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ABSTRACT

This paper is the revised version of SC/J16/JR31, which described the results of multiple linear regression analyses of PCB in blubber of common minke whales (*Balaenoptera acutorostrata*) based on the JARPN and JARPNII, presented to the Expert Workshop to review the results from the JARPNII Programme. To examine yearly changes of PCB in the western North Pacific, PCB concentrations in blubber of O-stock mature males of minke whales from the western North Pacific, were measured. Averages and standard deviations of PCB concentrations in blubber of minke whales from sub-area 7 (period 2002-2012), off Kushiro (period 2002-2014), off Sanriku (period 2003-2014), sub-areas 8 (period 2002-2009) and 9 (period 2002-2013) were 0.83±0.49, 0.63±0.41, 1.2±0.58, 1.0±0.75 and 0.59±0.34, ppm wet wt., respectively. Multiple linear regression analysis was carried out. Data included adjustment for confounders, sampling years, sampling longitude, latitude, sampling date, body length, blubber thickness and main prey species. No significant correlations between year and food items were observed for all areas. It is suggested that PCB levels in minke whales from the western North Pacific were stable during 2002-2014, and that these levels may not have any adverse effect on whale health. The results of this revised version confirmed the main conclusion in SC/F16/JR31.

KEYWORDS: COMMON MINKE WHALE; NORTH PACIFIC; PCB; MONITORING

INTRODUCTION

Pollutants bioaccumulate through the food web in the marine ecosystem. Because cetaceans are located at the top of the ecosystem they are frequently used for monitoring the pollutants in the marine environment. They are mobile and long-lived animals, and these characteristics mean that pollutants can be monitored in wide sea areas and integrated in some way over time. Polychlorinated biphenyl (PCB) is man-made chemical that had been widely used throughout the world in electrical equipment such as transformers and capacitors until the 1970s. In spite of the ban of production and usage in the 1970s, PCB is still being released into the environment due to its lipophilic and highly persistent character. Especially, top marine predators such as whales tend to accumulate PCB in their fatty tissues with growth (Tanabe *et al.*, 1981; Connell, 1988). The Japanese Whale Research Programme under Special Permit in the North Pacific Phase II (JARPNII) was designed so that samples could be obtained for investigating the quantitative behaviour and fate of PCB in the marine environment.

In the western North Pacific, yearly change of PCB concentrations in marine mammals have been reported previously. Tanabe *et al.*, (1994) reported temporal variation of PCB in female northern fur seals. The concentration showed a maximum in around 1976 and then decreased until 1988. Aono *et al.*, (1997) examined PCB in blubber of common minke whales (*Balaenoptera acutorostrata*) from the western North Pacific between 1987 and 1994. No trend in the concentration was observed in this period. Kajiwara *et al.* (2004) reported that the PCB concentrations and compositions were steady-stable in fat tissues of female northern fur seals collected in the period 1972-1998 from the Japanese Pacific coast, suggesting a continuous input of PCB into the marine environment in significant quantities.

In the 2009 review workshop, Yasunaga and Fujise (2009) presented a study on temporal changes of PCB concentrations in blubber samples of common minke, sei (*B. borealis*) and Bryde's (*B. edeni*) whales from the western North Pacific. Yearly changes of PCB concentrations were not observed in minke, sei and Bryde's whales in the research period 2002-2007, whereas previous studies reported temporal variation of PCB concentrations in the northern fur seals (Tanabe *et al.*, 1994; Kajiwara *et al.*, 2004) and minke whales (Aono *et al.*, 1997) from the western North Pacific with a maximum in 1976 and a decreasing trend until approximately 2000. These results lead us to propose the following working hypothesis. PCB concentrations in baleen whales from the western North Pacific decreased until the end of the decade of the 1990's and then they have stabilized since the 2000's.

This study examines concentrations and yearly changes of PCB concentrations in O-stock mature male common minke whales. Further, body length, blubber thickness, stomach content and sexual maturity information obtained during JARPN and JARPNII surveys are considered to assist in the interpretation of factors affecting PCB concentrations.

This paper is a revised version of SC/F16/JR31 to cover the recommendations of the expert panel of the Expert Workshop to review the results from the JARPNII Programme held at Tokyo from 22-26 of February. The panel recommended that the statistical analyses should be improved and the pollutant concentrations found should be evaluated in comparison with data from previous studies conducted in comparable species and available in the literature.

MATERIALS AND METHODS

Samples and sampling method

Blubber tissues of mature males of the common minke whales (Okhotsk Sea-West Pacific stock) from sub-area 7, off Sanriku, off Kushiro, sub-areas 8 and 9 were collected by JARPNII researchers in the surveys conducted in the period from 2002 to 2015 (Fig. 1). Table 1 shows the sample sizes *n* and maturity stage as well as means of body length, blubber thickness and PCB concentrations in blubber by year, with standard deviations (SD). The blubber samples were frozen and stored at -20˚C until chemical analysis.

Laboratory analysis

The blubber samples were sent to the Japan Food Research Laboratories (Tokyo, Japan) for PCB analyses. Analyses were performed according to the public analytical method of Japan (Japan Ministry of Welfare, 1972).

Statistical analysis

The yearly changes of PCB concentrations in whales were assessed by multiple linear regression in the context of other factors in whales (R Development Core Team, 2006). The following independent variables: “Year”, “Date”, “Latitude”, “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). Anchovy is the baseline prey item in sub-areas 7-9 so the effects of anchovy being the main prey item are included in the model intercepts. Data sets were excluded from analyses in case of empty stomach and damage by harpoon. Also, multiple robust linear regression analyses were conducted to examine the effect of outliers in the same way. Furthermore, a generalized additive model (GAM) was used to examine flexion point in the yearly changes of total Hg concentrations in muscle of whales. A *p* value of less than 0.05 was considered to indicate statistical significance in all tests. These statistical analyses were performed using the free software R, version 3.3.0 (R Development Core Team, 2006).

RESULTS

Table 1 shows the PCB concentrations in blubber of O stock mature males of minke whales from sub-area 7, off Kushiro, off Sanriku, sub-areas 8 and 9. Averages and standard deviations of PCB concentrations in blubber samples of minke whales were 0.83±0.49, 0.63±0.41, 1.2±0.58, 1.0±0.75 and 0.59±0.34, ppm wet wt., respectively.
To examine yearly changes of PCB concentrations in minke whales and their confounders in sub-area 7, off Kushiro, off Sanriku, sub-areas 8 and 9, multiple linear regression analyses were conducted, and the results are given in Tables 2-6, respectively. Based on the F test results in these tables, the overall regression was statistically significant except for those from off Sanriku (Table 4). In the other cases, PCB concentrations were not associated with Year (Table 2-3, 5-6). Regression models were significant for all areas, except for off Sanriku. Consequently, Body length (+) and Date (-) were significantly associated in PCB concentrations in minke whales from sub-area 7 (Table 2), Body length (+), blubber thickness (-) and date (-) were significantly associated in those from off Kushiro (Table 3), Body length (+), Mackerel (-) and Pacific saury (-) were associated in those from sub-area 8 (Tables 5), and Body length (+) was significantly associated in those from sub-area 9 (Tables 6). Similarly, PCB concentrations in minke whale were not significantly associated with Year by multiple robust linear regression analyses (Tables 7-11). Also, flexion points were not observed in simple plots and, when possible, smoothing plots using the GAM of PCB concentrations against their sampling year in Figs. 2b, 2c and 2e, while the smoothing plots in sub-areas 7 and 8 were removed because of insufficient data sets.

DISCUSSION

In the multiple regression analyses of PCB concentrations in minke whales, Body length was significantly associated for positive covariance in the all areas, and Blubber thickness and Date were significantly associated for negative covariance in some areas. One reason for this is a strong positive association between persistent PCB concentrations and age or body length in marine mammals (Aguilar *et al.*, 1999; Tanabe *et al.*, 1987). Furthermore, negative correlations between PCB concentrations and Date or Blubber thickness in minke whales were observed, because PCB concentrations may be diluted by rapidly increasing body weight and fat volume in a feeding season. On the other hand, Year and Main food items were not significantly associated in these analyses, whereas they were significantly associated in the total Hg analyses of minke whales from sub-areas 7 and 9 (Yasunaga and Fujise, 2016). This is attributed to higher persistence of PCB in a whale body as compared to Hg. Furthermore, results of multiple robust linear regression and GAM analyses suggested no effect of outliers and flexion points on these results. By considering the covariates, PCB concentrations stabilized in minke whales from the western North Pacific during 2002-2014.

There are some reports of yearly changes of PCB concentrations in the western North Pacific using marine mammals as biological indicator. Tanabe *et al.*, (1994) reported temporal variation of PCB with a maximum in 1976 and a decreasing trend until 1988 in female northern fur seals. Kajiwara *et al.* (2004) reported that PCB concentrations in fat tissues of female northern fur seals collected from off Sanriku coast in the period 1972 - 1998 continually decreased since the early 1980s. Aono *et al.*, (1997) reported that the PCB concentrations in blubber of common minke whales from the western North Pacific (offshore) between 1987 (1.5-3.0 ppm wet wt.) and 1994 (0.62-3.1 ppm wet wt.) were similar, whereas these concentrations were lower than those in the present study during 2002-2014. These results indicate that ban of usage of PCB in developed nations after the 1970s has influenced on PCB concentrations in whales in the western North Pacific. On the other hand, Kajiwara et al. (2008) reported that PCB concentrations in melon-headed whales from the coast of Japan in 2001/02 were significantly lower than those in 1982, whereas there was no significant difference between those in 2001/02 and in 2006. Isobe *et al.* (2009) reported that there were no significant differences of PCB concentrations in striped dolphins from the coast of Japan among samples from 1978, 1979, 1986 and 1992. These observations indicate that the rate of degradation and deposit of PCB in this area would have been slow since approximately 2000' and/or an exiguous PCB existing in the environment would continuously input into the marine environment near the Japanese coast. Our findings support the hypothesis from the 2009 JARPNII review, that "The PCB concentrations in marine mammals in coastal Japan had continually decreased until the end of 1990's, and it has stabilized since at least from 2002 (Yasunaga and Fujise, 2009)".

Kannan et al. (2000) reported a threshold concentration of 17,000 ng/g fat wt. for adverse effects from PCB exposure in the blubber of marine mammals. PCB levels in common minke whales in this study are much lower than this level, and these levels may not have adverse effects on whale health. Furthermore, the mRNA expression levels of seven cytochrome P450 genes in common minke whales from the western North Pacific showed no clear correlations with the concentration of PCB (Niimi *et al.*, 2014), suggesting that PCB levels in the liver are lower than hepatic toxicity levels in this species.

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Table 1. Mean ± SD of body length, blubber thickness and PCB concentration in blubber of common minke whales (mature males) from the western North Pacific. Data are shown for years with samples from 2002 through 2014.

subarea	year	maturity	*n*	body length (m)	blubber thickness (cm)	PCB in blubber (ppm wet wt.)
7	2002	mature	33	(7.52 ± 0.27)	(3.7 ± 0.8)	(0.74 ± 0.31)
	2003	mature	11	(7.42 ± 0.40)	(2.4 ± 0.5)	(1.38 ± 0.79)
	2004	mature	6	(7.56 ± 0.21)	(4.1 ± 0.6)	(0.42 ± 0.11)
	2005	mature	17	(7.51 ± 0.23)	(3.3 ± 0.9)	(0.83 ± 0.44)
	2006	mature	16	(7.39 ± 0.39)	(2.4 ± 0.7)	(0.87 ± 0.40)
	2007	mature	41	(7.47 ± 0.26)	(3.0 ± 0.7)	(0.75 ± 0.32)
	2009	mature	11	(7.71 ± 0.26)	(3.2 ± 0.7)	(0.81 ± 0.48)
	2011	mature	23	(7.47 ± 0.34)	(3.5 ± 0.6)	(0.60 ± 0.30)
	2012	mature	19	(7.37 ± 0.34)	(2.6 ± 0.4)	(1.24 ± 0.71)
	total		177	(7.48 ± 0.31)	(3.1 ± 0.8)	(0.83 ± 0.49)
Kushiro	2002	mature	14	(7.22 ± 0.34)	(4.3 ± 1.0)	(0.64 ± 0.26)
	2004	mature	23	(7.43 ± 0.24)	(4.2 ± 0.6)	(0.50 ± 0.22)
	2005	mature	25	(7.44 ± 0.32)	(3.5 ± 0.6)	(0.58 ± 0.18)
	2006	mature	10	(7.52 ± 0.29)	(4.4 ± 0.8)	(0.72 ± 0.54)
	2007	mature	14	(7.33 ± 0.59)	(4.1 ± 0.8)	(0.67 ± 0.30)
	2008	mature	5	(7.26 ± 0.21)	(4.3 ± 1.0)	(0.58 ± 0.31)
	2009	mature	6	(7.54 ± 0.37)	(4.3 ± 0.4)	(0.84 ± 0.35)
	2010	mature	3	(7.49 ± 0.21)	(3.8 ± 0.4)	(1.00 ± 0.45)
	2011spring	mature	4	(7.40 ± 0.41)	(3.2 ± 0.6)	(1.51 ± 1.20)
	2011autumn	mature	10	(7.26 ± 0.37)	(4.4 ± 1.0)	(0.53 ± 0.26)
	2012	mature	5	(7.48 ± 0.21)	(5.0 ± 0.7)	(0.51 ± 0.15)
	2013	mature	23	(7.33 ± 0.35)	(5.0 ± 0.9)	(0.56 ± 0.36)
	2014	mature	10	(7.33 ± 0.28)	(5.0 ± 0.8)	(0.69 ± 0.77)
	total		152	(7.38 ± 0.35)	(4.3 ± 0.9)	(0.63 ± 0.41)
Sanriku	2003	mature	8	(7.10 ± 0.35)	(2.9 ± 0.5)	(0.82 ± 0.14)
	2005	mature	3	(7.27 ± 0.13)	(2.5 ± 0.3)	(1.10 ± 0.26)
	2006	mature	6	(7.24 ± 0.32)	(2.8 ± 0.2)	(1.48 ± 1.00)
	2007	mature	10	(7.50 ± 0.30)	(2.5 ± 0.4)	(1.11 ± 0.53)
	2008	mature	3	(7.49 ± 0.32)	(3.2 ± 0.3)	(1.55 ± 0.75)
	2009	mature	1	(6.85 ±)	(2.8 ±)	(1.60 ±)
	2010	mature	5	(7.32 ± 0.24)	(3.1 ± 0.6)	(1.20 ± 0.51)
	2012	mature	2	(7.31 ± 0.37)	(3.4 ± 0.57)	(1.16 ± 1.05)
	2013	mature	2	(7.52 ± 0.18)	(3.5 ± 0.07)	(1.09 ± 0.44)
	2014	mature	2	(7.38 ± 0.39)	(2.7 ± 0.3)	(1.13 ± 0.25)
	total		42	(7.32 ± 0.32)	(2.8 ± 0.5)	(1.16 ± 0.58)
8	2002	mature	5	(7.71 ± 0.21)	(3.2 ± 0.6)	(0.87 ± 0.43)
	2003	mature	27	(7.50 ± 0.24)	(2.4 ± 0.4)	(1.13 ± 0.86)
	2005	mature	2	(7.54 ± 0.08)	(2.2 ± 0.00)	(1.82 ± 1.81)
	2006	mature	24	(7.51 ± 0.26)	(2.9 ± 0.6)	(0.99 ± 0.77)
	2007	mature	10	(7.55 ± 0.26)	(2.3 ± 0.4)	(0.83 ± 0.38)
	2008	mature	3	(7.52 ± 0.05)	(2.7 ± 0.4)	(0.86 ± 0.36)
	2009	mature	6	(7.23 ± 0.34)	(3.2 ± 0.6)	(0.65 ± 0.51)
	total		77	(7.51 ± 0.26)	(2.6 ± 0.6)	(1.00 ± 0.75)
9	2002	mature	21	(7.55 ± 0.21)	(2.9 ± 0.6)	(0.69 ± 0.25)
	2003	mature	28	(7.50 ± 0.32)	(2.9 ± 0.6)	(0.56 ± 0.21)
	2004	mature	50	(7.47 ± 0.21)	(3.9 ± 0.7)	(0.46 ± 0.23)
	2005	mature	25	(7.49 ± 0.29)	(3.5 ± 0.6)	(0.62 ± 0.44)
	2006	mature	16	(7.56 ± 0.30)	(3.4 ± 0.6)	(0.62 ± 0.43)
	2007	mature	4	(7.56 ± 0.20)	(2.2 ± 0.3)	(0.76 ± 0.44)
	2008	mature	36	(7.45 ± 0.26)	(3.1 ± 0.7)	(0.58 ± 0.36)
	2009	mature	5	(7.41 ± 0.41)	(3.0 ± 0.8)	(0.72 ± 0.49)
	2010	mature	9	(7.66 ± 0.23)	(3.2 ± 0.5)	(0.72 ± 0.61)
	2013	mature	3	(7.59 ± 0.22)	(4.0 ± 1.3)	(0.93 ± 0.19)
	total		197	(7.50 ± 0.26)	(3.3 ± 0.8)	(0.59 ± 0.34)

Table 2. Results of multiple linear regression analyses with "PCB levels in blubber of common minke whales from subarea 7" as the dependent variable.

a) Analysis of Variance Table

Source	Sum of Squares	DF	Mean Square	Other Statistics
Intercept B_0	18.82	1	18.82	R^2=0.285, Adjusted R^2=0.231
Regression | B_0	13.52	12	1.126	F=5.259, p<0.05
Residual	33.841	158	0.214	SE=0.463
Total	66.172	171		

b) Variables

Model	B	SE	T	p value
Intercept	315.17278	236.33293	1.334	0.184
Year	-46.166	30.288	-1.52	0.130
Body length	4.065	0.920	4.42	**<0.05**
Blubber thickness	0.072	0.186	0.39	0.700
Latitude	1.475	2.031	0.73	0.469
Longitude	5.013	3.681	1.36	0.175
Date	-1.649	0.371	-4.44	**<0.05**
MainPrey_Euphausiids	0.220	0.127	1.74	0.084
MainPrey_JFSquid	0.168	0.292	0.58	0.566
MainPrey_Mackerel	0.063	0.469	0.13	0.894
MainPrey_Sardine	0.025	0.339	0.07	0.942
MainPrey_Saury	0.300	0.154	1.95	0.053
MainPrey_WalleyePollock	0.050	0.163	0.31	0.758

Table 3. Results of multiple linear regression analyses with "PCB levels in blubber of common minke whales from off Kushiro" as the dependent variable.

a) Analysis of Variance Table

Source	Sum of Squares	DF	Mean Square	Other Statistics
Intercept B_0	6.14	1	6.14	R^2=0.1418, Adjusted R^2=0.1063
Regression | B_0	3.19	6	0.532	F=3.992, p<0.05
Residual	33.006	145	0.228	SE=0.4771
Total	12.926	152		

b) Variables

Model	B	SE	T	p value
Intercept	-205.8748	213.5155	-0.964	0.337
Year	-3.735	22.169	-0.17	0.866
Body length	1.982	0.802	2.47	**<0.05**
Blubber thickness	-0.523	0.191	-2.73	**<0.05**
Latitude	1.750	15.275	0.12	0.909
longitude	45.529	27.878	1.63	0.105
Date	-1.110	0.414	-2.68	**<0.05**

Table 4. Results of multiple linear regression analyses with "PCB levels in blubber of common minke whales from off Sanriku" as the dependent variable.

a) Analysis of Variance Table

Source	Sum of Squares	DF	Mean Square	Other Statistics
Intercept B_0	0.06	1	0.06	R^2=0.0625, Adjusted R^2=-0.098
Regression | B_0	0.59	6	0.098	F=0.389, p=0.881
Residual	8.789	35	0.251	SE=0.5011
Total	9.437	42		

b) Variables

Model	B	SE	T	p value
Intercept	-460.02764	538.4993	-0.854	0.399
Year	89.848	89.825	1.00	0.324
Body length	0.047	0.052	0.91	0.371
Blubber thickness	0.041	0.531	0.08	0.939
Latitude	5.196	35.646	0.15	0.885
longitude	-48.841	108.346	-0.45	0.655
Date	-0.287	1.169	-0.25	0.808

Table 5. Results of multiple linear regression analyses with "PCB levels in blubber of common minke whales from subarea 8" as the dependent variable.

a) Analysis of Variance Table

Source	Sum of Squares	DF	Mean Square	Other Statistics
Intercept B_0	4.27	1	4.27	R^2=0.411, Adjusted R^2=0.306
Regression | B_0	13.23	11	1.203	F=3.929, p <0.05
Residual	18.994	62	0.306	SE=0.5535
Total	36.501	74		

b) Variables

Model	B	SE	T	p value
Intercept	-101.73	569.2797	-0.179	0.859
Year	13.126	75.277	0.17	0.862
Body length	11.054	2.124	5.20	**<0.05**
Blubber thickness	-0.156	0.366	-0.43	0.671
Latitude	-3.991	3.919	-1.02	0.313
Longitude	-1.454	6.661	-0.22	0.828
Date	1.009	1.362	0.74	0.462
MainPrey_Copepods	-0.233	0.609	-0.38	0.703
MainPrey_Euphausiids	-0.432	0.363	-1.19	0.239
MainPrey_JFSquid	-0.989	0.606	-1.63	0.108
MainPrey_Mackerel	-1.049	0.442	-2.37	**<0.05**
MainPrey_Saury	-0.355	0.176	-2.02	**<0.05**

Table 6. Results of multiple linear regression analyses with "PCB levels in blubber of common minke whales from subarea 9" as the dependent variable.

a) Analysis of Variance Table

Source	Sum of Squares	DF	Mean Square	Other Statistics
Intercept B_0	21.62	1	21.62	R^2=0.1418, Adjusted R^2=0.0747
Regression | B_0	-4.77	14	-0.341	F=2.112, p <0.05
Residual	49.299	179	0.275	SE=0.5248
Total	16.139	194		

b) Variables

Model	B	SE	T	p value
Intercept	-189.41845	259.88996	-0.729	0.467
Year	26.553	34.443	0.77	0.442
Body length	3.833	1.114	3.44	**<0.05**
Blubber thickness	0.018	0.190	0.09	0.925
Latitude	-2.180	1.515	-1.44	0.152
Longitude	-2.600	1.816	-1.43	0.154
Date	0.332	0.690	0.48	0.631
MainPrey_AtkaMackerel	-0.599	0.558	-1.07	0.285
MainPrey_Copepods	-0.284	0.258	-1.10	0.272
MainPrey_Euphausiids	0.106	0.221	0.48	0.632
MainPrey_Mackerel	0.185	0.342	0.54	0.589
MainPrey_MAFSquid	0.020	0.285	0.07	0.945
MainPrey_OceanicLightfish	-0.640	0.545	-1.18	0.241
MainPrey_PacificPomfret	0.051	0.255	0.20	0.842
MainPrey_Saury	-0.107	0.133	-0.80	0.424

Table 7. Results of multiple robust linear regression analyses with "PCB levels in blubber of common minke whales from subarea 7" as the dependent variable.

a) Residual SE and regression coefficient

Robust residual SE	0.437
R^2	0.291
Adjusted R^2	0.237

b) Variables

Model	B	SE	T	*p* value
Intercept	342.22361	338.59895	1.011	0.314
Year	-50.377	41.770	-1.21	0.230
Body length	3.909	0.906	4.31	**<0.05**
Blubber thickness	0.042	0.172	0.25	0.806
Latitude	1.454	2.738	0.53	0.596
Longitude	6.098	5.608	1.09	0.279
Date	-1.646	0.368	-4.47	**<0.05**
MainPrey_Euphausiids	0.221	0.137	1.61	0.109
MainPrey_JFSquid	0.146	0.276	0.53	0.598
MainPrey_Mackerel	0.092	0.078	1.17	0.244
MainPrey_Sardine	0.041	0.126	0.32	0.747
MainPrey_Saury	0.310	0.139	2.22	**<0.05**
MainPrey_WalleyePollock	0.039	0.218	0.18	0.858

Table 8. Results of multiple robust linear regression analyses with "PCB levels in blubber of common minke whales from off Kushiro" as the dependent variable.

a) Residual SE and regression coefficient

Robust residual SE	0.412
R^2	0.190
Adjusted R^2	0.157

b) Variables

Model	B	SE	T	*p* value
Intercept	-119.0491	205.1501	-0.58	0.563
Year	-10.004	20.194	-0.50	0.621
Body length	2.854	1.404	2.03	**<0.05**
Blubber thickness	-0.527	0.155	-3.40	**<0.05**
Latitude	9.251	16.664	0.56	0.580
longitude	31.597	27.870	1.13	0.259
Date	-1.020	0.335	-3.05	**<0.05**

Table 9. Results of multiple robust linear regression analyses with "PCB levels in blubber of common minke whales from off Sanriku" as the dependent variable.

a) Residual SE and regression coefficient

Robust residual SE	0.457
R^2	0.084
Adjusted R^2	-0.073

b) Variables

Model	B	SE	T	*p* value
Intercept	-705.2146	586.06122	-1.203	0.237
Year	126.698	79.525	1.59	0.120
Body length	0.042	0.057	0.73	0.468
Blubber thickness	0.083	0.463	0.18	0.858
Latitude	2.418	52.485	0.05	0.964
longitude	-53.700	128.444	-0.42	0.678
Date	-0.863	1.380	-0.63	0.536

Table 10. Results of multiple robust linear regression analyses with "PCB levels in blubber of common minke whales from subarea 8" as the dependent variable.

a) Residual SE and regression coefficient

Robust residual SE	0.435
R^2	0.442
Adjusted R^2	0.343

b) Variables

Model	B	SE	T	*p* value
Intercept	-322.6232	504.5876	-0.639	0.525
Year	43.073	68.143	0.63	0.530
Body length	11.181	1.905	5.87	**<0.05**
Blubber thickness	-0.227	0.271	-0.84	0.404
Latitude	-2.998	3.541	-0.85	0.400
Longitude	-3.620	8.105	-0.45	0.657
Date	1.136	1.133	1.00	0.320
MainPrey_Copepods	-0.228	0.236	-0.97	0.338
MainPrey_Euphausiids	-0.449	0.267	-1.68	0.097
MainPrey_JFSquid	-1.013	0.195	-5.20	**<0.05**
MainPrey_Mackerel	-1.057	0.238	-4.45	**<0.05**
MainPrey_Saury	-0.359	0.160	-2.25	**<0.05**

Table 11. Results of multiple linear robust regression analyses with "PCB levels in blubber of common minke whales from subarea 9" as the dependent variable.

a) Residual SE and regression coefficient

Robust residual SE	0.475
R^2	0.157
Adjusted R^2	0.091

b) Variables

Model	B	SE	T	*p* value
Intercept	-224.0	262	-0.855	0.394
Year	31.290	34.550	0.91	0.366
Body length	3.784	0.928	4.08	**<0.05**
Blubber thickness	0.007	0.220	0.03	0.973
Latitude	-2.363	1.275	-1.85	0.066
Longitude	-2.766	1.821	-1.52	0.131
Date	0.459	0.662	0.69	**<0.05**
MainPrey_AtkaMackerel	-0.651	0.241	-2.70	0.008
MainPrey_Copepods	-0.401	0.434	-0.92	0.357
MainPrey_Euphausiids	0.009	0.273	0.03	0.975
MainPrey_Mackerel	0.109	0.310	0.35	0.726
MainPrey_MAFSquid	-0.077	0.359	-0.22	0.830
MainPrey_OceanicLightfish	-0.706	0.281	-2.51	**<0.05**
MainPrey_PacificPomfret	0.033	0.263	0.12	0.902
MainPrey_Saury	-0.170	0.220	-0.77	0.440

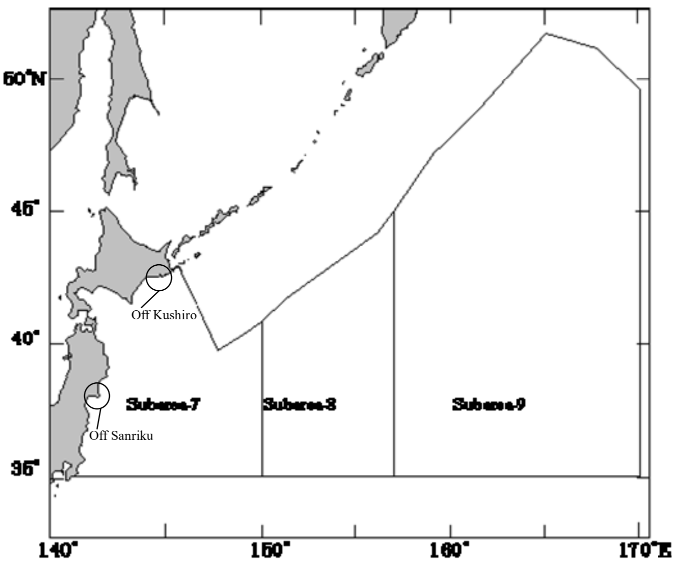

Figure 1. Sub-areas surveyed by the JARPNII research. Sub-areas based on IWC (1994), excluding the EEZ of Russia

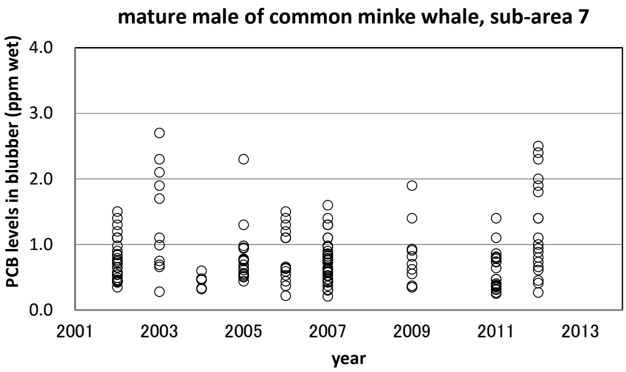

Figure 2a. Simple plots of PCB concentrations in blubber of common minke whales (mature males, O-stock) in sub-area 7 against research years during the period 2002-2012

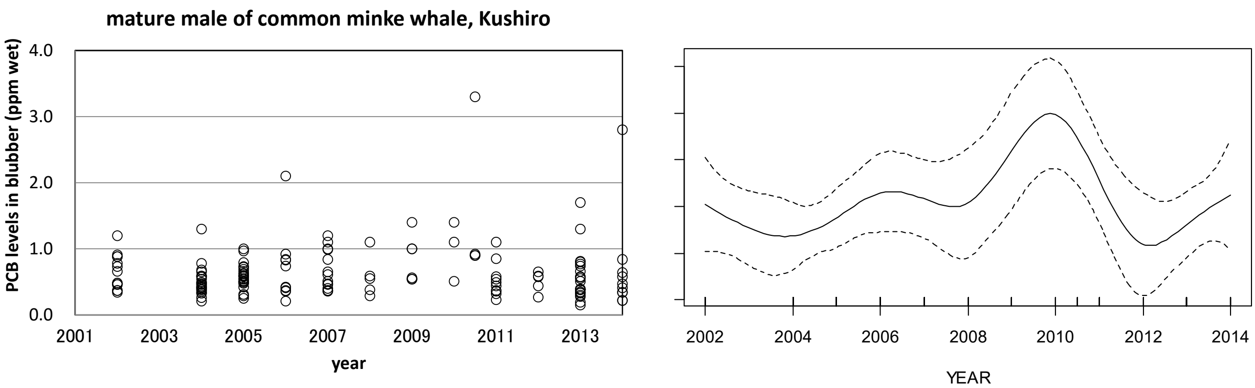

Figure 2b. Simple plots and smoothing plots using the GAM of PCB concentrations in blubber of common minke whales (mature males, O-stock) in off Kushiro against research years during the period 2002-2014

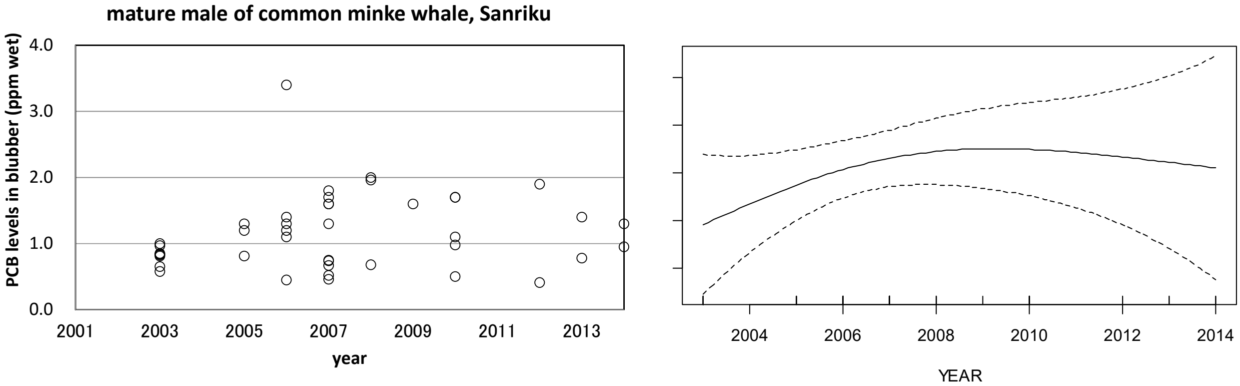

Figure 2c. Simple plots and smoothing plots using the GAM of PCB concentrations in blubber of common minke whales (mature males, O-stock) in off Sanriku against research years during the period 2002-2014

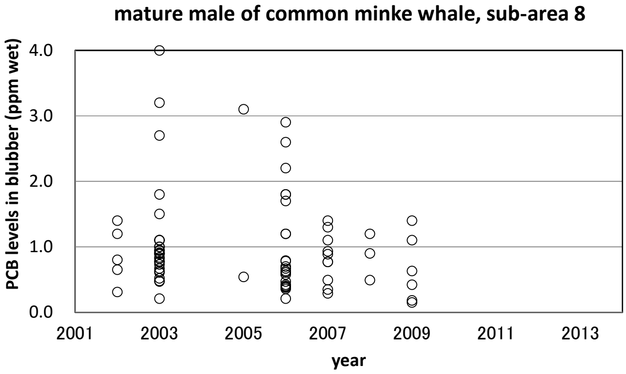

Figure 2d. Simple plots of PCB concentrations in blubber of common minke whales (mature males, O-stock) in sub-area 8 during the period 2002-2009

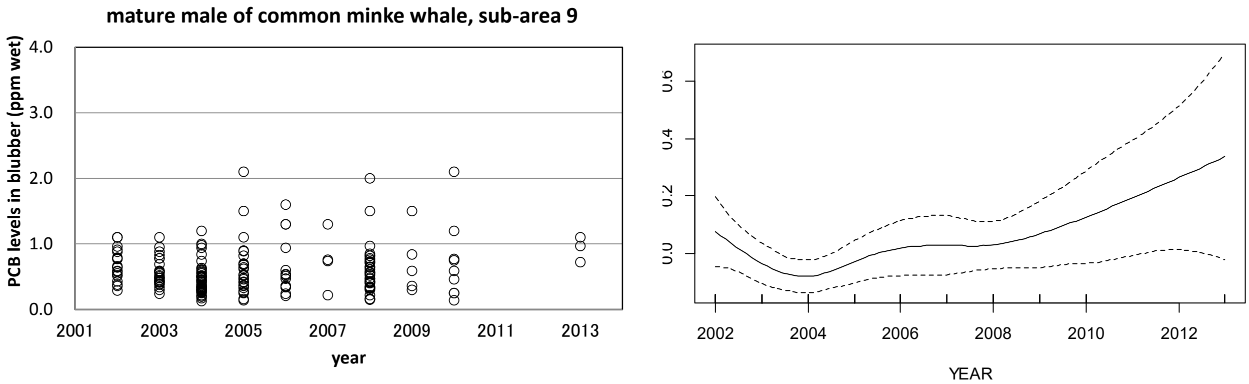

Figure 2e. Simple plots and smoothing plots using the GAM of PCB concentrations in blubber of common minke whales (mature males, O-stock) in sub-area 9 against research years during the period 2002-2013