BIOACCUMULATION OF DDTs AND PCBs IN THE SOUTHERN MINKE WHALE (*BALAENOPTERA ACUTOROSTRATA*)

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Abstract: DDTs (*p, p'*-DDE+*p, p'*-DDT) and polychlorinated biphenyls (PCBs) were determined in the liver of male minke whales collected from the Southern Ocean during the 1980–1981 whaling season. DDTs ranged from 3.6 to 70 ng/g and PCBs from 1.2 to 18 ng/g on lipid weight basis. These values were apparently lower than those in northern baleen whales and also in southern toothed whales. This seems to be attributable to the smaller extent of contamination by these pollutants in the southern hemisphere and the habits of minke whales feeding on lower trophic organisms, primarily eupausiids, in the Antarctic ecosystem. Considerably high concentrations of DDTs and PCBs were found in young minke whales and a continuous increase of these was observed in older animals after approximately 20 years of age. These trends probably arise from feeding habits of minke whales associated with migration and segregation in age groups of young and old.

1. Introduction

The bioaccumulation phenomenon of organochlorines in the natural ecosystem is very complicated, where environmental, ecological and chemical factors interact. The situation for marine mammals with regard to bioaccumulation is known to be variable according to the animal species, living habitats, feeding habits, age, sex and also chemical species (PHILLIPS, 1980). In order to understand the comprehensive bioaccumulation phenomenon in marine mammals, it is necessary to examine the specific bioaccumulation in animal species with representative ecological and physiological aspects, and to deduce generalizable laws from these observations.

This paper describes the bioaccumulation of DDTs and PCBs in the southern minke whale, *Balaenoptera acutorostrata*. The minke whale is one of the typical baleen whales and the smallest species of the genus *Balaenoptera*. This species is a main object of the whaling at present. There are some ecological reports on the southern minke whale (TAYLOR, 1957; ARSENYEV, 1960; KASUYA and ICHIHARA, 1965; GASKIN, 1968; OHSUMI *et al.*, 1970; WILLIAMSON, 1975; BEST, 1982). Migration of the southern minke whale is not fully understood, but it is supposedly distributed over a wide area of the southern hemisphere. In summer season, however, the majority of the animal concentrate in high latitudinal waters of the Antarctic. The food of the southern minke whale consists predominantly of euphausiids, and the extent of feeding in summer is considerably greater than in winter. Their life-span is under 50 years and the average age at sexual maturity is estimated to be 7–8 years. It is interesting that

the southern minke whale forms geographical segregation with age and sex.

There are not many reports on the organochlorine residues in the baleen whale, and most of these reports are on the monitoring survey (WOLMAN and WILSON, 1970; ADDISON *et al.*, 1972; SASCHENBRECKER, 1973; HOLDEN, 1975; TARUSKI *et al.*, 1975; ALZIEU and DUGUY, 1979; VIALE, 1981; HENRY and BEST, 1983). Most species of baleen whales feed principally on lower trophic organisms such as euphausiids, amphipods and copepods. It is, therefore, expected that the level of organochlorines is lower in baleen whales than in toothed whales. In the case of minke whales, the migration in association with geographical segregation might have a special impact on the bioaccumulation of organochlorines.

2. Materials and Methods

2.1. Samples

The minke whales were collected from the Indian sector of the Southern Ocean (Fig. 1) during the whaling season of November 1980 to February 1981. Of these animals, livers of 30 male samples of different ages were employed for chemical analysis of DDTs and PCBs. The samples were cut into about one inch cube and stored in the plastic case at $-20°C$ until analysis. The age of minke whales was determined by S. OHSUMI, Far Seas Fisheries Research Laboratory, Fisheries Agency, and H. KATO, The Whales Research Institute, using the ear plug (OHSUMI *et al.*, 1970).

2.2. Chemical analysis

About 10 g of liver sample was ground with anhydrous soldium sulfate and the pulverized mixture was subjected to extraction with mixed solvents of diethyl ether and

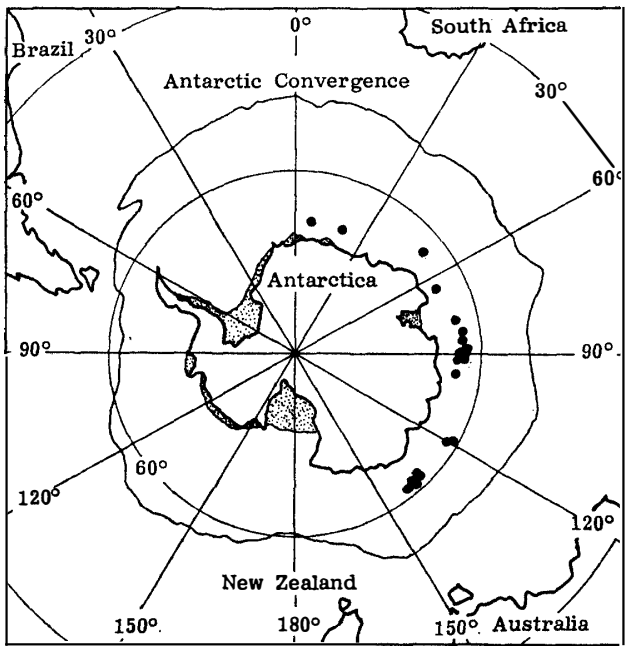

Fig. 1. Sampling locations of minke whales.

hexane (3:1) in a soxhlet extractor. An aliquot of this extract was dried and the lipid content was measured gravimetrically. The remainder of this extract was concentrated and analyzed for DDTs and PCBs by the alkaline alcohol digestion method of WAKIMOTO *et al.* (1971). The concentrated extract was refluxed in 1 N KOH-ethanol solution for one hour. DDTs and PCBs extracted into ethanol were transferred to hexane. Subsequently, the hexane layer was concentrated and cleaned up by 1.5 g of silica gel (Wako gel S-1) packed in a glass column. DDTs and PCBs were eluted with 200 m*l* of hexane at an elution rate of 1 drop/s and then concentrated. After cleaning the concentrated hexane with 5% fuming sulfuric acid, it was further micro-concentrated to 200 μl and injected into the electron-capture gas chromatographs (GC-ECD), Shimadzu GC-5A and GC-8A, for the quantification of DDTs and PCBs. The column was 2 mm across $\times$ 5 m long packed with purified Apiezon L grease for the determination of PCBs and 2 mm across $\times$ 1.8 m long packed with 2% QF-1 + 1.5% OV-17 for the determination of DDTs. Chromosorb W, AW HMDS, 100/120 mesh, was used as the support for both columns. DDTs were measured as a single *p, p'*-DDE peak, since *p, p'*-DDT was converted into *p, p'*-DDE during the alkaline alcohol digestion.

A few representative samples were also injected into a Shimadzu 9020 DF gas chromatograph-mass spectrometer equipped with an electron-impact ion source and a SCAP-1123 data-system for the measurement and identification of PCB isomers and congeners. PCBs were determined by selected ion monitoring at *m/z* 222, 256, 292, 326, 360, 394, 430 and 466 for di-, tri, tetra-, penta-, hexa-, hepta-, octa- and nonachlorobiphenyls, respectively. A packed column was the same as the GC-ECD used for PCB analysis. The other details on GC and GC-MS conditions followed, as described in our previous reports (NIHON KAIYÔ GAKKAI, 1979; TANABE *et al.*, 1981).

Contaminations from plastic cases, glassware and solvents were checked preliminarily and found to be negligible. Overall procedural blanks of DDTs and PCBs were less than 0.01 ng/g on the wet liver weight basis.

3. Results and Discussion

3.1. Concentration levels of DDTs and PCBs in the minke whale

DDTs and PCBs were detected in all liver samples of minke whales analyzed (Table 1). DDTs in liver ranged from 0.17 and 1.9 ng/g and PCBs from 0.05 to 0.59 ng/g, on the wet weight basis. On the lipid weight basis, DDTs and PCBs were found to be in the ranges of 4.0 to 70 ng/g and 1.2 to 18 ng/g, respectively.

These concentrations are compared with the data on some other whales so far reported (Table 2). Although little information is available on the concentration of PCBs in the whales living in the southern hemisphere, the concentration levels of DDTs in baleen whales including minke whales are apparently lower than those in toothed whales. Baleen whales feed mainly on planktonic or micronectonic crustaceans, while the food of toothed whales consists largely of fishes (GASKIN, 1982). It is well known that the concentrations of DDTs and PCBs in aquatic organisms are amplified in higher trophic levels (WOODWELL *et al.*, 1967; TEN BERGE and HILLEBRAND, 1974; PORTMANN, 1975). This trend has also been observed in the Antarctic marine eco-

Table 1. Concentrations of DDTs and PCBs in the liver of male minke whales.

Sample No.	Body length (m)	Age (year)	Lipid content (%)	Wet wt basis (ng/g)		Lipid wt basis (ng/g)		DDTs/ PCBs
				DDTs	PCBs	DDTs	PCBs	
108	6.4	1	3.3	0.63	0.09	19	2.6	7.0
505	7.5	2	4.6	0.61	0.09	13	1.9	6.8
464	7.2	2	4.5	0.74	0.10	16	2.2	7.4
1043	7.7	3	3.3	1.5	0.59	44	18	2.5
2143	8.5	4	4.9	0.38	0.06	7.8	1.2	6.3
110	8.4	5	3.8	1.2	0.05	31	1.3	24
1467	8.6	5	5.2	0.90	NA	17	NA	—
303	8.4	6	3.1	0.89	0.12	28	3.9	7.4
897	8.5	6	4.6	1.1	0.25	24	5.4	4.4
1463	8.3	6	5.1	0.94	0.20	19	3.9	4.7
929	9.0	7	3.6	0.66	0.31	18	8.6	2.1
306	8.5	10	4.0	0.61	0.15	15	3.8	4.1
506	9.0	10	3.4	0.18	0.09	5.3	2.6	2.0
991	8.8	15	4.8	0.29	0.21	6.1	4.3	1.4
1072	8.4	15	4.6	0.50	0.30	11	6.5	1.7
370	8.6	20	4.6	0.56	0.20	12	4.3	2.8
855	9.3	20	4.4	0.35	0.18	8.0	4.1	1.9
859	8.9	20	4.2	0.17	0.05	4.0	1.2	3.4
866	8.8	25	3.7	0.50	0.17	14	4.6	2.9
1315	8.5	25	4.6	0.94	0.11	21	2.4	8.5
391	9.2	30	4.4	0.36	0.28	8.1	6.3	1.3
1782	9.0	30	4.9	0.91	0.25	19	5.1	3.6
1965	8.9	30	4.8	0.71	NA	15	NA	—
174	8.1	35	4.2	1.3	0.45	31	11	2.9
1054	8.6	35	4.0	1.3	0.22	32	5.6	5.9
2247	7.9	35	3.5	0.82	0.20	23	5.7	4.1
142	8.6	40	4.1	1.0	0.27	25	6.6	3.7
443	8.2	40	4.1	0.79	0.40	19	9.7	2.0
790	8.7	40	2.7	1.9	0.24	70	8.9	7.9
801	7.9	45	3.3	0.92	0.18	28	5.4	5.1
Mean			4.1	0.79	0.21	20	5.3	4.9

NA: not analyzed.

system, where the concentrations of DDTs and PCBs were one order of magnitude lower in krill than in fish (HIDAKA *et al.*, 1983). The feeding habits of baleen whales as well as minke whales account well for the low accumulation levels of DDTs and PCBs.

From a global viewpoint, much lower concentrations of DDTs and PCBs are observed in toothed and baleen whales of the southern hemisphere than those of the northern hemisphere (Table 2). A similar difference has also been reported in open ocean surface waters and small cetaceans between the northern and the southern hemispheres of the western Pacific (TANABE *et al.*, 1983a). These observations can be explained by the smaller amounts of DDT and PCB usage in the countries of the southern hemisphere than in the northern hemisphere. However, GOLDBERG (1975) reported that the major countries consuming DDT would have shifted from the

Table 2. Comparison of DDT and PCB concentrations (ng/g, lipid weight) in minke whales to those in some other baleen and toothed whales.

Locality	Species	Type of whale	Tissue	DDTs	PCBs	References
Northern hemisphere						
Eastern Canada	Beluga whale	Toothed	Blubber	7.4	ND	ADDISON *et al.* (1972)
	Sperm whale	Toothed	Blubber	7.7	1	ADDISON *et al.* (1972)
	Fin whale	Baleen	Blubber	4.2–32	ND–7.0	ADDISON *et al.* (1972)
Baltic Sea	Beluga whale	Toothed	Liver	9.0	2.9	HARMS *et al.* (1977/78)
Southern hemisphere						
Durban	Sperm whale	Toothed	Blubber	0.25–1.9	ND	HENRY and BEST (1983)
	Fin whale	Baleen	Blubber	ND–0.48	ND	HENRY and BEST (1983)
	Minke whale	Baleen	Blubber	ND–1.6	ND	HENRY and BEST (1983)
Antarctic	Sperm whale	Toothed	Blubber	7–35	ND–1	ADDISON *et al.* (1972)
	Sei whale	Baleen	Blubber	0.31	ND	ADDISON *et a'* (1972)
	Blue whale	Baleen	Blubber	0.18	ND	ADDISON *et a.* (1972)
	Minke whale	Baleen	Liver	0.004–0.070	0.001–0.018	Present study

ND: not detected.

mid-latitudes of the northern hemisphere to the tropical regions and the southern hemisphere during the last decade. The mean concentration ratio of DDTs to PCBs in small cetaceans living in the North Pacific is found to be 1.5 (TANABE *et al.*, 1983b). In a case of southern minke whales, higher ratios ranging from 1.3 to 24 (mean ratio =4.9) are obtained (Table 1). This may support the view of recently increasing use of DDT in the southern hemisphere.

3.2. Biological magnification of PCBs and DDTs in the Antarctic ecosystem from seawater to minke whale through food chain

The concentrations of DDTs and PCBs on the lipid weight basis in the Antarctic marine ecosystem are summarized in Table 3.

The uptake routes of DDTs and PCBs seem to occur primarily from water in the krill (*Euphausia superva*), both water and the krill in the fish (*Trematomus bernacchii*), and from the krill in the minke whale. An apparent bioaccumulation was found at every step of this food chain, but the magnification through food observed in the minke whale is less effective than that from water in the case of the krill and fish. The concentration ratio of DDTs and PCBs in the minke whale to the krill was found to be 22 and 7.1, respectively. In this food chain, fish and minke whale seem to occupy the same trophic level, since both animals feed mainly on the krill. A similar concentration level of DDTs and PCBs between these two animals also supports this.

Table 3. Concentrations (seawater: ng/l, organisms: ng/g on lipid weight basis) of DDTs and PCBs in the Antarctic marine ecosystem, and bioaccumulation capacity of organisms.

	Concentration		Estimated bioconcentration factor*	
	DDTs	PCBs	DDTs	PCBs
Seawater[a)]	0.0013	0.054	1	1
Krill (*Euphausia superba*)[b)]	0.93	0.75	7.2×10^5	1.4×10^4
Fish (*Trematomus bernacchii*)[c)]	13	3.1	1.0×10^7	5.7×10^4
Minke whale (in liver)	20	5.3	1.5×10^7	9.8×10^4

* Ratios of concentration in organisms to that in seawater.
a) Data from TANABE *et al.* (1983a). b) Data from HIDAKA *et al.* (1983).
c) Data from SUBRAMANIAN *et al.* (1983).

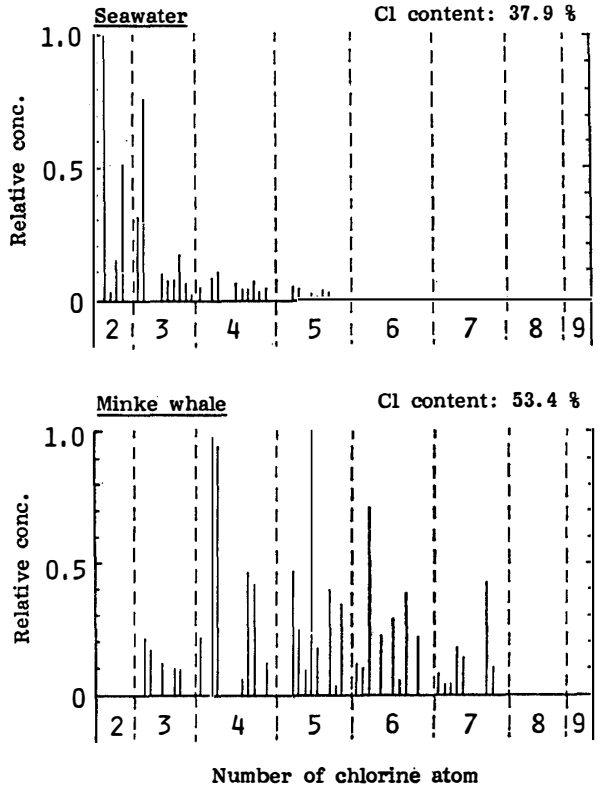

Fig. 2. PCB isomer and congener compositions in Antarctic seawater and minke whale. Each bar shows the relative concentration of individual PCB isomers and congeners measured by mass fragmentography. Maximum peak of PCB values was treated as 1.0. Details of each peak and its chemical structure are given in our previous report (TANABE et al., 1981).

This indicates that, under certain circumstances, it is practically possible for the same or higher accumulation level of DDTs and PCBs to occur in fish than in marine mammals.

It is interesting that the relative concentrations of DDTs and PCBs in organisms were apparently different from seawater. Organisms accumulated higher concen-

trations of DDTs than PCBs notwithstanding the greater abundance of PCBs in seawater (Table 3). It is known that DDTs and higher chlorinated biphenyls are extremely lipophilic and stable in animal bodies, while lower chlorinated biphenyls are rather biodegradable and less bioaccumulative (TATSUKAWA and TANABE, 1980). As shown in Fig. 2, PCB isomer and congener compositions in seawater and minke whale are evidently different. Smaller amounts of lower chlorinated biphenyls were observed in minke whale than in seawater. Similar trend has also been reported in Antarctic fish and ambient water (SUBRAMANIAN *et al.*, 1983). These observations strongly suggest that lower chlorinated biphenyls are less accumulative in fish and degraded in the body of minke whale. This seems to have resulted in the lower concentrations of PCBs than DDTs found in Antarctic organisms.

3.3. Age trend of the concentrations of DDTs and PCBs in the minke whale

There are some reports on the variation of organochlorine concentrations with age of marine mammals (FRANK *et al.*, 1973; ADDISON *et al.*, 1973; ADDISON and SMITH, 1974; HELLE *et al.*, 1976; DRESCHER *et al.*, 1977; REIJNDERS, 1980; TANABE *et al.*, 1980), whereas no data are available on larger whales so far and the present study may be the first of this kind. We could find the consistent age trend of both DDTs and PCBs in the liver of minke whales (Fig. 3). Considerably high concentrations of DDTs were found in young minke whales. After 4 years, an apparent decrease of DDT levels was observed until approximately 20 years, followed by an increase with age. A similar trend was also found in PCBs.

We previously examined the age trend of DDTs in striped dolphins collected from the western North Pacific and their residue levels on the age of minke whales are compared with that of striped dolphins (Fig. 3). The two animals showed somewhat different age trends of DDTs. Comparing with mature animals between 10 and 20 years of age, DDT concentrations in younger age ($<$10 years) were rather higher in minke whales than in striped dolphins. The large amount of DDT transfer during suckling in lactational process is well documented in marine mammals (ANAS and WILSON, 1970; GASKIN *et al.*, 1971; ADDISON and BRODIE, 1977) and also in striped dolphins (TANABE *et al.*, 1980, 1982). These data have been reported on high concentrations of DDTs in young animals. This is in agreement with the results of this study. The young minke whales seem to have also been affected by this lactational transfer. In addition to this, the differential migration and feeding habits of young minke whales might have led to their high accumulation levels of DDTs. GAMBELL *et al.* (1975) and BEST (1982) suggested that some of immature population of minke whales remain in lower latitudes during the summer and feed not only on euphausiids but also on copepods and fishes available there. In the western Indian Ocean, it is known that the concentrations of atmospheric DDTs and PCBs increase towards low latitudes from Antarctica (TANABE *et al.*, 1983a). A similar trend may be expected in the organochlorine residues in plankton and fish. If the suggested feeding in low latitudes by minke whales (GAMBELL *et al.*, 1975; BEST, 1982) is true, higher concentrations of DDTs observed in young minke whales can also be explained on this basis.

The feeding grounds of mature minke whales are restricted in higher latitudes, where they feed predominantly on euphausiids. It is, therefore, considered that the

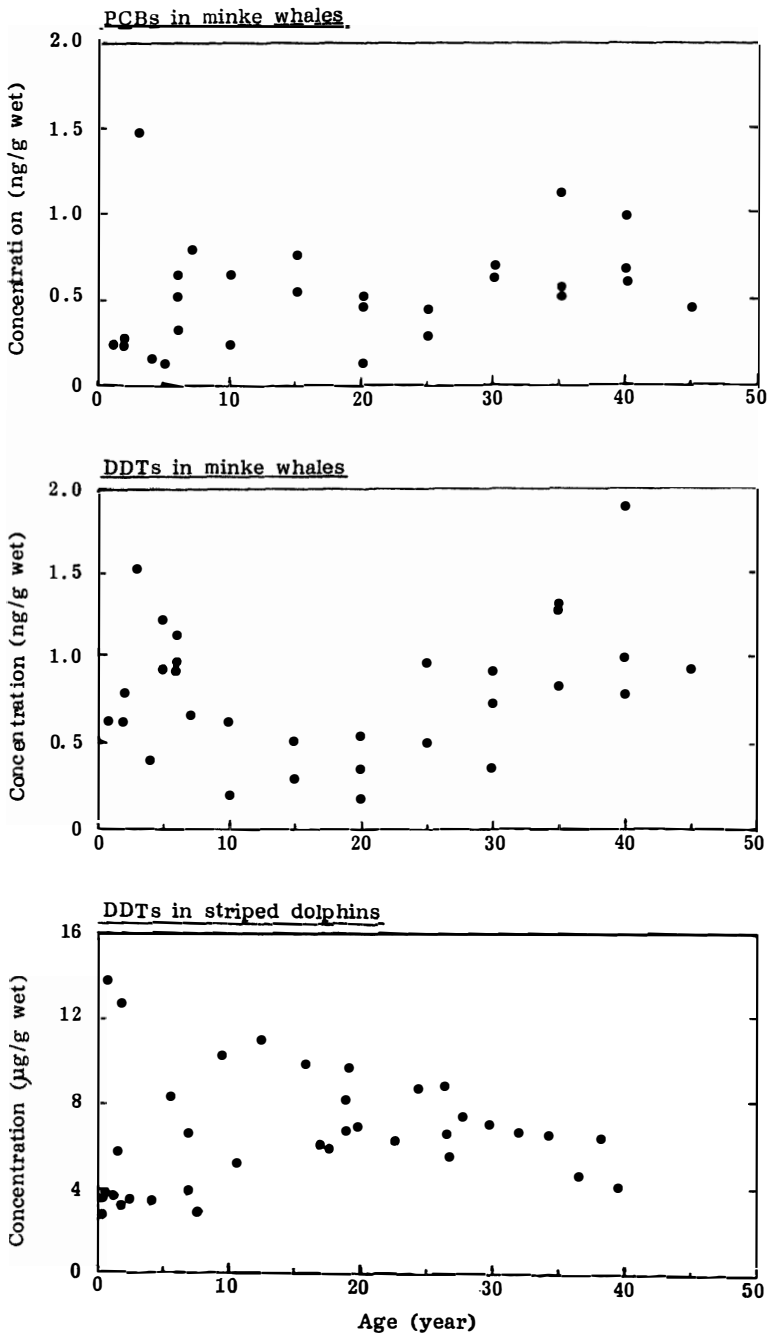

Fig. 3. Age trends of DDTs and PCBs in the liver of male minke whales and in the blubber of male striped dolphins (Stenella coeruleoalba). *Data on striped dolphins are cited from a previous report* (TANABE *et al., 1980*).

uptake of DDTs and PCBs dcreases after young age, since the concentrations of these pollutants in Antarctic euphausiids are expected to be lower than those in copepods and fish of lower latitudes. Additionally, the growth of minke whales also contributes to the decrease of DDT and PCB concentrations in their bodies. A considerable decline of DDT and PCB concentrations after young age of minke whales (4–20 years of age in Fig. 3) may be explained by the change of feeding grounds and the growth.

A remarkable discordance in the age trend of DDT concentrations between striped dolphins and minke whales was found in older animals after approximately 20 years (Fig. 3). An apparent decrease of DDT concentrations was observed in older striped dolphins, while a reverse trend was found in older minke whales. The decrease of DDT concentrations in striped dolphins has been explained by the decline of intake amounts of food in older animals (TANABE *et al.*, 1980). If this explanation would be applicable to other marine mammals also, the intake amounts of food in minke whales should increase in older individuals. However, this is quite unpractical because the growth of minke whales ceases at the age of about 18 years (OHSUMI and MASAKI, 1975; BEST, 1982), thus the nutrition requirement for their growth is less after this age and the food intake would naturally decrease. Then, for the increased concentrations of DDTs and PCBs in older minke whales, there is no explanation other than the change of their feeding grounds and/or of the quality of their food organisms. OHSUMI *et al.* (1970) suggested that there is segregation by age in minke whales during the summer in the Antarctic, particularly in males. Although no data are available for the relationship between segregation and feeding habits in older minke whales, the following plausible assumption can be made on the ecological behavior of older animals, considering from the analytical data of DDTs and PCBs:

1) The older minke whales feed not only on euphaussids but also on higher trophic organisms such as fish in the Antarctic feeding grounds.

2) The resident period of minke whales in the Antarctic feeding grounds becomes shorter with the increase of age after 20 years, and older animals feed partly on copepods and fish in lower latitudes.

As mentioned before, concentratinos of DDTs are higher in Antarctic fish than in krill (Table 3) and also may be expected to be higher in copepods and fish of lower latitudes than in eupausiids of the Antarctic. This is a noticiable reason to favor the two assumptions above.

Although further study is required, the persistent organochlorines might be useful as a chemical tracer to elucidate the ecological aspects of migration, segregation and feeding habits still left uncleared in minke whales and also other large whales.

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