *et al.*, 2010). Consequently, yearly trend of total Hg in sea surface water and the baleen whales from the North Pacific remained stable for the research period, while anthropogenic Hg emission in Asia have risen steadily over the past several decades (UNEP, 2013).

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Table 1. Biological data and total mercury concentrations in muscle of common minke whales (males) from western North Pacific during 1994 and 2014

subarea	year	maturity	*n*	body length (m)	blubber thickness (cm)	muscular Hg (ppm wet wt.)
7	1996	mature	18	(7.36 ± 0.28)	(3.1 ± 0.4)	(0.23 ± 0.05)
	1998	mature	35	(7.50 ± 0.27)	(2.6 ± 0.4)	(0.20 ± 0.05)
	1999	mature	31	(7.41 ± 0.29)	(3.6 ± 0.8)	(0.20 ± 0.04)
	2000	mature	6	(7.30 ± 0.25)	(3.6 ± 1.0)	(0.24 ± 0.04)
	2001	mature	27	(7.45 ± 0.31)	(2.4 ± 0.5)	(0.21 ± 0.04)
	2002	mature	33	(7.52 ± 0.27)	(3.7 ± 0.8)	(0.22 ± 0.03)
	2003	mature	11	(7.42 ± 0.40)	(2.4 ± 0.5)	(0.20 ± 0.07)
	2004	mature	6	(7.56 ± 0.21)	(4.1 ± 0.6)	(0.22 ± 0.02)
	2005	mature	17	(7.51 ± 0.23)	(3.3 ± 0.9)	(0.27 ± 0.04)
	2006	mature	16	(7.39 ± 0.39)	(2.4 ± 0.7)	(0.22 ± 0.05)
	2007	mature	41	(7.47 ± 0.26)	(3.0 ± 0.7)	(0.23 ± 0.04)
	2009	mature	11	(7.71 ± 0.26)	(3.2 ± 0.7)	(0.21 ± 0.06)
	2011	mature	23	(7.47 ± 0.34)	(3.5 ± 0.6)	(0.25 ± 0.05)
	2012	mature	19	(7.37 ± 0.34)	(2.6 ± 0.4)	(0.24 ± 0.08)
	total		294	(7.46 ± 0.30)	(3.1 ± 0.8)	(0.22 ± 0.05)
Kushiro	2002	mature	14	(7.22 ± 0.34)	(4.3 ± 1.0)	(0.21 ± 0.06)
	2004	mature	23	(7.43 ± 0.24)	(4.2 ± 0.6)	(0.20 ± 0.03)
	2005	mature	25	(7.44 ± 0.32)	(3.5 ± 0.6)	(0.25 ± 0.05)
	2006	mature	10	(7.52 ± 0.29)	(4.4 ± 0.8)	(0.22 ± 0.03)
	2007	mature	14	(7.33 ± 0.59)	(4.1 ± 0.8)	(0.23 ± 0.06)
	2008	mature	5	(7.26 ± 0.21)	(4.3 ± 1.0)	(0.25 ± 0.01)
	2009	mature	6	(7.54 ± 0.37)	(4.3 ± 0.4)	(0.21 ± 0.07)
	2010	mature	3	(7.49 ± 0.21)	(3.8 ± 0.4)	(0.23 ± 0.02)
	2011spring	mature	4	(7.40 ± 0.41)	(3.2 ± 0.6)	(0.24 ± 0.03)
	2011autumn	mature	10	(7.26 ± 0.37)	(4.4 ± 1.0)	(0.23 ± 0.02)
	2012	mature	5	(7.48 ± 0.21)	(5.0 ± 0.7)	(0.21 ± 0.06)
	2013	mature	23	(7.33 ± 0.35)	(5.0 ± 0.9)	(0.19 ± 0.04)
	2014	mature	10	(7.33 ± 0.28)	(5.0 ± 0.8)	(0.21 ± 0.09)
	total		152	(7.38 ± 0.35)	(4.3 ± 0.9)	(0.22 ± 0.05)
Sanriku	2003	mature	8	(7.10 ± 0.35)	(2.9 ± 0.5)	(0.18 ± 0.04)
	2005	mature	3	(7.27 ± 0.13)	(2.5 ± 0.3)	(0.29 ± 0.02)
	2006	mature	6	(7.24 ± 0.32)	(2.8 ± 0.2)	(0.19 ± 0.05)
	2007	mature	10	(7.50 ± 0.30)	(2.5 ± 0.4)	(0.25 ± 0.08)
	2008	mature	3	(7.49 ± 0.32)	(3.2 ± 0.3)	(0.19 ± 0.03)
	2009	mature	1	(6.85 ±)	(2.8 ±)	(0.21 ±)
	2010	mature	5	(7.32 ± 0.24)	(3.1 ± 0.6)	(0.20 ± 0.05)
	2012	mature	2	(7.31 ±)	(3.4 ±)	(0.18 ±)
	2013	mature	2	(7.52 ±)	(3.5 ±)	(0.30 ±)
	2014	mature	2	(7.38 ± 0.39)	(2.7 ± 0.3)	(0.31 ± 0.04)
	total		42	(7.32 ± 0.32)	(2.8 ± 0.5)	(0.22 ± 0.06)

Table 1. Continued

subarea	year	maturity	*n*	body length (m)	blubber thickness (cm)	muscular Hg (ppm wet wt.)
8	1996	mature	11	(7.44 ± 0.33)	(2.6 ± 0.5)	(0.25 ± 0.04)
	1997	mature	26	(7.44 ± 0.36)	(3.5 ± 0.6)	(0.27 ± 0.06)
	1998	mature	28	(7.54 ± 0.25)	(2.6 ± 0.4)	(0.23 ± 0.05)
	2001	mature	13	(7.78 ± 0.34)	(2.3 ± 0.4)	(0.21 ± 0.05)
	2002	mature	5	(7.71 ± 0.21)	(3.2 ± 0.6)	(0.20 ± 0.11)
	2003	mature	27	(7.50 ± 0.24)	(2.4 ± 0.4)	(0.18 ± 0.06)
	2005	mature	2	(7.54 ±)	(2.2 ±)	(0.16 ±)
	2006	mature	24	(7.51 ± 0.26)	(2.9 ± 0.6)	(0.21 ± 0.05)
	2007	mature	10	(7.55 ± 0.26)	(2.3 ± 0.4)	(0.22 ± 0.06)
	2008	mature	3	(7.52 ± 0.05)	(2.7 ± 0.4)	(0.23 ± 0.02)
	2009	mature	6	(7.23 ± 0.34)	(3.2 ± 0.6)	(0.20 ± 0.06)
	total		155	(7.52 ± 0.30)	(2.8 ± 0.6)	(0.22 ± 0.06)
9	1994	mature	16	(7.42 ± 0.27)	(3.5 ± 0.7)	(0.36 ± 0.16)
	1995	mature	68	(7.45 ± 0.31)	(3.1 ± 0.5)	(0.27 ± 0.06)
	1997	mature	39	(7.41 ± 0.32)	(3.1 ± 0.5)	(0.25 ± 0.11)
	2000	mature	12	(7.51 ± 0.23)	(2.6 ± 0.5)	(0.16 ± 0.03)
	2001	mature	19	(7.69 ± 0.29)	(2.5 ± 0.4)	(0.19 ± 0.05)
	2002	mature	21	(7.55 ± 0.21)	(2.9 ± 0.6)	(0.20 ± 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	25	(7.49 ± 0.29)	(3.5 ± 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)
	2008	mature	36	(7.45 ± 0.26)	(3.1 ± 0.7)	(0.30 ± 0.15)
	2009	mature	5	(7.41 ± 0.41)	(3.0 ± 0.8)	(0.19 ± 0.06)
	2010	mature	9	(7.66 ± 0.23)	(3.2 ± 0.5)	(0.22 ± 0.03)
	2013	mature	3	(7.59 ± 0.22)	(4.0 ± 1.3)	(0.19 ± 0.06)
	total		351	(7.49 ± 0.28)	(3.2 ± 0.7)	(0.24 ± 0.10)

Table 2. Biological data and mercury concentrations in muscle of sei whales (males) from western North Pacific during 2002 and 2014

subarea	year	matuarity	*n*	body length (m)	blubber thickness (cm)	musclar Hg (ppm wet wt.)
9	2002	mature	5	(13.60 ± 0.16)	(4.7 ± 0.5)	(0.050 ± 0.012)
	2003	mature	5	(13.80 ± 0.43)	(4.7 ± 0.7)	(0.057 ± 0.007)
	2004	mature	5	(13.61 ± 0.04)	(4.1 ± 0.6)	(0.050 ± 0.009)
	2005	mature	5	(13.54 ± 0.38)	(4.8 ± 0.6)	(0.049 ± 0.011)
	2006	mature	5	(13.84 ± 0.51)	(4.9 ± 0.6)	(0.052 ± 0.006)
	2007	mature	5	(13.92 ± 0.08)	(5.8 ± 0.7)	(0.058 ± 0.010)
	2011	mature	15	(13.82 ± 0.42)	(4.8 ± 0.8)	(0.039 ± 0.009)
	2012	mature	21	(13.74 ± 0.45)	(5.0 ± 0.5)	(0.030 ± 0.011)
	2013	mature	26	(13.76 ± 0.50)	(5.6 ± 0.8)	(0.040 ± 0.009)
	2014	mature	21	(13.80 ± 0.36)	(4.8 ± 0.5)	(0.053 ± 0.009)
total	2002-2014	mature	113	(13.76 ± 0.41)	(5.0 ± 0.8)	(0.044 ± 0.013)

Table 3. Biological data and mercury concentrations in muscle of Bryde's whales (males) from western North Pacific during 2002 and 2014

subarea	year	matuarity	*n*	body length (m)	blubber thickness (cm)	musclar Hg (ppm wet wt.)
8, 9	2002	mature	5	(12.67 ± 0.43)	(4.5 ± 0.6)	(0.051 ± 0.008)
	2004	mature	5	(12.59 ± 0.36)	(4.4 ± 0.7)	(0.045 ± 0.008)
	2006	mature	5	(12.36 ± 0.47)	(4.5 ± 0.5)	(0.040 ± 0.011)
	2007	mature	5	(12.63 ± 0.35)	(3.9 ± 0.7)	(0.049 ± 0.008)
	2011	mature	3	(12.31 ± 0.27)	(3.6 ± 0.5)	(0.022 ± 0.005)
	2012	mature	6	(12.85 ± 0.48)	(4.8 ± 1.0)	(0.046 ± 0.019)
	2013	mature	9	(12.79 ± 0.38)	(4.7 ± 0.8)	(0.047 ± 0.010)
total	2002-2013	mature	38	(12.64 ± 0.41)	(4.4 ± 0.8)	(0.044 ± 0.013)

Table 4. Results of multiple linear regression analysis with "total Hg levels in muscle of common minke whales from subarea 7" as the dependent variable.

a) Model of regression

Model	R^2	$R^{2\prime}$
1	0.981	0.980

b) Analysis of Variance Table

Model	DF	SE	F value	P value
Regression	274		1068	<0.001
Residual	274	0.221		

c) Variables

Model	B	SE	T	P value
Year	25.722	6.801	3.78	**<0.001**
Body length	-0.092	0.220	-0.42	0.676
Blubber thickness	0.072	0.061	1.19	0.236
longitude	-0.078	0.529	-0.15	0.884
latitude	-0.048	0.427	-0.11	0.911
Date	0.037	0.042	0.88	0.378
MainPrey_Anchovy	-196.550	52.934	-3.71	**<0.01**
MainPrey_Euphausiids	-196.477	52.929	-3.71	**<0.01**
MainPrey_JFSquid	-196.483	52.922	-3.71	**<0.01**
MainPrey_Mackerel	-196.176	52.946	-3.71	**<0.01**
MainPrey_Sardine	-196.835	52.951	-3.72	**<0.01**
MainPrey_Saury	-196.460	52.921	-3.71	**<0.01**
MainPrey_WalleyePollock	-196.428	52.934	-3.71	**<0.01**

Table 5. Results of multiple linear regression analysis with "total Hg levels in muscle of common minke whales from off Kushiro" as the dependent variable.

a) Model of regression

Model	R^2	$R^{2\prime}$
1	0.975	0.974

b) Analysis of Variance Table

Model	DF	SE	F value	P value
Regression	146		950.7	<0.001
Residual	146	0.255		

c) Variables

Model	B	SE	T	P value
Year	2.989	7.420	0.40	0.688
Body length	0.874	0.427	2.05	**<0.05**
Blubber thickness	-0.368	0.096	-3.82	**<0.001**
latitude	0.932	8.143	0.11	0.909
longitude	-5.895	12.355	-0.48	0.634
Date	0.136	0.216	0.63	0.532

Table 6. Results of multiple linear regression analysis with "total Hg levels in muscle of common minke whales from off Sanriku" as the dependent variable.

a) Model of regression

Model	R^2	$R^{2\prime}$
1	0.975	0.971

b) Analysis of Variance Table

Model	DF	SE	F value	P value
Regression	36		233.7	<0.001
Residual	36	0.269		

c) Variables

Model	B	SE	T	P value
Year	24.639	32.754	0.75	0.457
Body length	-0.031	0.028	-1.12	0.272
Blubber thickness	-0.461	0.280	-1.65	0.109
latitude	22.444	18.758	1.20	0.239
longitude	-54.886	57.835	-0.95	0.349
Date	1.111	0.475	2.34	**<0.05**

Table 7. Results of multiple linear regression analysis with "total Hg levels in muscle of common minke whales from subarea 8" as the dependent variable.

a) Model of regression

Model	R^2	$R^{2\prime}$
1	0.968	0.965

b) Analysis of Variance Table

Model	DF	SE	F value	P value
Regression	140		348.7	<0.001
Residual	140	0.298		

c) Variables

Model	B	SE	T	P value
Year	-23.423	14.788	-1.58	0.115
Body length	0.911	0.623	1.46	0.146
Blubber thickness	0.358	0.122	2.94	**<0.01**
latitude	0.253	1.389	0.18	0.856
longitude	-6.367	2.648	-2.41	**<0.05**
Date	-0.066	0.523	-0.13	0.900
MainPrey_Anchovy	205.475	107.118	1.92	0.057
MainPrey_Copepods	205.482	107.134	1.92	0.057
MainPrey_Euphausiids	205.412	107.133	1.92	0.057
MainPrey_JFSquid	205.444	107.134	1.92	0.057
MainPrey_Mackerel	205.822	107.145	1.92	0.057
MainPrey_Saury	205.660	107.109	1.92	0.057

Table 8. Results of multiple linear regression analysis with "total Hg levels in muscle of common minke whales from subarea 9" as the dependent variable.

a) Model of regression

Model	R^2	$R^{2'}$
1	0.956	0.954

b) Analysis of Variance Table

Model	DF	SE	F value	P value
Regression	331		446.2	<0.001
Residual	331	0.338		

c) Variables

Model	B	SE	T	P value
Year	-38.440	7.845	-4.90	**<0.001**
Body length	0.419	0.492	0.85	0.395
Blubber thickness	0.168	0.089	1.88	0.061
latitude	2.349	0.666	3.53	**<0.001**
longitude	-0.122	0.947	-0.13	0.897
Date	-1.485	0.291	-5.10	**<0.001**
MainPrey_Anchovy	284.248	59.440	4.78	**<0.001**
MainPrey_AtkaMackerel	283.767	59.455	4.77	**<0.001**
MainPrey_Copepods	284.147	59.467	4.78	**<0.001**
MainPrey_Euphausiids	284.118	59.444	4.78	**<0.001**
MainPrey_Mackerel	284.285	59.480	4.78	**<0.001**
MainPrey_Min.arm squid	283.987	59.454	4.78	**<0.001**
MainPrey_OceanicLightfish	283.768	59.477	4.77	**<0.001**
MainPrey_PacificPomfret	284.941	59.454	4.79	**<0.001**
MainPrey_Salmonids	284.422	59.423	4.79	**<0.001**
MainPrey_Saury	284.391	59.446	4.78	**<0.001**

Table 9. Results of multiple linear regression analysis with "total Hg levels in muscle of sei whales from subarea 9" as the dependent variable.

a) Model of regression

Model	R^2	$R^{2'}$
1	0.991	0.989

b) Analysis of Variance Table

Model	DF	SE	F value	P value
Regression	76		640	<0.001
Residual	76	0.330		

c) Variables

Model	B	SE	T	P value
Year	-58.878	23.932	-2.46	**<0.05**
Body length	2.777	1.298	2.14	**<0.05**
Blubber thickness	0.046	0.263	0.18	0.861
latitude	0.394	1.183	0.33	0.740
longitude	-2.826	1.626	-1.74	0.086
Date	-0.452	0.542	-0.83	0.407
MainPrey_Anchovy	451.250	182.421	2.47	**<0.05**
MainPrey_Copepods	451.053	182.466	2.47	**<0.05**
MainPrey_Euphausiids	450.978	182.411	2.47	**<0.05**
MainPrey_Mackerel	451.224	182.484	2.47	**<0.05**
MainPrey_Min.arm squid	451.305	182.482	2.47	**<0.05**
MainPrey_Sardine	451.469	182.478	2.47	**<0.05**
MainPrey_Saury	451.034	182.468	2.47	**<0.05**

Table 10. Results of multiple linear regression analysis with "total Hg levels in muscle of Bryde's whales from subareas 8 and 9" as the dependent variable.

a) Model of regression

Model	R^2	$R^{2'}$
1	0.996	0.994

b) Analysis of Variance Table

Model	DF	SE	F value	P value
Regression	20		556.8	<0.001
Residual	20	0.236		

c) Variables

Model	B	SE	T	P value
Year	-51.096	32.449	-1.58	0.131
Body length	3.656	1.698	2.15	**<0.05**
Blubber thickness	0.299	0.307	0.97	0.342
latitude	-2.978	1.708	-1.74	0.097
longitude	6.070	4.352	1.40	0.178
Date	1.030	0.642	1.60	0.124
MainPrey_Anchovy	353.841	237.095	1.49	0.151
MainPrey_Euphausiids	353.823	237.142	1.49	0.151
MainPrey_Mackerel	353.812	237.076	1.49	0.151

Table 11. Comparison between muscular Hg levels in common minke whales per main prey items observed from subarea 7 and the whole body Hg levels in the prey items from the western North Pacific

		Anchovy	Euphausiids	JFSquid	Mackerel	Sardine	Saury	WalleyePollock
Muscle of whales	Ave.±SD	0.21 ± 0.051	0.22 ± 0.049	0.22 ± 0.03	0.33 ±	0.17 ±	0.23 ± 0.043	0.24 ± 0.056
	n	238	33	8	1	2	26	28
whole of prey spp.	Ave.±SD	0.037 ± 0.025	0.005 ± 0.003	0.058 ±	0.020 ± 0.002	0.018 ±	0.038 ± 0.015	0.045 ±
	n	20*	19*	57**	5*	66**	41*	2*

*: Yasunaga and Fujise (2009); **: Ministry of Health, Labour and Welfare (2005)

Table 12. Comparison between muscular Hg levels in common minke whales per main prey items observed from subarea 9 and the whole body Hg levels in the prey items from the western North Pacific

		Anchovy	Atka Mackerel	Copepods	Euphausiids	Mackerel	MAFSquid	Oceanic Lightfish	Pacific Pomfret	Salmonids	Saury
Muscle of whales	Ave.±SD	0.22 ± 0.10	0.13 ±	0.17 ± 0.07	0.18 ± 0.09	0.19 ± 0.04	0.19 ± 0.12	0.11 ±	0.44 ± 0.26	0.32 ± 0.08	0.24 ± 0.09
	n	83	1	6	15	3	5	1	6	5	257
whole of prey spp.	Ave.±SD	0.037 ± 0.025	0.086 ±	0.005 ± 0.003	0.005 ± 0.003	0.020 ± 0.002	±	±	0.23 ± 0.03	0.027 ±	0.038 ± 0.015
	n	20*	61**	5*	19*	5*			3*	41**	41*

*: Yasunaga and Fujise (2009); **: Ministry of Health, Labour and Welfare (2005)

Table 13. Comparison between muscular Hg levels in sei whales per main prey items observed from subarea 9 and the whole body Hg levels in the prey items from the western North Pacific

		Anchovy	Copepods	Euphausiids	Mackerel	Min.arm squid	Sardine	Saury
Muscle of whales	Ave.±SD	0.049 ± 0.013	0.043 ± 0.014	0.045 ± 0.016	0.045 ± 0.016	0.040 ± 0.005	0.052 ±	0.041 ± 0.015
	n	11	48	9	9	3	2	7
whole of prey spp.	Ave.±SD	0.037 ± 0.025	0.005 ± 0.003	0.005 ± 0.003	0.020 ± 0.002		0.018 ±	0.038 ± 0.015
	n	20*	5*	19*	5*		66**	41*

*: Yasunaga and Fujise (2009); **: Ministry of Health, Labour and Welfare (2005)

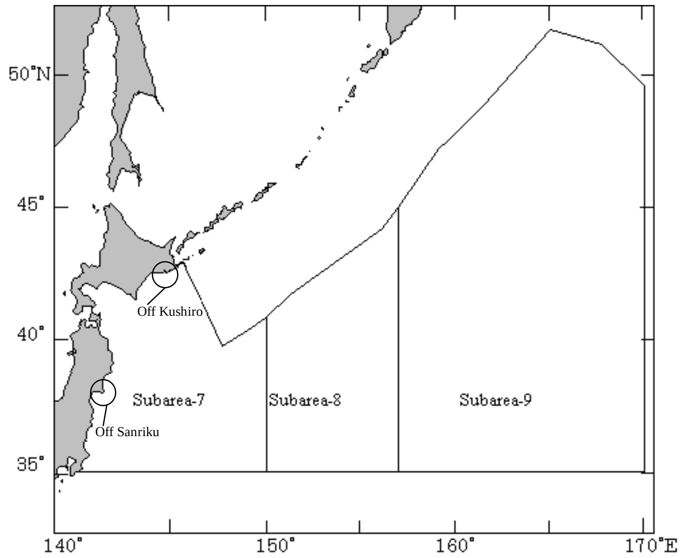

Figure 1. Sub-areas surveyed by the JARPNII research. Sub-areas based on IWC (1994), excluding the EEZ of Russia

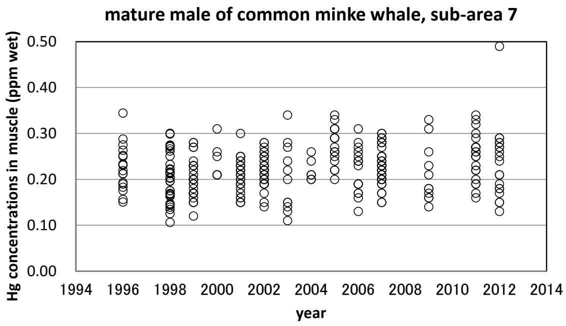

Figure 2a. Yearly change of Total Hg concentrations in muscle of common minke whales (mature males, O-stock) in sub-area 7 during the period 1996-2012

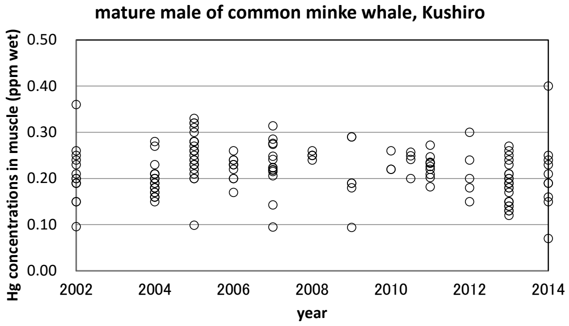

Figure 2b. Yearly change of Total Hg concentrations in muscle of common minke whales (mature males, O-stock) in off Kushiro during the period 2002-2014

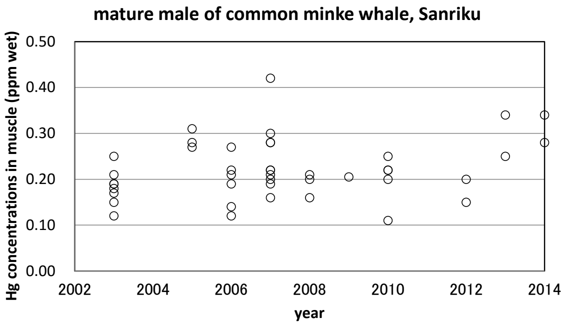

Figure 2c. Yearly change of Total Hg concentrations in muscle of common minke whales (mature males, O-stock) in off Sanriku during the period 2002-2014

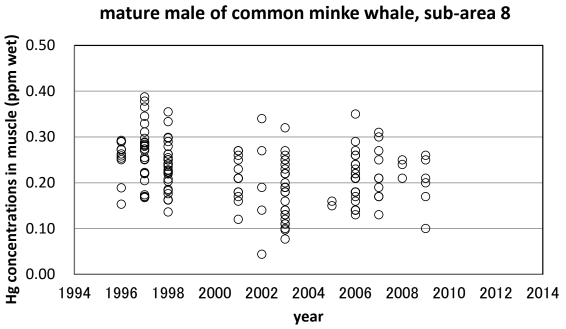

Figure 2d. Yearly change of Total Hg concentrations in muscle of common minke whales (mature males, O-stock) in sub-area 8 during the period 1996-2009

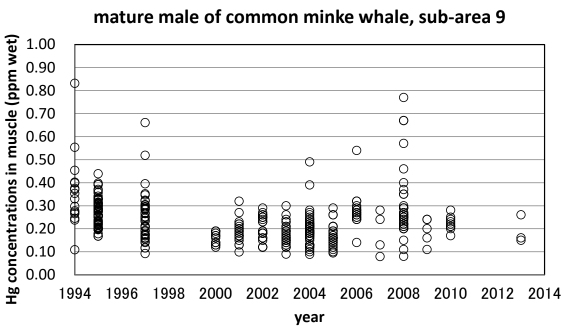

Figure 2e. Yearly change of Total Hg concentrations in muscle of common minke whales (mature males, O-stock) in sub-area 9 during the period 1994-2013

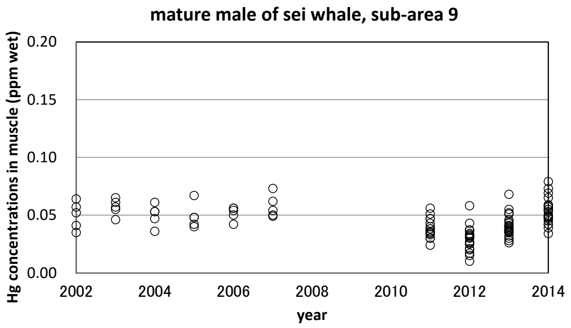

Figure 2f. Yearly change of Total Hg concentrations in muscle of sei whales (mature males) in sub-area 9 during the period 2002-2014

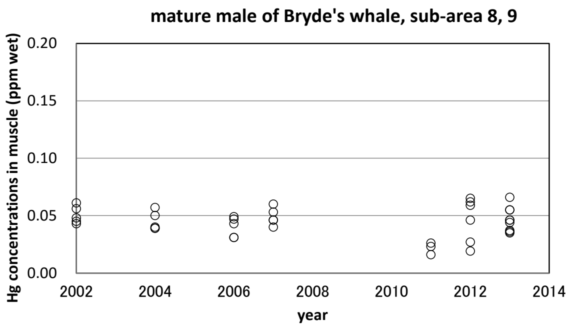

Figure 2g. Yearly change of Total Hg concentrations in muscle of Bryde’s whales (mature males) in sub-areas 8 and 9 during the period 2002-2013