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Accumulation features of POPs of baleen whales in the western North Pacific based on samples collected during the 2012 JARPNII surve

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ABSTRACT

Concentrations of PCB congeners, DDT isomers, HCH isomers, HCB and CHL isomers were determined in the blubber of 5 mature males of each of common minke (*Balaenoptera acutorostrata*), sei (*B. borealis*) and Bryde's (*B. edeni*) whales taken from the western North Pacific in 2012. For comparison, those compounds were also determined in the blubber of 5 mature males of Antarctic minke whales taken from Antarctic Area V in 2010/11. Concentrations of PCBs were highest among organochlorines in the whales from the western North Pacific, whereas they were lower than concentrations of HCB, DDTs and CHLs in Antarctic minke whales from the Antarctic Ocean. Principal Component Analysis showed differences of trophic level and habitat of PCB congener profiles in the whales. Over 4 chlorinated chlorobiphenyl (CB) congeners in the studied whales contributed to the difference of trophic levels, and the CB-32, 16 and 25 contributed to the geographical difference. The main component isomers from pesticide products originating in DDTs and HCHs were comparatively lower, and those originating in CHLs were not detected in the whales from the western North Pacific. These results suggest that in the western North Pacific, a great deal of time would have passed from the release of DDTs, HCHs and CHLs into the environment.

KEYWORDS: COMMON MINKE WHALE; SEI WHALE; BRYDE'S WHALE; NORTH PACIFIC; PCB; PESTICIDE; ISOMERS

INTRODUCTION

Pollutants accumulate through the food web in the marine ecosystem. As top predators, cetaceans are frequently used for pollutant monitoring in the marine environment. Cetaceans are mobile, long-lived animals, and this means that pollutants can be meaningfully monitored in wide areas and integrated temporally. Therefore, whales are good indicators to monitor fate and behaviour of organochlorines (OCs) in the marine environment.

Polychlorinated biphenyls (PCBs) and man-made pesticides, dichlorodiphenyltrichloroethanes (DDTs), hexachlorocyclohexanes (HCHs), hexachlorobenzene (HCB) and chlordanes (CHLs), had been widely used in the world. In spite of the ban of their production and usage in the 1970s in developed countries, PCBs are still being released into the environment, and these pesticides have occasionally been used for control of malaria vector and other noxious insects.

The several products of PCB formulation and pesticides contain different components of congeners and isomers, and also environmental and biological half-life times of each congener and isomer are different. PCBs, DDTs, HCHs and CHLs mainly have 209 congeners, 3, 3 and 5 isomers in the environment, respectively. Therefore the profiles are implicated in historical records in the marine environment. For instance, CB52 and CB66 of PCB congeners, are implicated in the ability to metabolize PCBs in animals (Tanabe *et al.*, 1988), and HCHs have two sources which are technical HCH (containing the whole isomer mixture) and as Lindane (γ–HCH, after separation of the waste isomers).

The present study examines fate and behaviour of PCBs and pesticides in common minke whale (*Balaenoptera acutorostrata*), sei (*B. borealis*) and Bryde's (*B. edeni*) whales taken from the western North Pacific in the 2012 JARPNII survey using OC profiles.

MATERIALS AND METHODS

Samples

Common minke (Okhotsk Sea-West Pacific stock) from sub-area 7, sei from sub-area 9 and Bryde's whales from sub-areas 8 and 9 were sampled through the 2012 JARPNII survey (Table 1, Fig. 1). For analyses, only mature males were used. 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). Maturity of one common minke whale could not be identified by testis weight, however its body length (8.16 m) was much longer than the body length of physical maturity (7.8 m, Kato, 2002). A detailed biological survey was conducted on the research base ship for all the whales sampled (Table 1). For the purpose of OCs analysis, blubber tissues were obtained from the central dorsal part of each whale by researchers on board the research base ship. The blubber samples were sent to the Miura Institute of Environmental Science (Ehime, Japan) after return to port and stored at -20 ºC until chemical analyses. In addition, Antarctic minke whales from area V in Antarctic were used for comparison and treated in the same way.

Laboratory analysis

Chemical analyses of the PCBs, DDTs, HCB, HCHs and CHLs were carried out using the standard method described by the Environmental Agency of Japan (Japan Environmental Agency, 1998), with some modifications. The chemical analyses were performed by the Miura Institute of Environmental Science.

Approximately 10 g of blubber were placed into a glass test tube, surrogate standard was added, and then homogenized with 20 mL of acetone and 40 mL of n-hexane. Then, the solution was filtered. This extraction procedure was repeated two times. All the solvent layers were combined and washed with 100 mL of 2% sodium chloride solution. The extracts were filtered through 20 g of anhydrous Na_2SO_4 and finally concentrated to 10 mL. Two millilitres of each of the extracts were purified using multilayer silica gel column chromatography composed of two components – 4 g of silica gel impregnated with sulfuric acid (44% mass fraction: 44% H_2SO_4–Si) and 3 g of silica gel impregnated with silver nitrate (10% mass fraction: 10%$AgNO_3$–Si). All the analytes were eluted with 200 mL of 5% dichloromethane/n-hexane. After that, the clean-up of the extract was performed by gel permeation chromatography (column: Shodex CLNpak PAE-2000AC) in order to remove remaining hydrocarbons. The mobile phase used acetone with a flow rate of 3.5 mL/min. The eluted solutions were then concentrated.

PCBs and OCs were determined by a GC–MS (JEOL Ltd., JMS-700; JMS-SX102A). Concentrations of OCs were expressed on a lipid weight basis. The quality control of the data was provided throughout the analyses by use of the certified reference material 'Organics in cod liver oil' (NIST 1588a). The results were 1626.4 ng/g fresh wt. for ∑PCBs, 596 ng/g for pp-DDE, 236 ng/g for pp-DDD, 417 ng/g. for pp-DDT, 161.2 ng/g for cischlordane, 217.4 ng/g for trans-nonachlor, 67.0 ng/g for cis-nonachlor, 133 ng/g for HCB, and 78.7 ng/g for a-HCH. While the certified values by NIST were 1789.1 ng/g for fresh wt. ∑PCBs, 651 ± 11 ng/g/ for pp-DDE, 254 ± 11 ng/g for pp-DDD, 524 ± 12 ng/g for pp-DDT, 167.0 ± 5.0 ng/g for cis-chlordane, 214.6 ± 7.9 ng/g for trans-nonachlor, 94.8 ± 2.8 ng/g for cis-nonachlor, 157.8 ± 5.0 ng/g/ for HCB, and 85.3 ± 3.4 ng/g for a-HCH. Here, ∑PCBs includes PCB congener numbers 28, 31, 44, 49, 52, 66, 87, 95, 101, 105, 110, 118, 128, 132, 138, 149, 151, 153, 156, 159, 163, 164, 170, 180, 182, 183, 187, 190, 194 and 201 (IUPAC numbering).

Statistical analysis

The data of PCB congeners in blubbers of whales were subjected to principal component analysis (PCA) using the detectable 112 PCB congeners to assess the accumulation features of the congeners. Principal components were derived from standardized data via the correlation matrix. These statistical analyses were executed by SPSS ver.11 for Windows (SPSS Co. Ltd.).

RESULTS AND DISCUSSION

Contamination status

Table 2 shows the concentrations of OCs in blubber of common minke, sei and Bryde's whales taken from the western North Pacific in 2012 and Antarctic minke whales taken from Antarctic Area V in 2011/2012. OCs were detected in all the blubber samples. All OCs levels in baleen whales from the western North Pacific were in the order of common minke > sei = Bryde's whales. This reflects the difference of their trophic levels.

The residue levels of OCs on lipid basis in common minke, sei, Bryde's and Antarctic minke whale were in the order of PCBs > DDTs > CHLs > HCHs > HCB, PCBs > DDTs > HCHs > CHLs > HCB, PCBs > DDTs > CHLs >HCB > HCHs and HCB > DDTs > CHLs > PCBs > HCHs, respectively. The levels of PCBs were highest among OCs in the whales from the northern Pacific, whereas they were comparatively lower than HCB, DDTs and CHLs in Antarctic minke whales. PCBs are still being released into the environment, whereas production and usage were banned in the 1970s in developed countries of the middle latitude of the northern hemisphere (Weber and Goerke, 2003). Furthermore, PCBs with higher lipophilicity are less transportable than the other OCs in the marine environment. These results are consistent with previous studies of OC monitoring with other animals (Tanabe *et al.*, 1994; Ueno et al., 2003).

Composition of PCB congeners

Table 3 shows average PCB congeners (ng/g lipid wt.) detected in the blubber of common minke, sei, Bryde's and Antarctic minke whales, and Fig. 2 shows their profiles. The most prevalent congeners in all whale species were hexachlorobiphenyl CB-153, 132 and 168. The second prevalent congeners in common minke, sei and Bryde's whales from the western north Pacific were hexachlorobiphenyl CB-138, 163 and 160, whereas those in Antarctic minke whales were pentachlorobiphenyl CB-90, 101. The congener levels in common minke whales from the Northeast Atlantic are reported to be in order of CB-153 > 128 > 138 (Kleivane and Skaare, 1998). This suggests that secondary dominant congeners in baleen whales would reflect their habitat.

PCA was conducted using the detectable 112 PCB congeners in common minke, sei, Bryde's and Antarctic minke whales (Figs. 3a, 3b). The two principal components (PCs) represented 72.5 % (PC1) and 8.5 % (PC2) of the variance (Fig. 3a). Both components of PCA were separated among the species, except for one common minke whale. This result showed that differences of nutritional level and habitat among congeners dominated the variance modelled by PC1 and PC2, respectively. Examination of congener loadings in Figure 3b shows that middle and higher chlorinated congeners, over 4 chlorinated chlorobiphenyls, on the right are dominant influences in PC1 (Fig. 3b). This would indicate that higher chlorinated biphenyls have higher biological concentration coefficients. This result is consistent with those of previous studies, such as PCB monitoring in small toothed-whales (Tanabe *et al.*, 1988). In PC2, the main influences CB-32, 16 and CB-25 on the top, relative to CB-117, 115, 85 and CB-80 on the bottom (Fig. 3b). The former congeners were detectable in only Antarctic minke whales, whereas the later congeners were not detectable. CB-85 contained in Adélie penguin (*Pygoscelis adeliae*) and the south polar skua (*Catharacta maccormicki*) was comparatively higher (over 5% in total PCBs), whereas CB-80 in those were not detectable (Focardi *et al.*, 1995)

Composition of DDT, HCH and CHL isomers

The average of percentage of *p,p'*-DDT in the whales were in the order of Antarctic minke whale (20.0 %) > Bryde's whale (8.7 %) ≈ common minke whale (7.4 %) > sei whale (3.3 %) (Fig. 4).

Technical DDTs which has been used to control malaria is composed of almost all *p,p'*-DDT (De Jager *et al.*, 2006). *p,p'*-DDT released in the environment is changed to *p,p'*-DDE in animal body and the environment (Okonkwo *et al.*, 2008). In addition, Klumpp *et al.* (2002) reported high *p,p'*-DDT residues in mussels and fish tissues, and revealed a new input of DDT in China. Our result suggests that usage of technical DDTs in the southern hemisphere is more recent than in the northern hemisphere. Furthermore, one of the reasons for the lower *p,p'*-DDT ratio of sei whales compared to common minke and Bryde's whales in the northern hemisphere might be the distance from their habitat to the technical DDT source.

The percentage of β-HCH accounted for over 90% of total HCHs in common minke, sei and Bryde's whales from the western North Pacific, whereas the percentage of γ-HCH was the dominant isomer of total HCHs in Antarctic minke whales.

β-HCH is the most persistent and refractory of HCHs (Wu *et al.*, 1997). Also, in the late 1940s and early 1950s, technical HCH (containing the whole isomer mixture) had been used as insecticide (Vijgen *et al.*, 2011). Some companies began in the 1950s to isolate the active ingredient (pure γ-HCH), which has been used under the name Lindane (Willet *et al.* 1998; Walker *et al.* 1999). Our results indicate that the three baleen whales from the western North Pacific could be recently unexposed to both technical HCH and Lindane, whereas Antarctic minke whales from Antarctic Ocean could yet to have been exposed to Lindane.

The percentages of CHL isomers in common minke, sei and Bryde's whales from the western North Pacific were in the order of trans-nanochlor > cis-nonachlor, whereas those in Antarctic minke whales were in the order of trans-nanochlor > oxychlordane. And, trans-chlordane was not detected in all 4 whale species studied.

Technical CHLs were used in termite control in Japan until 1986 (Loganathan *et al.*, 1993). Their trans-chlordane / trans-nanochlor ratios are in the range of 2.9-3.4, and decreasing ratio in the environment means that time has passed after technical CHLs release (Patton *et al.*, 1989; Ueno *et al.*, 2003). It is suggested that the baleen whales from the western North Pacific and Antarctic would not have been recently exposed by new technical CHLs. Furthermore, the percentage of oxychlordane, a metabolite of the technical CHLs, in Antarctic minke whales was higher than those in the baleen whales from the western North Pacific, suggesting that Antarctic minke whale would hardly have been exposed to technical CHLs.

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Table 1. Biological data of common minke, sei and Bryde’s whales from western North Pacific, and Antarctic minke whales from Antarctic Ocean.

Species	Research year	Area	Sex	Maturity	Body length (m)
common minke whale	2012	subarea 7	M	mature	7.33
	2012	subarea 7	M	mature	7.55
	2012	subarea 7	M	mature	7.40
	2012	subarea 7	M	mature	7.70
	2012	subarea 7	M	unknown	8.16
sei whale	2012	subarea 9	M	mature	13.55
	2012	subarea 9	M	mature	13.74
	2012	subarea 9	M	mature	13.48
	2012	subarea 9	M	mature	14.03
	2012	subarea 9	M	mature	13.48
Bryde's whale	2012	subarea 9	M	mature	12.22
	2012	subarea 9	M	mature	12.69
	2012	subarea 9	M	mature	13.06
	2012	subarea 8	M	mature	13.32
	2012	subarea 8	M	mature	13.38
Antarctic minke whale	2010/2011	Antarctic Area V	M	mature	8.67
	2010/2011	Antarctic Area V	M	mature	8.78
	2010/2011	Antarctic Area V	M	mature	8.35
	2010/2011	Antarctic Area V	M	mature	8.77
	2010/2011	Antarctic Area V	M	mature	8.31

Table 2. Organochlorine concentrations (ng/g lipid wt.) in the blubber of common minke, sei, Bryde’s and Antarctic minke whales

Species	*n*	Fat (%)	PCBs	DDTs	HCHs	HCB	CHLs
common minke whale	5	29.3	3100	2000	670	250	1300
		(20.6 - 49.1)	(1400 - 8000)	(800 - 5800)	(410 - 1500)	(160 - 360)	(620 - 3100)
sei whale	5	73.0	130	71	91	21	59
		(65.6 - 77.4)	(67 - 210)	(32 - 130)	(30 - 150)	(15 - 28)	(31 - 90)
Bryde's whale	5	51.9	140	82	13	17	68
		(17.5 - 79.5)	(85 - 200)	(36 - 130)	(7.0 - 19)	(14 - 22)	(38 - 88)
Antarctic minke whale	5	61.2	33	69	0.52	140	34
		(44.0 - 75.0)	(19 - 57)	(35 - 110)	(0.22 - 0.89)	(90 - 250)	(18 - 59)

Table 3. Average of PCB congeners (ng/g lipid wt.) in the blubber of common minke, sei, Bryde's and Antarctic minke whales

PCB isomers		common minke whale		sei whale		Bryde's whale		Antarctic minke whale	
Nos. of Cl	IUPAC No.	ng/g	%	ng/g	%	ng/g	%	ng/g	%
D2CBs	#10,#4	0.41	0.01	0.37	0.29	0.48	0.34	0.063	0.19
	#8,#5	1.2	0.04	0.70	0.55	1.1	0.81	0.054	0.17
	#11	N.D	0.00	N.D	0.00	N.D	0.00	0.053	0.16
	#12,#13	N.D	0.00	N.D	0.00	0.30	0.21	N.D	0.00
	#15	0.37	0.01	0.24	0.19	0.29	0.21	0.030	0.09
T3CBs	#19	N.D	0.00	0.11	0.09	N.D	0.00	N.D	0.00
	#18	3.6	0.12	1.2	0.97	1.2	0.89	0.14	0.44
	#17	0.49	0.02	0.37	0.29	0.47	0.33	0.036	0.11
	#24,#27	0.29	0.01	0.15	0.12	N.D	0.00	0.031	0.09
	#32,#16	0.87	0.03	0.59	0.46	0.76	0.54	0.065	0.20
	#26	0.50	0.02	0.22	0.17	0.26	0.18	0.026	0.08
	#25	0.53	0.02	0.15	0.12	0.23	0.16	N.D	0.00
	#31,#28	5.6	0.18	2.4	1.90	3.3	2.32	0.23	0.70
	#33,#20	3.5	0.11	0.83	0.65	1.1	0.78	0.11	0.33
	#22	0.51	0.02	0.43	0.34	0.62	0.44	0.045	0.14
	#37	N.D	0.00	0.22	0.17	N.D	0.00	N.D	0.00
T4CBs	#53	2.1	0.07	0.34	0.27	0.30	0.21	0.068	0.21
	#51	0.82	0.03	N.D	0.00	N.D	0.00	N.D	0.00
	#45	0.73	0.02	0.34	0.27	N.D	0.00	N.D	0.00
	#69,#46	N.D	0.00	N.D	0.00	N.D	0.00	0.074	0.22
	#52,#73	103	3.33	8.6	6.77	5.4	3.81	2.0	6.19
	#43,#49	14	0.45	2.4	1.89	1.6	1.16	0.43	1.32
	#47,#48,#75	14	0.44	1.9	1.46	1.3	0.94	0.36	1.10
	#44	5.0	0.16	2.0	1.58	1.2	0.84	0.27	0.82
	#59,#42	2.0	0.07	0.45	0.35	0.52	0.37	0.11	0.35
	#41	2.6	0.08	N.D	0.00	0.46	0.33	0.16	0.50
	#64,#68	0.65	0.02	0.32	0.25	0.35	0.25	0.37	1.12
	#40,#57	1.1	0.03	0.26	0.20	N.D	0.00	0.073	0.22
	#74	63	2.03	3.2	2.48	2.7	1.92	0.67	2.03
	#70,#76	3.0	0.10	0.51	0.40	0.50	0.35	0.093	0.28
	#80	N.D	0.00	N.D	0.00	N.D	0.00	0.11	0.33
	#66	8.0	0.26	2.5	1.97	1.4	0.99	0.26	0.78
	#56,#60	1.9	0.06	0.55	0.43	0.57	0.40	0.058	0.18
P5CBs	#96	1.4	0.05	N.D	0.00	N.D	0.00	N.D	0.00
	#103	1.5	0.05	N.D	0.00	N.D	0.00	N.D	0.00
	#100	1.4	0.05	N.D	0.00	N.D	0.00	N.D	0.00
	#94	1.2	0.04	N.D	0.00	N.D	0.00	N.D	0.00
	#93	2.7	0.09	N.D	0.00	N.D	0.00	0.088	0.27
	#95	59	1.90	6.6	5.20	4.4	3.12	1.8	5.51
	#121,#92	14	0.47	0.78	0.61	0.60	0.43	0.13	0.39
	#89	6.9	0.22	1.5	1.17	N.D	0.00	0.36	1.09
	#84	2.8	0.09	0.85	0.67	N.D	0.00	0.13	0.38
	#90,#101	105	3.39	10	7.84	N.D	0.00	3.1	9.42
	#99	194	6.24	6.0	4.69	6.2	4.44	1.2	3.73
	#119	3.2	0.10	N.D	0.00	N.D	0.00	N.D	0.00
	#97,#86	6.0	0.19	1.6	1.24	1.2	0.83	0.26	0.80
	#125,#87	11	0.35	2.0	1.59	1.5	1.08	0.46	1.40
	#117,#115,#85	N.D	0.00	N.D	0.00	N.D	0.00	0.96	2.93
	#110	18	0.58	1.1	0.82	2.2	1.57	0.22	0.68
	#82	2.5	0.08	0.44	0.35	0.39	0.28	0.090	0.27
	#124	2.0	0.07	N.D	0.00	N.D	0.00	N.D	0.00
	#123,#106	9.8	0.31	0.46	0.36	0.56	0.40	0.15	0.47
	#118	222	7.14	7.6	5.95	9.1	6.49	1.6	4.79
	#114	N.D	0.00	0.34	0.26	0.40	0.28	N.D	0.00
	#122	0.83	0.03	N.D	0.00	N.D	0.00	N.D	0.00
	#105,#127	7.7	0.25	1.6	1.26	1.7	1.19	0.095	0.29

Table 3 continued

PCB isomers		common minke whale		sei whale		Bryde's whale		Antarctic minke whale	
Nos. of Cl	IUPAC No.	ng/g	%	ng/g	%	ng/g	%	ng/g	%
H6CBs	#155	6.7	0.22	N.D	0.00	0.58	0.41	N.D	0.00
	#150	1.7	0.05	N.D	0.00	N.D	0.00	N.D	0.00
	#148	2.8	0.09	N.D	0.00	N.D	0.00	N.D	0.00
	#136	28	0.91	1.3	1.04	1.3	0.92	0.55	1.67
	#154	7.6	0.24	N.D	0.00	N.D	0.00	N.D	0.00
	#151	25	0.81	2.7	2.08	3.0	2.13	0.89	2.73
	#135,#144	35	1.11	1.5	1.21	1.6	1.15	0.53	1.62
	#147	4.4	0.14	0.44	0.34	0.47	0.33	0.11	0.32
	#149	244	7.84	8.0	6.26	9.5	6.74	2.5	7.65
	#139,#140	3.7	0.12	N.D	0.00	N.D	0.00	N.D	0.00
	#134	2.1	0.07	N.D	0.00	N.D	0.00	N.D	0.00
	#143,#142,#133	11	0.34	0.40	0.31	0.40	0.28	0.13	0.39
	#146	81	2.60	2.3	1.77	3.3	2.35	0.77	2.36
	#153,#132,#168	643	20.69	15	12.08	22	15.37	3.4	10.26
	#141	2.5	0.08	0.45	0.36	0.81	0.58	0.19	0.57
	#130	22	0.71	0.54	0.42	0.70	0.50	0.13	0.38
	#137	19	0.60	0.62	0.49	0.79	0.56	0.17	0.51
	#138,#163,#160	446	14.34	11	8.30	16	11.09	2.5	7.68
	#129	1.5	0.05	N.D	0.00	N.D	0.00	N.D	0.00
	#166	4.3	0.14	N.D	0.00	N.D	0.00	N.D	0.00
	#159	1.2	0.04	N.D	0.00	N.D	0.00	N.D	0.00
	#128	11	0.35	1.0	0.82	0.97	0.69	0.12	0.37
	#167	18	0.59	0.55	0.43	0.69	0.49	0.18	0.53
	#156	25	0.79	0.67	0.53	1.0	0.74	0.18	0.55
	#157	7.5	0.24	N.D	0.00	N.D	0.00	N.D	0.00
H7CBs	#188	4.7	0.15	N.D	0.00	N.D	0.00	N.D	0.00
	#184	3.7	0.12	0.23	0.18	0.25	0.18	N.D	0.00
	#179	28	0.89	0.85	0.67	1.0	0.72	0.35	1.07
	#176	7.1	0.23	0.31	0.24	0.34	0.24	0.088	0.27
	#186	13	0.42	N.D	0.00	N.D	0.00	N.D	0.00
	#178	17	0.55	0.54	0.42	0.93	0.66	0.17	0.53
	#175	3.4	0.11	N.D	0.00	0.17	0.12	0.055	0.17
	#187,#182	120	3.85	3.0	2.34	4.7	3.37	0.93	2.82
	#183	43	1.37	0.93	0.73	1.5	1.05	0.19	0.57
	#185	2.0	0.06	N.D	0.00	N.D	0.00	0.052	0.16
	#174	37	1.18	0.85	0.67	1.4	1.03	0.39	1.18
	#177	28	0.90	0.70	0.55	1.2	0.84	0.20	0.62
	#171	11	0.37	0.23	0.18	0.46	0.33	0.053	0.16
	#172,#192	10	0.33	0.25	0.20	0.59	0.42	0.097	0.30
	#180	137	4.41	2.7	2.13	5.3	3.74	1.0	3.10
	#191	1.3	0.04	N.D	0.00	N.D	0.00	N.D	0.00
	#170,#190	48	1.54	0.97	0.76	1.7	1.18	0.27	0.82
	#189	3.3	0.11	N.D	0.00	0.18	0.13	N.D	0.00
O8CBs	#202	6.4	0.20	N.D	0.00	0.26	0.18	0.084	0.26
	#201	3.9	0.13	N.D	0.00	N.D	0.00	0.070	0.21
	#197	3.4	0.11	N.D	0.00	N.D	0.00	N.D	0.00
	#200	1.8	0.06	N.D	0.00	N.D	0.00	N.D	0.00
	#198	1.1	0.03	N.D	0.00	N.D	0.00	N.D	0.00
	#199	13	0.42	0.26	0.20	0.60	0.42	0.15	0.46
	#203,#196	14	0.44	0.30	0.23	0.49	0.35	0.087	0.27
	#195	3.1	0.10	N.D	0.00	N.D	0.00	N.D	0.00
	#194	9.3	0.30	0.21	0.16	0.30	0.21	0.078	0.24
	#205	1.2	0.04	N.D	0.00	N.D	0.00	N.D	0.00
N9CBs	#208	2.0	0.07	N.D	0.00	0.19	0.13	0.044	0.13
	#207	2.1	0.07	N.D	0.00	0.23	0.17	0.030	0.09
	#206	2.5	0.08	N.D	0.00	N.D	0.00	0.038	0.11
D10CBs	#209	3.7	0.12	0.13	0.10	0.38	0.27	0.037	0.11
Total-PCBs		3109	100.00	128	100.00	141	100.00	33	100.00

Table 4. Average concentrations (ng/g lipid wt.) and percentages (%) of DDT isomers in the blubber of common minke, sei, Bryde's and Antarctic minke whales

Species	*n*		*p,p'*-DDE	*p,p'*-DDD	*p,p'*-DDT	Total-DDTs
common minke whale	5	average	1602	328	99	2040
		percentage	(78.5)	(16.1)	(4.9)	
sei whale	5	average	44	18	7.9	71
		percentage	(62.5)	(24.7)	(11.1)	
Bryde's whale	5	average	61	13	7.8	82
		percentage	(74.5)	(15.8)	(9.5)	
Antarctic minke whale	5	average	48	6.4	16	69
		percentage	(70.1)	(9.3)	(22.5)	

Table 5. Average concentrations (ng/g lipid wt.) and percentages (%) of HCH isomers in the blubber of common minke, sei, Bryde's and Antarctic minke whales

Species	*n*		α-HCH	β-HCH	γ-HCH	Total-HCHs
common minke whale	5	average	21	648	7.9	670
		percentage	(3.2)	(96.7)	(1.2)	
sei whale	5	average	3.3	85	1.1	91
		percentage	(3.6)	(93.2)	(1.2)	
Bryde's whale	5	average	0.59	12	0.28	13
		percentage	(4.7)	(98.4)	(2.2)	
Antarctic minke whale	5	average	0.12	0.10	0.37	0.52
		percentage	(22.9)	(19.7)	(69.8)	

Table 6. Average concentrations (ng/g lipid wt.) and percentages (%) of CHL isomers in the blubber of common minke, sei, Bryde's and Antarctic minke whales

Species	*n*		oxychlordane	trans-chlordane	cis-chlordane	trans-nonachlor	cis-nonachlor	Total-CHLs
common minke whale	5	average	148	N.D.	33	950	210	1336
		percentage	(11.1)	(0.0)	(2.5)	(71.1)	(15.7)	
sei whale	5	average	7.6	N.D.	3.3	36	11.8	59
		percentage	(12.9)	(0.0)	(5.6)	(61.4)	(20.1)	
Bryde's whale	5	average	4.2	N.D.	9.8	39	14.3	68
		percentage	(6.2)	(0.0)	(14.5)	(57.8)	(21.0)	
Antarctic minke whale	5	average	11	N.D.	1.3	16	4.8	34
		percentage	(33.2)	(0.0)	(3.9)	(48.9)	(14.2)	

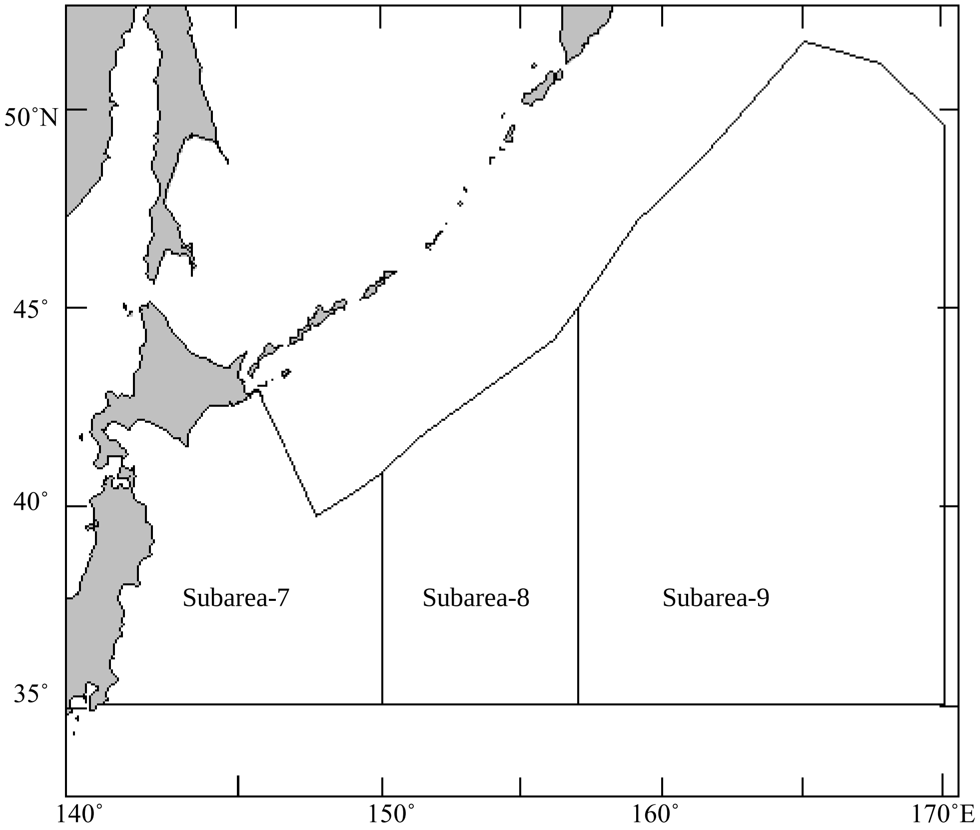

Figure 1. Subareas surveyed by the JARPNII research. Subareas based on IWC (1994), excluding the EEZ of Russia.

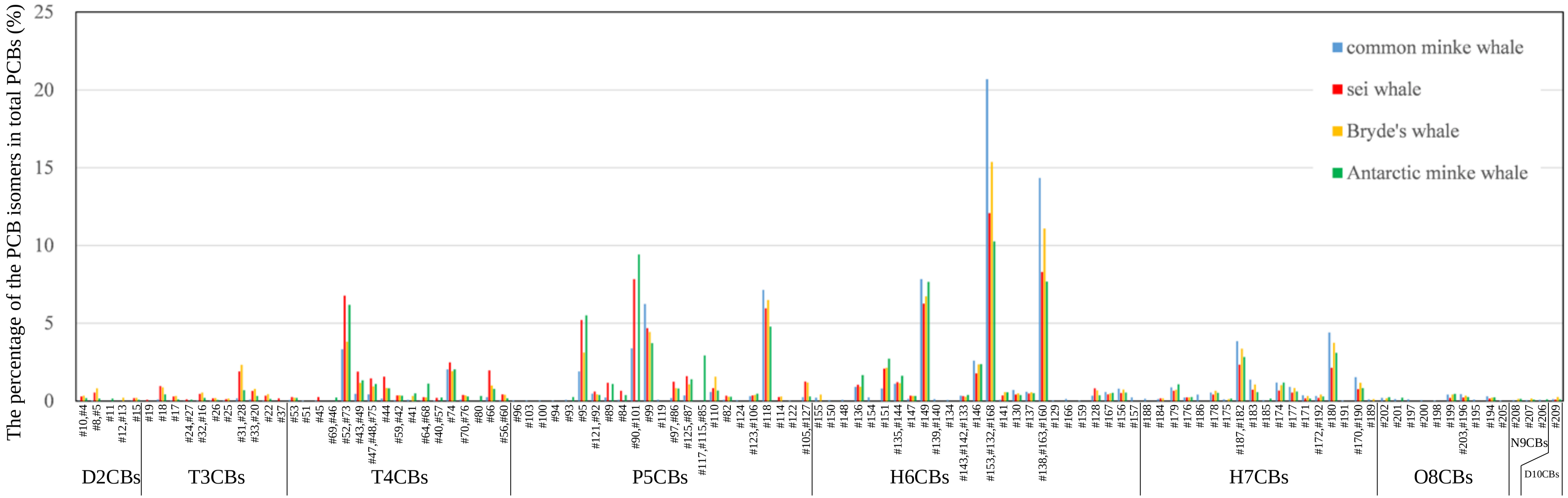

Figure 2. The percentage profiles of the PCB isomers in total PCBs (%) in blubber of common minke, sei, Bryde’s and Antarctic minke whales

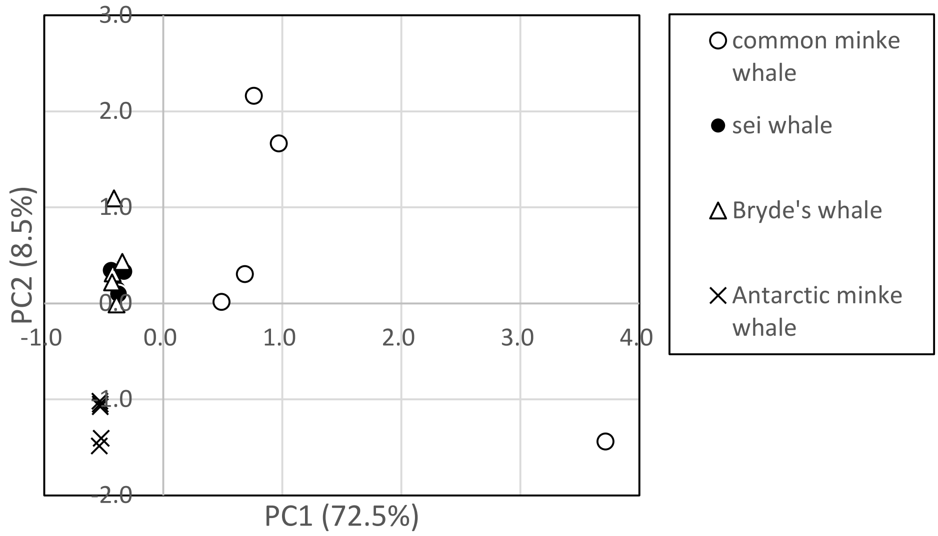

Figure 3a. Distribution of whale species plotted against the PC1 and PC2 in two-dimensional principal component analysis for the detectable 112 PCB congeners in blubber of common minke, sei, Bryde's and Antarctic minke whales

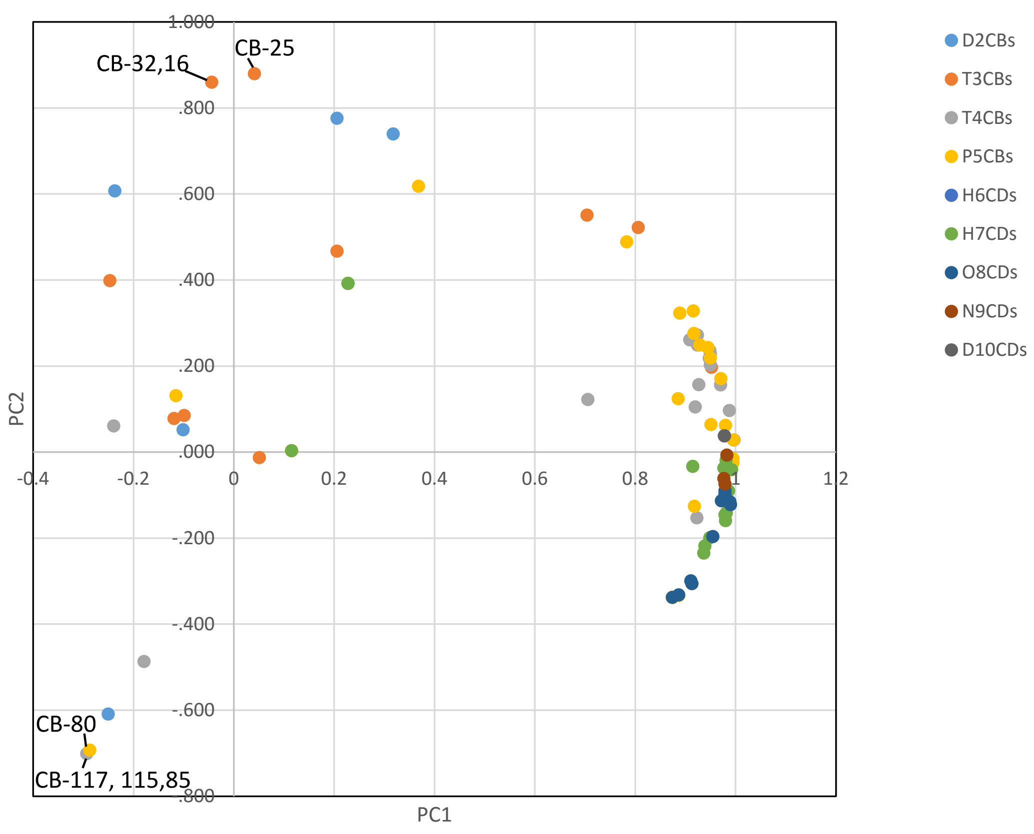

Figure 3b. Distribution of PCB congeners plotted against the PC1 and PC2 in two-dimensional principal component analysis for the detectable 112 PCB congeners in blubber of common minke, sei, Bryde's and Antarctic minke whales

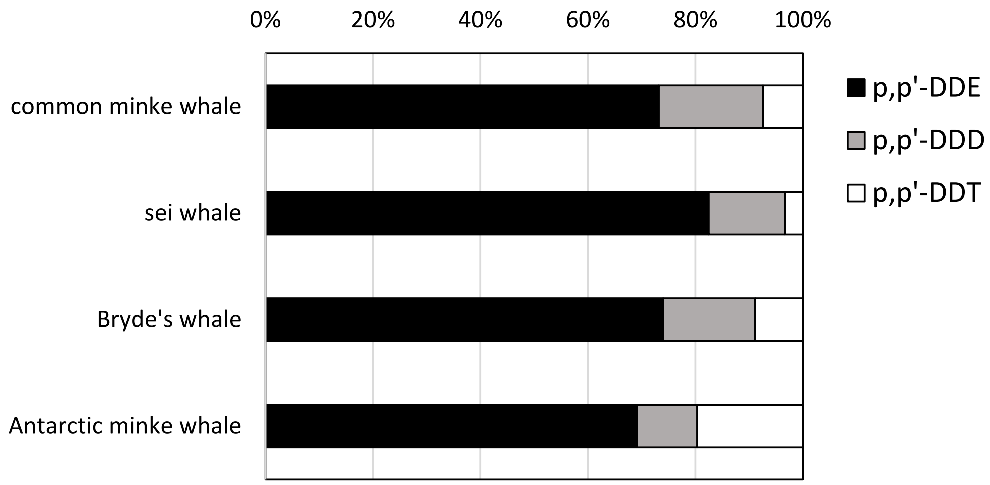

Figure 4 Compositions of DDTs in the blubber of common minke, sei, Bryde’s and Antarctic minke whales

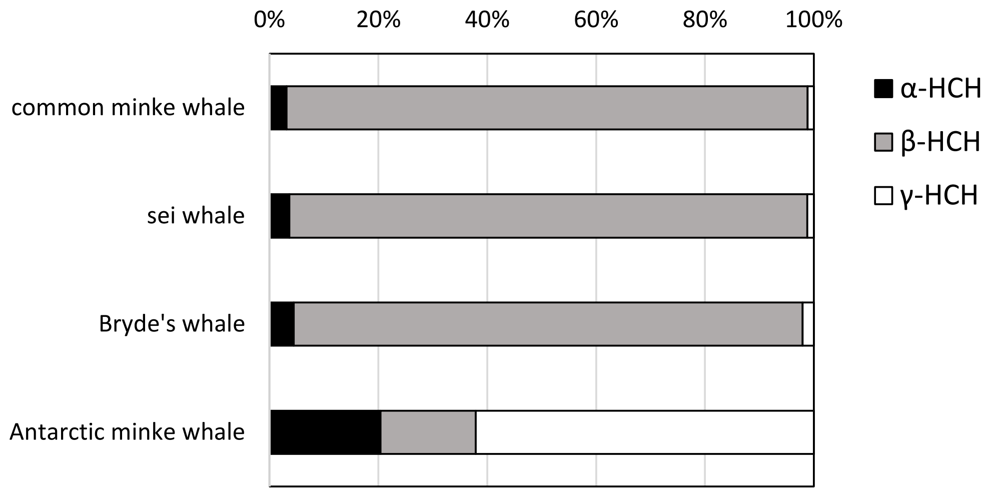

Figure 5 Compositions of HCHs in the blubber of common minke, sei, Bryde’s and Antarctic minke whales

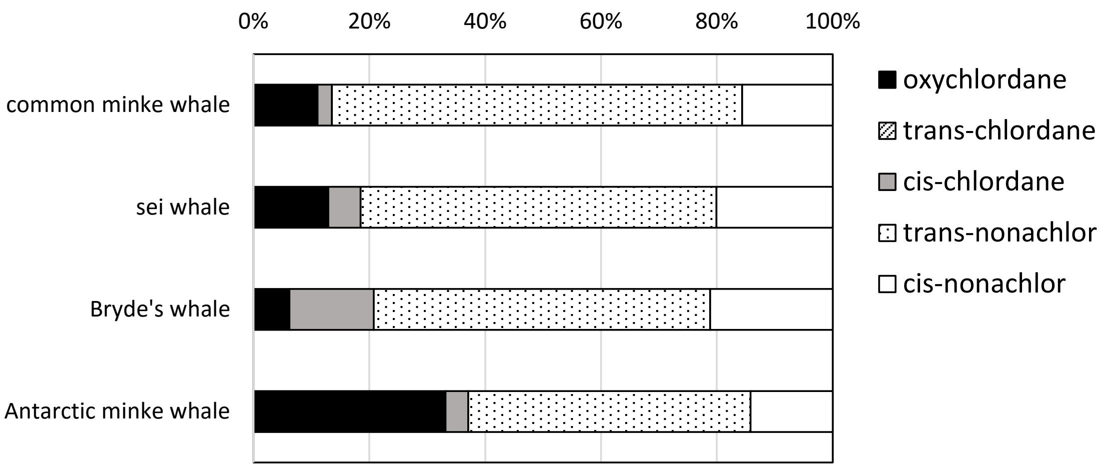

Figure 6 Compositions of CHLs in the blubber of common minke, sei, Bryde’s and Antarctic minke whales