Bull. Environ. Contam. Toxicol. (2006) 76:140–147

DOI: 10.1007/s00128-005-0900-z

Bulletin of Environmental Contamination and Toxicology

Ecochemical Approach Using Mercury Accumulation of Antarctic Minke Whale, *Balaenoptera bonaerensis,* as Tracer of Historical Change of Antarctic Marine Ecosystem During 1980–1999

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Received: 25 July 2005/Accepted: 7 November 2005

The biology and ecology of the Antarctic minke whale in the Antarctic Ocean have been studied and information on age, food habits, migration and reproductive activities are available (Ohsumi *et al.* 1970; Ohsumi and Masaki 1975; Masaki 1979; Kato 1983; Kato *et al.* 1984). Also, since the whale is a long-life marine mammal (about 50 years), feeding mainly on Antarctic krill, this animal may be useful as an "indicator species" to learn complex long-term accumulation characteristics of heavy metals and organo halogen compounds in the Antarctic marine ecosystem (Honda 1985).

So, we have focused on bioaccumulation processes of heavy metals and organo halogen compounds in the Antarctic since 1980. Of many studies reported so far, our most interest finding was unusual age-related accumulations of Hg in the minke whales collected during 1980/81 season (Honda 1985), being different from linear increases of the concentrations in other marine mammals. In general, it has been well known that hepatic Hg concentration of marine mammals increase with age (Koeman *et al.* 1975). Nevertheless, in 1980/81 season samples, the concentration increased with age until about 20 years and thereafter decreased year by year. Such unusual age trend of Hg indicates that the amount of Hg intake by the whale changed according to age.

A significant decrease in blue whale and fin whale stocks which occupy the ecological niches similar to those for the minke whale in the Antarctic marine ecosystem (Best 1982; Lows 1977; Beddington and May 1983), leads to an increase of available food per capita for the minke whale, resulting in its population increase prior to full exploitation. Also, biological changes with time in both growth rate and age at sexual maturity for the Antarctic minke whale were reported so far (Masaki 1979; Kato 1983; Kato *et al.* 1984).

Consequently, a structural disturbance of the Antarctic marine ecosystem due to the commercial whalings influences not only the physiological and ecological aspect such as population, sexual maturity and growth rate of the Antarctic minke whale, but also the accumulation of Hg in this animal. Honda *et al.* (1987)

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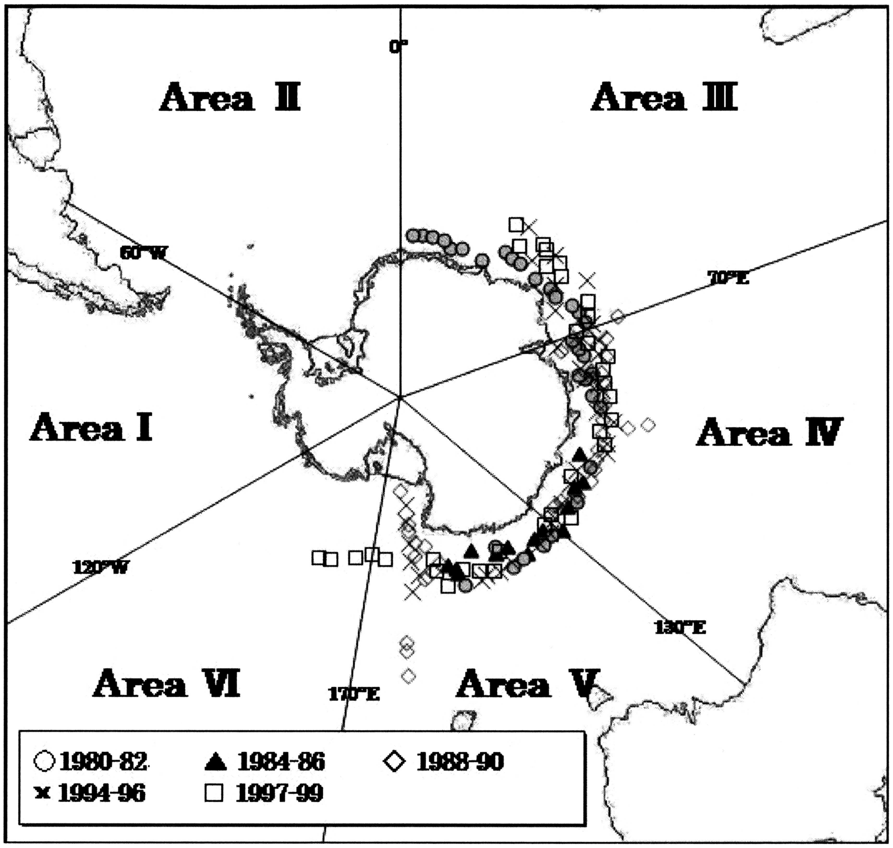

Figure 1. Sampling locations of the Antarctic minke whale.

also reported that if such situation is continued, in future Hg accumulation level of the Antarctic minke whale will be increased year by year. Watanabe *et al.* (1998) showed the increase of hepatic Hg concentration of the minke whale collected during 1984/85 season compared with those of 1980/81 season reported by Honda (1985), and it may support the idea predicted by Honda (1985).

This report clarified yearly age-related accumulations of Hg in the Antarctic minke whales collected during 1980-1999, and also discussed in relation to historical changes of the Antarctic marine ecosystem.

MATERIALS AND METHODS

Sampling locations of the minke whales by yearly season are shown in Figure 1. The muscle and liver tissues of all specimens were excised from the medial region after measurements of biometrics such as body weight, body length, weights of organs and tissues and sex. The foods, *ie.* Antarctic krill, were also taken from the stomach of all specimens. All samples were stored in polyethylene bags at –20 °C until analysis.

Antarctic minke whales were used in this study as shown in Table 1. Data on Hg in muscle and liver of minke whales collected in 1980/81, 1981/82, 1984/85 and 1985/86 seasons were used as reported by Honda *et al.* (1987),Yamamoto (1988) and Watanabe *et al.* (1998). These samples were collected during the Japanese commercial whaling operations. Recent samples (1988/89, 1989/90, 1994/95, 1995/96, 1997/98 and 1998/99 seasons) were collected in the Japanese Whale Research Program Under Special Permit (JALPA). These specimens were grouped into five yearly seasons because of deviations in age organization among sampling seasons (Table 1).

Muscle, liver and food samples were homogenized, and 5-10 g of samples were mineralized with a nitric, perchloric and sulfuric acid mixture in a flask equipped with a Liebig condenser and followed by potassium permanganate ($KMnO_4$) digestion. The excess of $KMnO_4$ was reduced with 2 % hydroxylamine hydrochloride solution and the mercury was reduced to Hg^0 with tin(II)chloride. The presence of Hg was determined by cold vapor atomic absorption spectrophotometry (Honda *et al.* 1982), and the limit of quantification for Hg was 0.002 ppm on a wet-weight basis.

Table 1. Hepatic Hg concentrations (ng/g wet wt.) in minke whales.

Yearly group	Hg (mean ± RSD)							
	1-5 years		6-15 years		16-25 years		26- years	
	(N)		(N)		(N)		(N)	
80-82	21	44.7 ±12.3	57	59.6 ±19.9	20	50.5 ±20.9	19	58.5 ±15.3
84-86	24	47.9 ±19.0	39	64.7 ±30.4	44	75.1 ±32.7	34	70.4 ±38.5
88-90	56	43.3 ±24.4	80	79.8 ±35.5	63	85.2 ±42.0	27	92.6 ±48.2
94-96	21	31.9 ±17.9	43	64.1 ±29.0	37	77.1 ±34.9	49	76.5 ±42.1
97-99	39	23.7 ±17.1	59	61.3 ±23.5	40	82.5 ±37.9	40	91.4 ±74.2

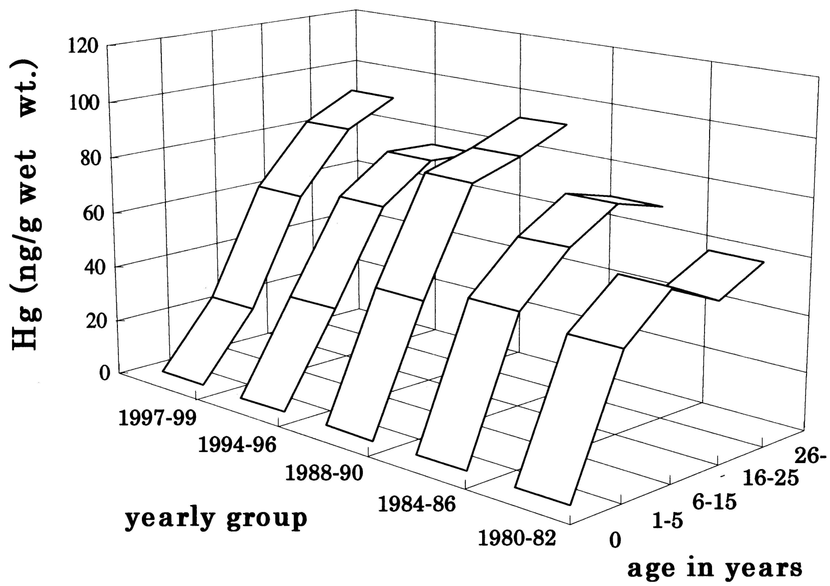

Figure 2. Yearly age-related changes of hepatic Hg concentrations in the Antarctic minke whales.

RESULTS AND DISCUSSION

A significant positive correlation (r^2=0.890, $p<0.05$) was found between muscular and hepatic Hg concentrations in the minke whales. Here, hepatic Hg concentrations in five yearly groups and their age-related accumulations are shown in Table 1 and Figure 2, respectively. All data were used because the sexual, geographical and seasonal changes of hepatic Hg concentrations and moisture contents were not observed for the Antarctic minke whales (Honda *et al.* 1987; Watanabe *et al.* 1998).

Remarkable yearly changes of Hg levels were found in Figure 2. In age groups of 26 years or more, hepatic Hg concentrations increased year by year until 1990. In particular, Hg levels for 1997-99 season whales were significantly higher (91.4±74.2 ng/wet g) than those (58.5±15.3 ng/wet g) for 1980-82 season ones (Mann-Whitney *U*-test, $p<0.05$,Table 1). The age-related trend observed in 1997-99 season groups linearly increased with age, being similar to those of the other marine mammals reported so far (Holden 1978; Honda *et al.* 1983).

One more interest trend was observed in Hg levels and growth rates for young age-groups (1-5 year old): Hg levels and body weights for 1997-99 season groups (Hg: 23.7±17.1 ng/wet g, BW: 2.7±1.0 t) were significantly lower than those (Hg: 43.3±24.4 ng/wet g, BW: 4.3±1.5 t) for 1988-90 season ones (Mann-Whitney U-test, $p<0.05$). In this comparison, all data were combined because no significant difference in deviation of age organization among 1-5 year individuals was found (Chi-Square Test for Independence, $p>0.05$).

Yearly Hg concentrations in the food, *ie*. Antarctic krill, collected from the stomach of the minke whales were examined to see amounts of Hg intake by this whale, and the results are shown in Table 2. There were no significant differences among yearly Hg levels in the krill, and also minke whale prey item did not change over years. Therefore, it seems that the yearly differences in age-related trends of Hg accumulation in the minke whales and their accumulation levels were due to amounts of food intake by the whale, but not due to yearly change of Hg concentrations in food of the animals.

In view of these observations mentioned above, total body burdens of Hg in the minke whales for 1980-82 and 1997-99 season groups were calculated from the weights and the concentrations of Hg in the muscle and liver tissues of which occupied about 80 % of whole body burden of Hg as reported by Yamamoto (1988), and the results are shown in Figure 3. Amounts of food intake by the whale were also estimated using the following equation:

$$dS(t)/dt = a \cdot W(t) \cdot X \cdot b - r \cdot S(t)$$

where a: Daily food-intake (%) per body weight
b: Absorption ratio of Hg (80 % after Honda 1985)
X: Concentration of Hg in food (5.8 ng/wet g in Table 2)
r: Excretion coefficient (0.15 after Honda 1985)
W(t): Body weight in age (t) of individual ($W(t) = 4.03\ t^{0.236}$ ($0<t\leq10$), $W(t) = 6.94\ t^{0}$ ($t>10$) after Ohsumi *et al.* 1970).

Table 2. Moisture contents and Hg concentrations in the Antarctic krill.

Yearly group	Number	Moisture Content (%)	Hg Mean±RSD (ng/g wet wt.)	Hg Range (ng/g wet wt.)
89/90	10	80	6.0 ± 3.1	3.6 - 12.7
90/91	10	79	7.7 ± 3.3	3.3 - 13.2
91/92	10	79	4.1 ± 1.7	2.2 - 6.7
92/93	10	80	5.7 ± 2.1	4.2 - 9.6
93/94	10	78	5.6 ± 1.5	3.3 - 6.8
94/95	10	78	5.7 ± 1.2	4.0 - 7.8
95/96	10	81	5.2 ± 1.3	3.3 - 6.8
96/97	10	80	5.4 ± 1.7	3.7 - 9.5
97/98	10	80	7.2 ± 1.6	4.9 - 10.0
98/99	10	78	5.4 ± 2.3	3.2 - 9.6
Total	100	79	5.8 ± 2.2	2.2 - 13.2

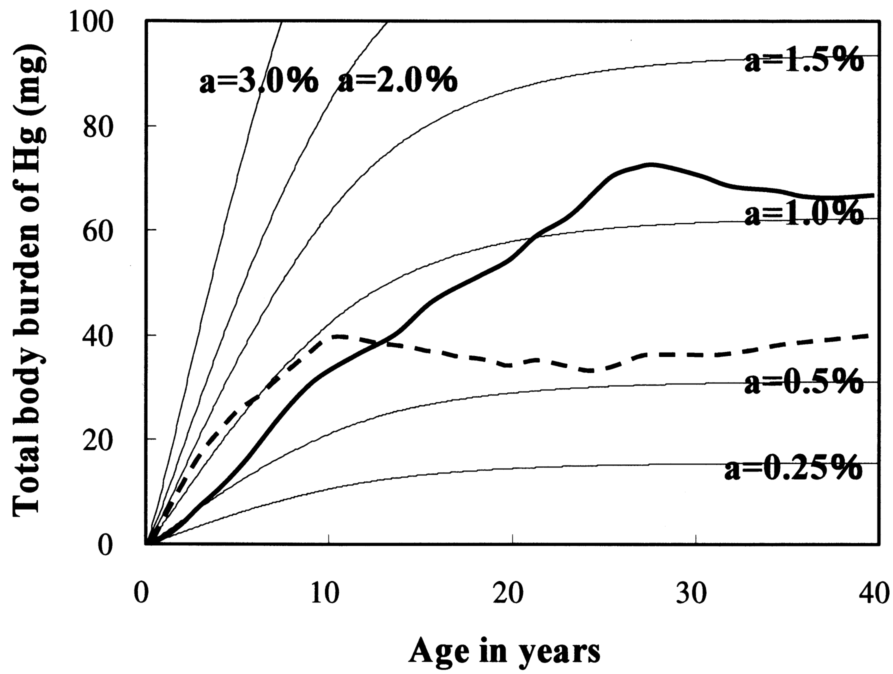

Figure 3. Age-related body burden of Hg in the minke whales for 1980-82 (▪▪▪▪▪) and 1997-99 (▬▬) season groups, and their simulation curves of feeding ratios. The age-related burdens of Hg were drawn by running mean method. a: Daily food-intake (%) per body weight.

As the results are shown in Figure 3, the food intake by the young whales (1-5 year old) for 1997-99 season group was estimated to be 0.5-0.75 % of body weight, and its ratios apparently fell about 50 % below those (1-1.5 %) for 1980-82 season group.

No significant yearly changes of Hg levels in the food of the minke whales were observed, thereby both the facts that hepatic Hg concentrations of the minke whale increased year by year, and their recent accumulation trends linearly increased with age as well as those of the other cetaceans reported so far, indicate that amounts of food intake by the whales increased as a result of decrease in other baleen whales by the commercial whalings. These evidences also completely prove the idea predicted by Honda (1985).

In contrast, recent young minke whales (1-5 year old) after the1990s showed significant decreases of Hg levels and growth rates as compared to those of the 1980s groups (Figure 2). The feeding ratios estimated from the intake-excretion equation of Hg also showed that the food intake by the young animals for 1997-99 season group fell about 50 % below those for 1980-82 season one. There are some concernments about the estimated food intake of the minke whales because absorption and excretion coefficients of Hg for the whales were based on those for other species, *ie.* striped dophin, and also the body weight-age equation of the whales was estimated from those of the whales during the 1970s. So, further degree of accuracy for the value of feeding ratios will be needed, however the feeding seems that food intake of the minke whale might decreased after the 1990s.

At this time, there are two possibilities to explain such a change of Hg accumulation levels. One is a recent increasing population of baleen whales fed on food, *ie*. Antarctic krill. There are some evidences; both the increases in minke whale stocks, and in the other baleen whale stocks which occupy the ecological niches similar to those for the minke whale in the Antarctic marine ecosystem were recognized by the International Whaling Commission. These might lead to an decrease of available food per capita for the minke whale, resulting in the decrease of Hg concentration levels, in particular, in the young animals during growing periods.

Another one is that a recent reducing food stock in the Antarctic Ocean might reflect on the decreases of Hg intake by the young minke whales at the growth stage being the most sensitive to Hg accumulation. Although there are not available for yearly change of Antarctic krill stocks, climate warming might affect on productivity of the krill. Arrigo *et al.* (2002) employed satellite imagery to document the potential for large icebergs to alter the dynamics of marine life, and reported that large iceberg restricted the northwestward drift of pack ice in the southwestern Ross Sea, one of the most biologically productive regions in the Antarctic, thereby reducing both the area of open sea available for phytoplankton growth and the length of the growing season. They also showed that productivity fell more than 40 % below normal, changing the feeding behavior of upper trophic level organisms such as the Adelie penguins that nest at Ross island. Such events by global warming is not much known, however, might reduce the productivities of phyto- and zooplanktons in another areas of the Antarctic Ocean, and it may be result in decrease of food intake or Hg intake by the minke whales.

Consequently, both the competition in food intake among recently increasing populations of baleen whales including the minke whale and the decrease in food stock as a result of global warming, might affect on the recent decrease of Hg accumulation levels in the young minke whales. How wide range of the Antarctic might be affected by global warming will need further investigations, however, if global warming is rapidly progressed, leading to decreasing the productivities of organisms, the ecology of wide areas of the Antarctic marine ecosystem will be affected. Furthermore, such ecochemical approach using persistent chemicals such as mercury as tracers is considered to be useful for learning the ecology of animals and the changes of ecosystem.

Acknowledgements. We thank to Dr. Hidehiro Kato, National Institute of Far Sea Fisheries, and Ms. Ryoko Zenitani of The Institute of Cetacean Research for providing age data of the whale samples and other biological information. We also thank to Prof. Ryo Tatsukawa, Ehime University, and Dr. Yoshiyuki

Yamamoto, Miura Co. Ltd. for supporting the conducting in this study.

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