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Temporal trend of PCB levels in common minke whales from the western North Pacific for the period 2002-2014

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ABSTRACT

To examine yearly changes of PCB in the western North Pacific, PCB concentrations in blubber of O-stock mature males of common minke whales (*Balaenoptera acutorostrata*) 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.

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 equipments 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 can 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 seal. 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.

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, and average of body length and blubber thickness of the whales sampled, by sub-area and survey. 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: "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 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 common minke whale (None); sub-area 8 minke whale (anchovy, copepods, euphausiids, Japanese flying squid, mackerel and Pacific saury); sub-area 9 minke whale (anchovy, Atka mackerel: *Pleurogrammus monopterygius*, copepods, euphausiids, mackerel, armhook squid: *Berryteuthis anonychus*, oceanic lightfish: *Vinciguerria nimbaria*, Pacific pomfret: *Brama japonica*, salmonids, Pacific saury). 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

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. Plots of total PCB concentrations against their sampling year are shown for minke whales during 2002 to 2014 in Figs. 2a-2e for each of the different sub-areas and two sea areas.

To examine the factors affecting PCB concentrations in minke, multiple regression linear analyses were conducted. The results for minke whales in sub-area 7, off Kushiro, off Sanriku, sub-areas 8 and 9 are shown in Tables 2, 3, 4, 5 and 6, respectively. 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 (-) was significantly associated those from off Kushiro (Table 3), and body length (+) was significantly associated those from sub-areas 8 and 9 (Tables 5 and 6).

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 sampling 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 sampling date or blubber thickness in minke whales were observed, because PCB concentrations may be diluted by rapidly increasing of body weight and fat volume in a feeding season. On the other hand, food items were not significantly associated in these analyses, whereas they were significantly associated in the THg 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. 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 seal. 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)".

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Table 1. Biological data and PCB levels in blubber of common minke whales (males) from the western North Pacific during 1994 and 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 ±)	(3.4 ±)	(1.16 ±)
	2013	mature	2	(7.52 ±)	(3.5 ±)	(1.09 ±)
	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 ±)	(2.2 ±)	(1.82 ±)
	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) Model of regression

Model	R^2	$R^{2'}$
1	0.489	0.447

b) Analysis of Variance Table

Model	DF	SE	F value	P value
Regression	158		11.61	<0.001
Residual	158	0.463		

c) Variables

Model	B	SE	T	P value
Year	-46.166	30.288	-1.52	0.129
Body length	4.065	0.920	4.42	**<0.001**
Blubber thickness	0.072	0.186	0.39	0.700
longitude	1.475	2.031	0.73	0.469
latitude	5.013	3.681	1.36	0.175
Date	-1.649	0.371	-4.44	**<0.001**
MainPrey_Anchovy	315.173	236.333	1.33	0.184
MainPrey_Euphausiids	315.393	236.322	1.34	0.184
MainPrey_JFSquid	315.341	236.335	1.33	0.184
MainPrey_Mackerel	315.236	236.354	1.33	0.184
MainPrey_Sardine	315.197	236.391	1.33	0.184
MainPrey_Saury	315.473	236.318	1.34	0.184
MainPrey_WalleyePollock	315.223	236.356	1.33	0.184

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) Model of regression

Model	R^2	$R^{2'}$
1	0.643	0.628

b) Analysis of Variance Table

Model	DF	SE	F value	P value
Regression	146		43.74	<0.001
Residual	146	0.477		

c) Variables

Model	B	SE	T	P value
Year	-20.402	13.877	-1.47	0.144
Body length	1.902	0.798	2.38	**<0.05**
Blubber thickness	-0.461	0.180	-2.56	**<0.05**
latitude	0.654	15.229	0.04	0.966
longitude	30.495	23.104	1.32	0.189
Date	-1.193	0.404	-2.95	**<0.01**

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) Model of regression

Model	R^2	$R^{2\prime}$
1	0.049	-0.109

b) Analysis of Variance Table

Model	DF	SE	F value	P value
Regression	36		0.31118	0.9267
Residual	36	0.499		

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) Model of regression

Model	R^2	$R^{2\prime}$
1	0.480	0.379

b) Analysis of Variance Table

Model	DF	SE	F value	P value
Regression	62		4.76	<0.001
Residual	62	0.554		

c) Variables

Model	B	SE	T	P value
Year	13.126	75.277	0.17	0.862
Body length	11.054	2.124	5.20	**<0.001**
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_Anchovy	-101.730	569.280	-0.18	0.859
MainPrey_Copepods	-101.963	569.408	-0.18	0.858
MainPrey_Euphausiids	-102.162	569.370	-0.18	0.858
MainPrey_JFSquid	-102.719	569.154	-0.18	0.857
MainPrey_Mackerel	-102.779	569.421	-0.18	0.857
MainPrey_Saury	-102.085	569.316	-0.18	0.858

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) Model of regression

Model	R^2	$R^{2\prime}$
1	0.667	0.639

b) Analysis of Variance Table

Model	DF	SE	F value	P value
Regression	179		23.9	<0.001
Residual	179	0.525		

c) Variables

Model	B	SE	T	P value
Year	26.553	34.443	0.77	0.441761
Body length	3.833	1.114	3.44	**<0.001**
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	0.631475
MainPrey_Anchovy	-189.418	259.890	-0.73	0.467051
MainPrey_AtkaMackerel	-190.017	259.851	-0.73	0.46558
MainPrey_Copepods	-189.702	259.908	-0.73	0.466416
MainPrey_Euphausiids	-189.313	259.845	-0.73	0.467223
MainPrey_Mackerel	-189.234	259.937	-0.73	0.467565
MainPrey_MAFSquid	-189.399	259.857	-0.73	0.467041
MainPrey_OceanicLightfish	-190.059	259.912	-0.73	0.465587
MainPrey_PacificPomfret	-189.368	259.890	-0.73	0.467171
MainPrey_Saury	-189.525	259.883	-0.73	0.466789

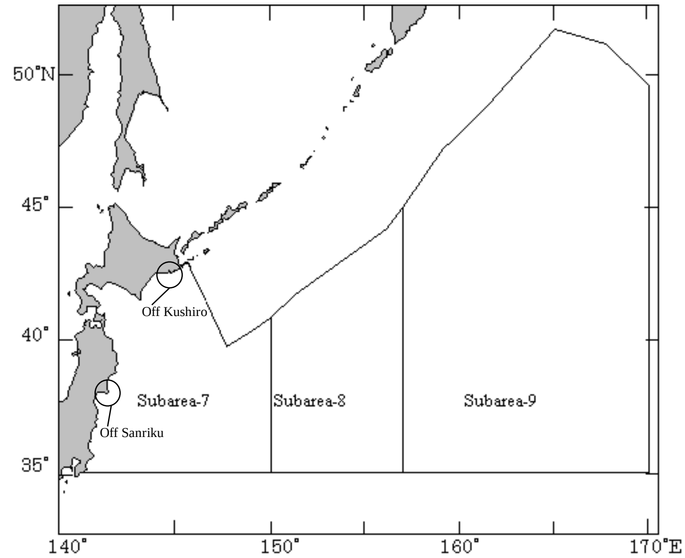

Figure 1. Sub-areas surveyed by the JARPNII research. Sub-areas based on IWC (1994), excluding the EEZ of Russia

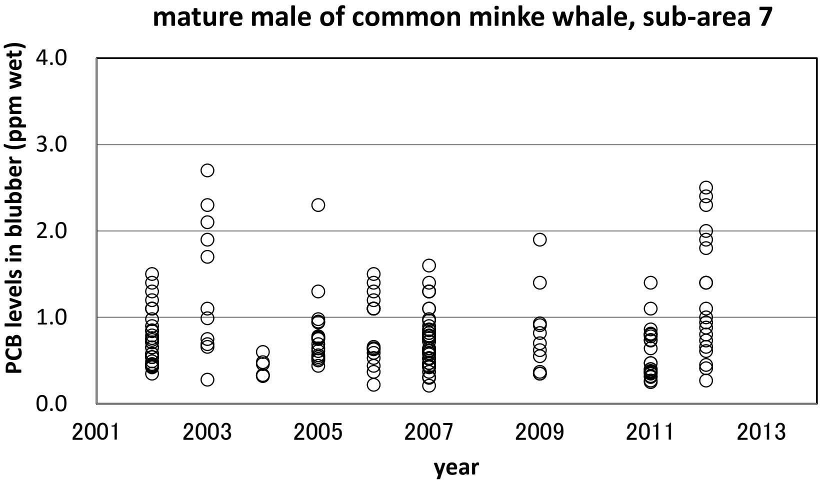

Figure 2a. Simple plots of PCB concentrations in blubber of common minke whales (mature males, O-stock) in sub-area 7 during the period 2002-2012

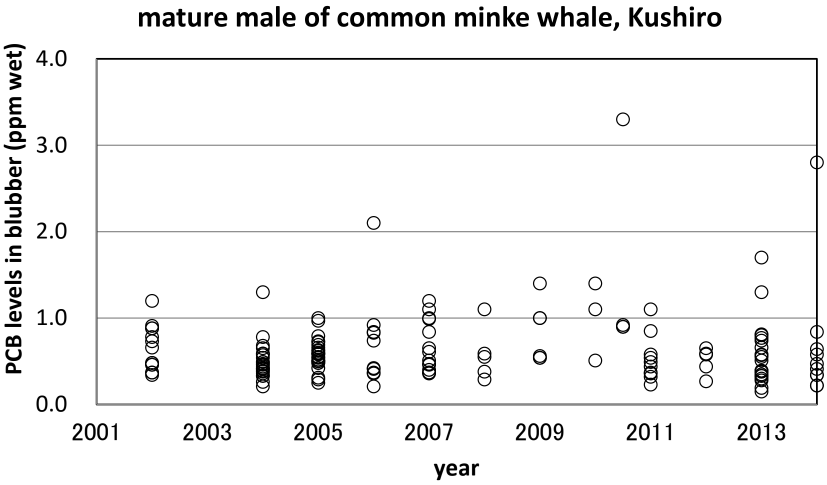

Figure 2b. Simple plots of PCB concentrations in blubber of common minke whales (mature males, O-stock) in off Kushiro during the period 2002-2014

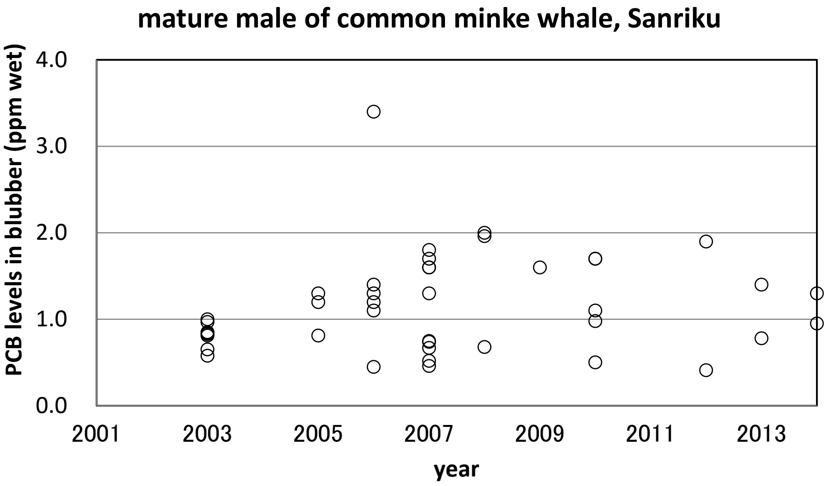

Figure 2c. Simple plots of PCB concentrations in blubber of common minke whales (mature males, O-stock) in off Sanriku during the period 2002-2014

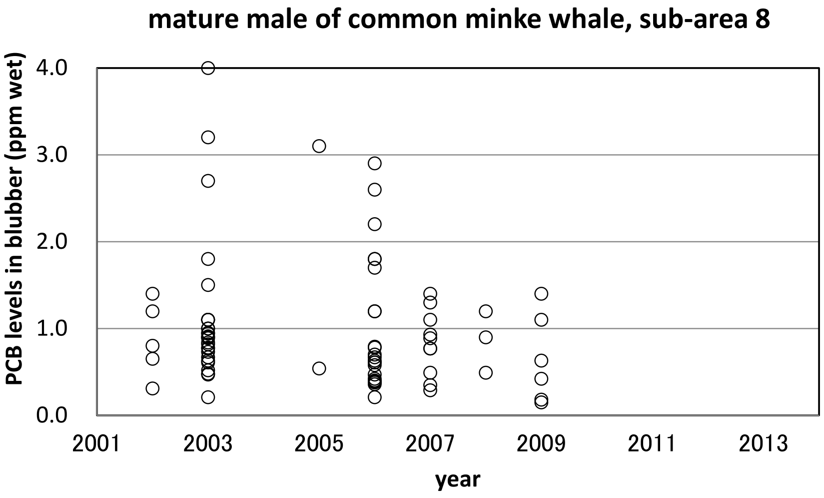

Figure 2d. Simple plots of PCB concentrations in blubber of common minke whales (mature males, O-stock) in sub-area 8 during the period 2002-2009

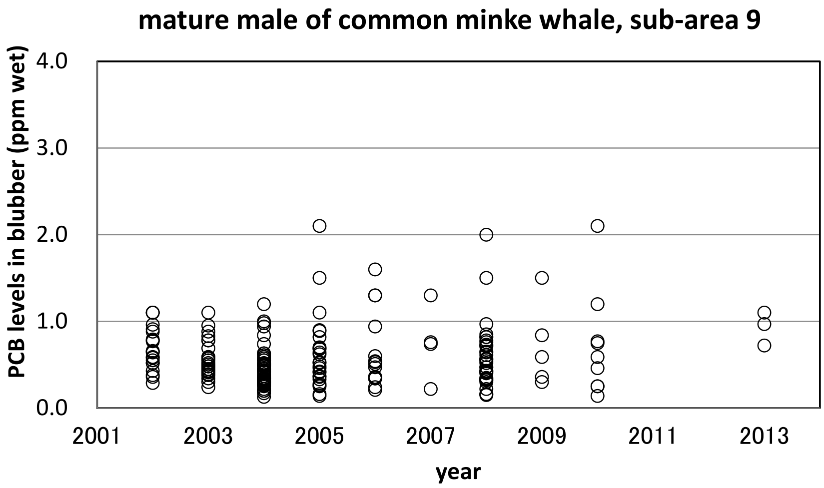

Figure 2e. Simple plots of PCB concentrations in blubber of common minke whales (mature males, O-stock) in sub-area 9 during the period 2002-2013