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Mercury Levels and its Chemical Form in Tissues and Organs of Seabirds

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Abstract. Liver, muscle, kidney, and feather samples from nine species of seabirds were analyzed for total and organic (methyl) mercury (MM). Total mercury (TM) levels in liver showed great intra- and inter-species variations, with the concentrations varied from 306 μg/g (dry weight) in black-footed albatross (*Diomedea nigripes*) to 4.9 μg/g in arctic tern (*Sterna paradisaea*), while MM levels were less relatively variable. The order of MM concentrations in tissues of all the seabirds except oldsquaw (*Clangula hyemalis*) was as follows: liver > kidney > muscle. The mean percentage of MM in total was 35%, 36%, and 66% in liver, kidney, and muscle, respectively, for all the species. Statistically significant negative correlations were found between the proportion of MM to TM and concentrations of TM in the liver and muscle of black-footed albatross and in the liver of laysan albatross. Furthermore, the percentage of MM decreased with an increase in TM concentrations in the liver, muscle, and kidney of all the species. Black-footed albatross had the highest concentration and burden of mercury in the liver, wherein more than 70% of the TM occurred as inorganic mercury. On the other hand, the mercury burdens in feathers were less than 10% of the body burdens, indicating that excretion of mercury by moulting is negligible. The results suggest that some seabirds are capable of demethylating MM in the tissues (mainly in liver), and store mercury as an immobilizable inorganic form in the liver. It is noteworthy that the species with a high degree of demethylation capacity and slow moulting pattern showed low mercury burdens in feathers.

Mercury is a persistent and bioaccumulative metal in humans and wildlife. Particularly, its methylated form of mercury is considerably toxic to higher trophic organisms, as it tends to biomagnify in the food chain. Therefore, carnivores and omnivores generally retain methyl mercury at higher levels than the lower trophic organisms (Burger *et al.* 1992).

Seabirds, particularly the members of the order Procellariiformes (albatrosses, petrels, and shearwaters), accumulate high concentrations of mercury in their body tissues (Anderlini *et al.* 1972). Concentrations of more than 95 μg mercury/g wet weight were found in a healthy black-footed albatross in the North Pacific Ocean (Honda *et al.* 1990). These levels are extraordinarily high when compared to those in other species. Nevertheless, mercury exhibits a characteristic bioaccumulation pattern in large procellariiform seabirds due to specific physiological processes rather than amplification in the food chain. A wide range of mercury burdens in seabirds were associated with dietary spectrum, moulting strategies, and variable lifespans (Muirhead and Furness 1988; Honda *et al.* 1990).

This prompted the study of the detoxification process of mercury in seabirds. However, details on the distribution and chemical forms of mercury in various organs in seabirds have not been evolved. Although several studies have attempted to describe the relationship between methyl mercury (MM) and total mercury (TM) concentrations in the liver in seabirds (Norheim and Froslie 1978; Norheim *et al.* 1982; Thompson and Furness 1989b; Dietz *et al.* 1990), not much is known on the accumulation of mercury in other body tissues to understand its dynamics. Muscle, kidney, and feather also contained a significant portion of TM (Braune and Gaskin 1987). For instance, TM burden in the muscle, kidney, and feathers of black kite (*Milvus migrans*) contained more than 80% of the total body burden (Honda *et al.* 1986). This indicates the need to examine TM and MM concentrations not only in liver, but also in other tissues and organs.

Bird feathers diminish mercury burdens during growth by the moulting process (Honda *et al.* 1986; Braune and Gaskin 1987), and many studies have used the feather as a non-destructive indicator to monitor the contaminant levels in internal tissues (Burger and Gochfeld 1991, 1993; Denneman and Douben 1993; Thompson *et al.* 1993). However, almost all of the feather mercury was found to exist in the organic form (Thompson and Furness 1989a); thus the mercury residues in feathers were interpreted to reflect only the MM levels in internal tissues. If the ratio of TM to MM is species-specific, then it may be difficult to estimate the TM burdens in the body based on MM levels in feathers. This prompted the need to clarify the chemical form of mercury retained in internal tissues and organs.

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In this paper, the levels and distribution of TM and MM in internal tissues and feathers of some seabird species are presented, and an attempt is made to describe the detoxification processes of mercury in birds. The analysis of several species permitted the comparison of the dynamics of TM and MM at different accumulation levels.

Materials and Methods

Sample Collection, Storage, and Preparation

Nine species of birds were collected from the following locations: black-footed albatross (*Diomedea nigripes*), laysan albatross (*Diomedea immutabilis*), and northern fulmar (*Fulmarus glacialis*) from the North Pacific in 1985; oldsquaw (*Clangula hyemalis*), herring gull (*Larus argentatus*), and arctic tern (*Sterna paradisaea*) from Chaun, Northeast Siberia in June, 1993 (caught by shooting under license); brown booby (*Sterna anaethetus*) from southwestern Ryukyu Islands; and royal albatross (*Diomedea epomophora*) and white-chinned petrel (*Procellaria aequinoctialis*) from southern Indian Ocean in September, 1992 (obtained by fishing gear). Liver, muscle, kidney, and feather (primary number 5) samples of seabirds from the North Pacific were the same as those analyzed for TM in a previous study (Honda *et al.* 1990). All birds were kept in polyethylene bags and stored at −20°C until dissection. After biometric measurements, birds were dissected, and organ and tissue samples, including pectoral muscle, liver, kidney, and body feather, were collected.

Mercury Analysis

The tissue sample was brought to room temperature, and the outer layer was removed to avoid external contamination, if any, during storage. A subsample was subsequently dried for 12 h in an oven at 80°C to estimate the moisture content in organs and tissues.

TM levels were determined by a cold vapor technique using Sansou Automatic Mercury Analyzer Model HG-3000 spectrophotometer (Honda *et al.* 1986), after mineralization of samples with nitric, sulfuric, and perchloric acids in flasks.

MM analyses were carried out by the method of Uthe *et al.* (1972) and described in detail in Thompson and Furness (1989b). Initially, the dried sample was ground to fine powder and mixed with copper sulphate, acidified sodium bromide, and toluene. MM is released from the tissue and passes into the toluene as methyl mercuric bromide. Part of the organic phase is removed and added to sodium thiosulphate solution, colution, converting the methyl mercuric bromide into hydrophilic methyl mercuric thiosulphate, which passes into the aqueous phase. A sample of the sodium thiosulphate solution, containing the methyl mercuric thiosulphate, is removed, acid digested, and analyzed as above. Although it is difficult to distinguish specific organo-mercurial species, previous studies using gas chromatography techniques found that monomethyl mercury was the major form of mercury found in bird tissues (Fimreite 1974; Norheim and Froslie 1978; Osborn *et al.* 1979; Norheim *et al.* 1982). The accuracy and precision of this method were tested by using standard solutions of methyl mercuric chloride. The recovery through the whole analytical procedure was 96.4% with high reproducibility.

Mercury concentrations, both TM and MM, were presented as Hg μg/g dry weight of liver, muscle, kidney, and feather tissues. The term 'significant' has been used in a statistical context based on calculation at the 95% confidence internal.

Results

Total Mercury and Methyl Mercury Levels in Liver, Muscle, and Kidney

TM and MM concentrations in several organs and tissues are shown in Table 1. The TM concentrations were the highest in liver and largely varied within and between species. TM levels in kidney and muscle showed relatively little difference among species as well as individuals within a species. Concentration of TM in the liver of black-footed albatross was highest among species (mean 306 μg/g dry weight). The concentrations in royal albatrosses, laysan albatrosses, white-chinned petrels, and northern fulmars were 58, 39, 29, and 14 μg/g dry weight, respectively.

MM concentrations were the highest in liver followed by kidney and muscle in all species except oldsquaw. Variations in MM concentrations between and within species were smaller than those of TM levels. For example, MM levels in the liver of black-footed albatross were 3 to 5 times higher than those in the kidney, whereas TM concentration in the liver was 10 times greater than in kidney. MM levels in the liver of brown booby ($r = 0.987$, $p < 0.001$) (Figure 1) and northern fulmar ($r = 0.650$, $p < 0.01$) significantly increased with an increase in TM; the highest mean concentrations of MM were found in the liver (20.4 μg/g dry weight) and kidney (6.2 μg/g dry weight) of black-footed albatross and in the muscle (2.9 μg/g dry weight) of brown booby.

Distribution of Total Mercury Burdens

Distribution of TM burdens in the tissues and organs of black-footed albatross, northern fulmar, and brown booby is shown in Figure 2. These three species are representative animals found to accumulate high, middle, and low levels of TM. The proportion of TM in tissues in Figure 2 was calculated based on the mean TM concentrations and the weight of tissues. TM burden in the feather of black-footed albatross was less than 10% of body burdens, while it was over 50% in the liver. In contrast to albatross, the burden in the feather of northern fulmar and brown booby was about 40%, and that in the liver was less than 25% of the total burden.

Percentage of Methyl Mercury to Total Mercury

The composition of MM to TM varied according to organs and tissues. In particular, muscle tissue showed the largest variation in MM to TM (Table 2). The overall mean percentage of MM for all species was 35%, 36%, and 66% in liver, kidney, and muscle, respectively. Significantly negative correlations were found between percentage of MM and TM levels in the liver and muscle of black-footed albatross ($r = -0.425$, $p < 0.05$) (Figure 3) and in the liver of laysan albatross ($r = -0.826$, $p < 0.05$).

There was a decrease in the mean proportion of MM with an increase in mean TM concentrations in liver, muscle, and kidney (Figure 4). In the liver of arctic tern, which appears to have relatively low concentrations of TM, the proportion of

Table 1. Total and organic mercury levels (μg/g dry weight) in liver, muscle, kidney, and feather of seabirds

Species	Tissue	n	Total mercury			Organic mercury		
			Mean	Median (min–max)	SD	Mean	Median (min–max)	SD
Oldsquaw *Clangula hyemalis*	Liver	8	31.4	2.5 (1.8–228)	79.5	2.2	0.8 (0.3–11.0)	3.6
	Muscle	5	1.5	0.7 (0.6–4.8)	1.8	1.6	0.8 (0.3–5.6)	2.3
	Kidney	4	6.0	2.6 (1.7–17.3)	7.5	3.8	1.6 (0.9–11.0)	4.9
	Feather	5	0.7	0.7 (0.5–0.9)	0.2	0.9	0.9 (0.6–1.2)	0.2
Royal Albatross *Diomedia epomophora*	Liver	2	58.1	(51.9–64.3)		9.8	(4.4–15.1)	
	Muscle	2	2.4	(2.0–2.8)		1.1	(0.0–2.1)	
	Kidney	2	14.9	(10.6–19.2)		3.6	(2.3–4.8)	
	Feather	2	6.8	(6.5–7.1)		N.A		
Black-footed Albatross *Diomedea nigripes*	Liver	31	306	260 (30.7–1180)	217	20.4	16.9 (0.0–70.8)	14.3
	Muscle	16	15.1	15.9 (2.2–26.4)	6.9	2.0	1.6 (0.7–5.0)	1.2
	Kidney	17	37.4	37.1 (17.8–53.1)	11.8	6.2	4.5 (2.5–18.0)	3.9
	Feather	12	39.7	40.5 (25.9–65.6)	12.9	N.A.		
Lysan Albatross *Diomedea immutabilis*	Liver	8	38.9	39.2 (24.3–55.6)	11.2	11.2	11.2 (8.1–14.6)	2.8
	Feather	8	7.2	7.2 (2.7–11.9)	2.8	N.A.		
White-chinned Petrel *Procellaria aequinoctialis*	Liver	2	29.0	(11.5–46.5)		8.0	(7.6–8.3)	
	Muscle	2	2.0	(1.6–2.4)		0.9	(0.6–1.1)	
	Kidney	2	18.8	(12.6–25.0)		4.3	(3.6–5.0)	
	Feather	2	24.0	(5.2–42.7)		N.A.		
Northern Fulmar *Fulmarus glacialis*	Liver	15	14.2	11.0 (5.2–43.5)	10.0	3.1	3.1 (0.6–6.2)	1.5
	Muscle	5	1.4	1.4 (0.3–3.0)	1.0	0.9	0.9 (0.0–2.0)	0.7
	Kidney	5	6.7	5.9 (4.3–11.6)	3.0	1.7	1.2 (0.0–5.1)	2.1
	Feather	17	4.8	4.2 (2.6–13)	2.4	N.A.		
Brown Booby *Sula leucogaster*	Liver	14	7.2	3.5 (0.6–46.8)	12.2	3.7	1.5 (0.5–21.1)	5.3
	Muscle	4	3.8	0.9 (0.5–13.0)	6.1	2.9	1.2 (2.0–8.8)	4.0
	Kidney	5	6.5	6.9 (3.2–8.4)	2.1	3.6	2.8 (0.8–10.2)	3.8
	Feather	11	2.9	2.9 (0.7–4.3)	1.0	N.A.		
Herring Gull *Larus argentatus*	Liver	6	4.2	3.9 (1.7–7.3)	2.0	1.2	1.0 (0.3–2.3)	0.8
	Muscle	5	0.8	0.7 (0.6–1.1)	0.2	0.6	0.6 (0.5–0.8)	0.1
	Kidney	5	3.6	3.6 (3.0–4.1)	0.4	1.3	1.6 (0.4–1.8)	0.6
	Feather	5	6.1	4.6 (3.2–14.2)	4.6	6.5	5.3 (3.4–14.4)	4.5
Arctic Tern *Sterna paradisaea*	Liver	6	4.9	4.1 (1.8–9.1)	2.8	2.3	2.3 (0.6–4.4)	1.3
	Muscle	3	0.9	0.8 (0.5–1.4)	0.5	1.1	1.0 (0.6–1.7)	0.6
	Kidney	3	3.6	3.2 (2.3–5.4)	1.6	1.9	1.2 (0.9–3.7)	1.5
	Feather	5	0.9	0.9 (0.9–1.2)	0.1	1.1	1.1 (0.8–1.0)	0.1

N.A.—Not Analyzed; SD—Standard deviation

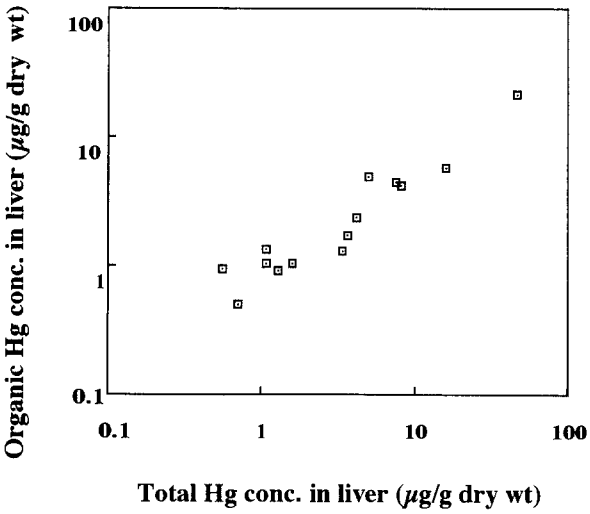

Fig. 1. Concentrations of organic mercury plotted against those of total mercury in the liver of brown booby.

MM to TM levels was 50%. However, northern fulmar, which showed intermediate TM levels, contained 25% of MM to TM, and black-footed albatross, categorized at the highest TM levels, revealed only 10% of MM. Similar trends were also found in the muscle and kidney.

It is also noteworthy that a higher proportion of mercury in its organic form was found in muscle than in liver and kidney (Table 2). Particularly, oldsquaw and arctic tern contained 90–100% mercury in its organic form in the muscle. However, in contrast, black-footed albatross showed a lower proportion of MM in muscle than in kidney.

The feather of seabirds also retained mercury at significant concentrations, and revealed a species-specific accumulation pattern (Table 1). Oldsquaw, herring gull, and arctic tern contained organic mercury of about 115% of TM (Table 2), implying that most of the mercury in the feather exists in its organic form.

In certain cases, the concentration of organic mercury exceeds that of TM. This was due to the unavoidable procedural error in determination of mercury.

Relationship between Total Mercury and Methyl Mercury in Liver, Muscle, and Kidney

The relationship of TM concentration was examined between kidney and liver, and a positive correlation was obtained ($r = 0.733$, $p < 0.001$, Mann-Whitney U-test) (Figure 5). Black-footed albatross, with the largest amount of mercury in the body, differed from other species. The ratios were found to be in the range of 10:1 to 30:1 in those species which accumulated relatively lower concentrations of mercury. However, in black-footed albatross, the ratios were from 30:1 to 100:1. A similar trend was also observed between TM and MM in the liver ($r = 0.650$, $p < 0.001$) (Figure 6). Significant correlations were also found between MM in the liver and TM in the kidney ($r = 0.770$, $p < 0.001$), muscle ($r = 0.737$, $p < 0.001$), and feather ($r = 0.459$, $p < 0.001$). However, values for black-footed albatross deviated from those of other species (Figure 7).

Discussion

Interspecies Variation and Distribution of Mercury in Tissues and Organs

The large interspecies variation in mercury concentrations in the organs and tissues (Table 1) was similar to those reported earlier (Fimreite 1974; Hutton 1981; Muirhead and Furness 1988; Honda *et al.* 1990).

Detailed information on the diet of seabirds, especially for pelagic seabirds, is scarce. Seabirds preys on zooplankton and fish, including squid, and in some cases, their feed changes with the habitat and season. Therefore, it is difficult to link observed mercury concentration with the uptake from the diet (Muirhead and Furness 1988). However, Honda *et al.* (1990) highlighted that the interspecies differences in dietary and feeding habits of birds were important to explain the variation of mercury levels, with the species feeding mainly on squid and/or fish accumulating high mercury levels. For example, black-footed albatross, which has a high frequency of fish in its diet (Ogi 1986), contained greater mercury levels than the laysan albatross, which feeds mainly on krill (Ogi 1986). Lock *et al.* (1992) also noted that seabird species feeding predominantly on crustaceans (some penguins, prions, and diving petrels) contained low mercury burdens. In contrast, other species feeding on squid, fish, and/or carrion showed high mercury burdens. In the present study, black-footed albatross and royal albatross, which mainly feed on fish and squid, had high mercury concentrations, whereas the other species, feeding mainly on crustaceans and insects, contained low mercury concentrations. Therefore, dietary and feeding habits could be a significant factor for the accumulation of mercury in seabirds.

To compare the differences in mercury distribution in the body, TM burdens were examined in the tissues and organs (Figure 2). The species with high mercury levels, such as black-

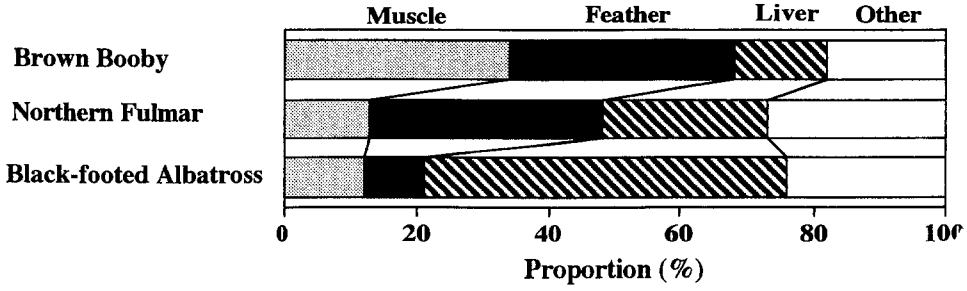

Fig. 2. Percentage composition of total mercury burdens in the tissues and organs of three seabird species

Table 2. Percentage proportion of organic mercury in total mercury concentrations in organs and tissues of seabirds

Species	Tissue	n	Mean	SD	Median
Oldsquaw	Liver	8	28	23	21
Clangula hyemalis	Muscle	5	90	36	109
	Kidney	4	60	20	58
	Feather	5	121	12	122
Royal Albatross	Liver	2	18	16	18
Diomedia epomophora	Muscle	2	37	53	37
	Kidney	2	28	23	28
Black-footed Albatross	Liver	31	10	11	6.0
Diomedea nigripes	Muscle	16	19	23	11
	Kidney	17	17	8.0	15
Lysan Albatross	Liver	8	32	14	31
Diomedea immutabilis					
White-chinned Petrel	Liver	2	44	39	44
Procellaria aequinoctialis	Muscle	2	43	5.0	43
	Kidney	2	24	6.0	24
Northern Fulmar	Liver	15	25	11	27
Fulmarys glacialis	Muscle	5	55	31	69
	Kidney	5	21	23	16
Brown Booby	Liver	14	66	36	62
Sula leucogaster	Muscle	4	103	28	105
	Kidney	5	54	54	36
Herring Gull	Liver	6	35	30	22
Larus argentatus	Muscle	5	80	24	77
	Kidney	5	37	15	40
	Feather	5	108	28	111
Arctic Tern	Liver	6	50	23	46
Stern paradisaea	Muscle	3	103	3.0	102
	Kidney	3	50	21	54
	Feather	5	117	14	116

SD—Standard deviation

footed albatross, showed that the mercury feather burdens were less than 10% of the body burdens, indicating that the excretion of mercury through moulting is negligible. The moulting process of bird feathers could diminish the mercury body burdens in birds (Honda *et al.* 1986). It should also be noted that albatrosses have a slower molting pattern in contrast to other species that undergo moulting every year (Furness *et al.* 1986). Therefore, albatrosses have less opportunity to excrete mercury from the body than those species that molt annually. In addition, most of the mercury lost from the body during molting is MM (Table 2). Therefore, the species with relatively slow molting cycles would excrete smaller amounts of MM through molting.

Variation of MM concentrations in the liver was small in spite of the large variation of TM levels (Table 1). This suggests that the variation of mercury concentrations in the tissues is mainly attributed to the inorganic mercury fraction.

Chemical Forms of Mercury and Their Detoxification Process

Numerous studies (Smith and Armstrong 1978; Gaskin *et al.* 1979: Falconer *et al.* 1983) have noted a decreasing trend in MM percentage with an increase of TM concentration in marine mammals. These results were considered evidence for the detoxification process whereby dietary MM is demethylated into the inorganic form. Although the relationship between methyl and inorganic mercury has been less investigated in birds than in marine mammals, studies have indicated a relatively lower proportion of MM to TM levels in the liver of birds (Fimreite 1974; Norheim and Froslie 1978; Thompson and Furness 1989b). In the present study, a significant negative correlation was found between the proportion of MM and TM, not only in the liver but also in the muscle of black-footed albatross. A similar trend was observed in the liver of several seabirds (Norheim *et al.* 1982; Thomson and Furness 1989b). It is noteworthy in the present study that the mean percentage of MM decreased with increasing TM levels, not only in liver, but also in muscle and kidney of all the seabirds examined (Figure 4). In this context, it is also interesting to note that the species with relatively low percentage of MM in liver (e.g., black-footed albatross) exhibited a similar pattern in muscle and kidney. On the other hand, the species (e.g., Arctic tern) with high MM in liver showed consistently increased MM proportion in muscle and kidney. The data on MM in muscle and kidney of birds are very scarce. Some investigators have noticed that the bulk of the mercury in muscle (Thompson *et al.* 1990) and kidney (Osborn *et al.* 1979) existed in its toxic methyl form. However, the results of the present study indicated variable levels of MM in association with TM concentrations in muscle and kidney of seabird species. These findings indicate that the proportion of MM is strongly dependent on the mercury quantities not only in the liver, but also in the muscle and kidney of seabirds.

It has been demonstrated that the prey consumed by pelagic seabirds mostly retained mercury in its methylated form (Koe-

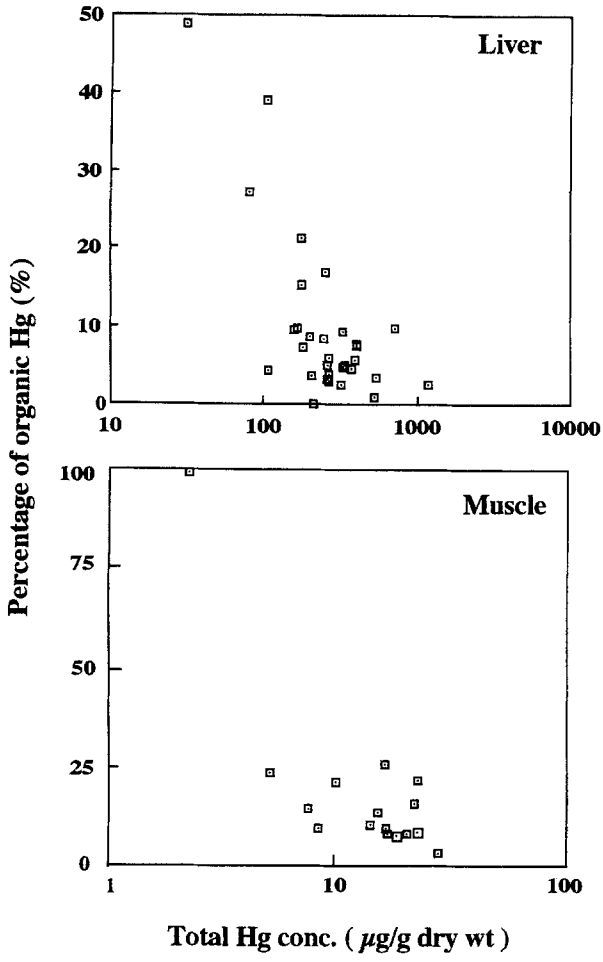

Fig. 3. Percentage of organic mercury to total mercury concentrations plotted against total mercury concentrations in the liver and muscle of Black-footed albatross

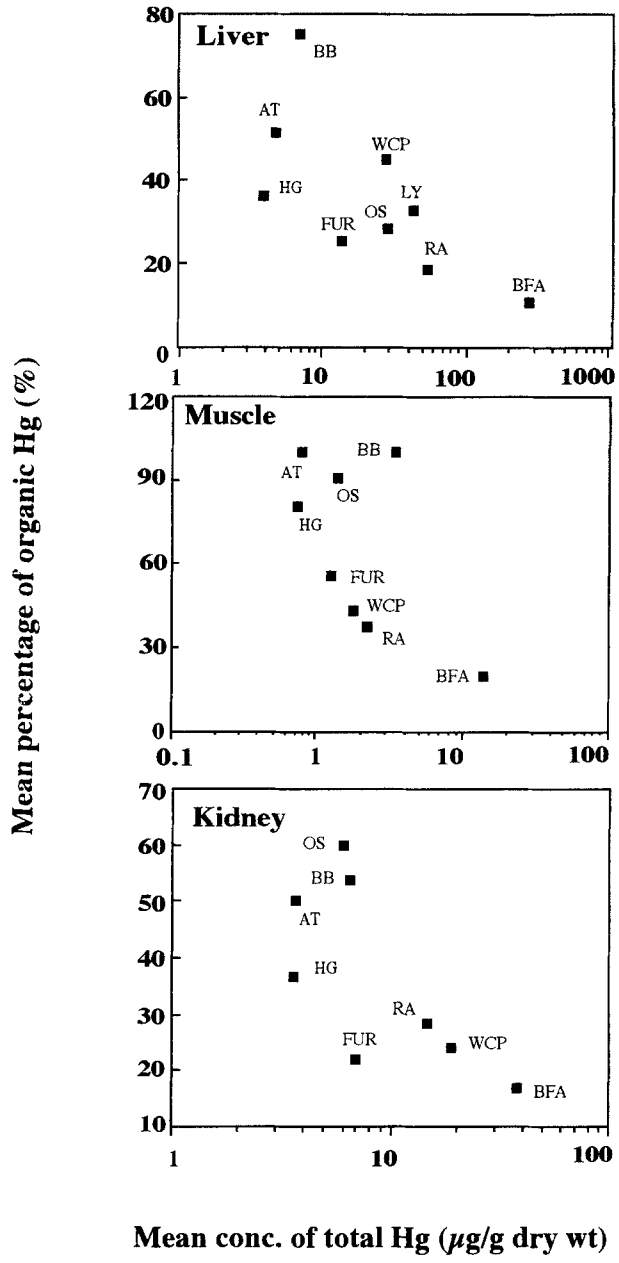

Fig. 4. Mean percentage of organic mercury in total mercury concentrations plotted against mean concentrations of total mercury (OS: oldsquaw; RA: royal albatross; BFA: black-footed albatross; WCP: white-chinned petrel; FUR: northern fulmar; BB: brown booby; HG: herring gull; AT: Arctic tern)

man *et al.* 1975). This means that the lower proportion of MM to TM levels found in seabirds is caused by the formation of inorganic mercury through demethylation processes in their bodies. The variable proportion of MM may suggest species-specific differences in the capacity to carry out the demethylation process. Freeman and Horne (1973) suggested that seals may have enzyme systems for demethylating MM in the liver and kidney as these organs showed the lowest percentage of MM. Laboratory experiments using rats and mice also showed that liver and kidney contained demethylating enzyme systems (Norseth and Clarkson 1970; Yamamoto *et al.* 1983). The positive correlations of TM and MM concentrations in different tissues and organs (Figures 5, 6) suggest that inorganic mercury in the liver is less transported more slowly to each tissue than MM, which is efficiently transported. Because of its chemical stability and lipophilicity, MM, in contrast to inorganic forms, readily transfers into the blood, and distributes to other tissues and organs. Considering the specific accumulation of MM in black-footed albatross (Figure 6), it is likely that the demethylation occurs not only in the liver, but also in the muscle and kidney of some birds. The variable proportion of MM might have arisen from the inherent demethylation capacity of different organs and tissues in association with species-specific ability of MM metabolism.

To our knowledge, the inter-species differences in mercury burdens as well as the relationship between TM and MM in tissues of birds have not been previously reported. The present study has made clear the differences in mercury burdens among black-footed albatross and other species. These differences may be due to the specific transfer of MM in organs and tissues including feather, as well as the modes of ingestion, demethylation mechanisms, and excretion. It is possible to estimate further that pelagic seabirds, especially albatrosses, can demethylate MM in the liver as well as some marine mammals (Koeman *et al.* 1973), and they store the mercury as the immobiliza-

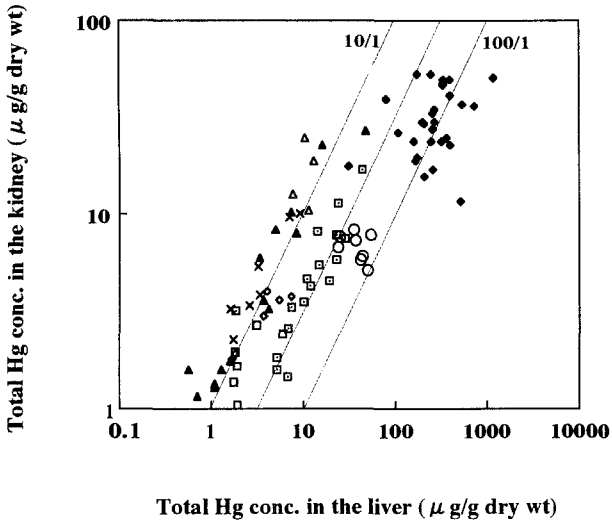

Fig. 5. Relationship of total mercury concentrations between liver and kidney of the seabirds (□: oldsquaw; △: royal albatross; ◆: black-footed albatross; △: white-chinned petrel; ⊡: northern fulmar; ▲: brown booby; ◇: herring gull; ×: arctic tern; ○: lysan albatross)

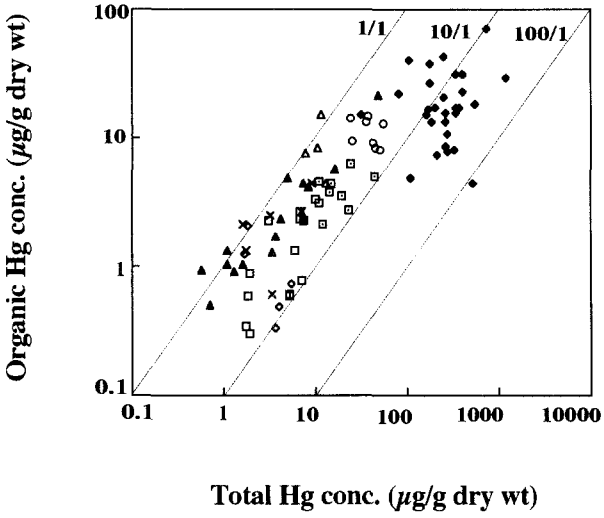

Fig. 6. Relationship between total mercury and organic mercury concentrations in the liver of seabirds (□: oldsquaw; △: royal albatross; ◆: black-footed albatross; △: white-chinned petrel; ⊡: northern fulmar; ▲: brown booby; ◇: herring gull; ×: arctic tern; ○: lysan albatross)

ble inorganic form in the liver rather than shedding MM to other tissues and organs.

In particular, albatrosses with slower moulting patterns have less opportunity to excrete MM from the body than species that undergo a complete moult annually. Conversion of MM into an inorganic form could be a complemental response for the limited opportunity to eliminate MM by albatrosses. Demethylated mercury would accumulate in tissues and organs and this would be further amplified in seabirds with long lifespans. The demethylation of MM may be a significant detoxification process for seabirds so that they can tolerate MM better than considered previously. The demethylation capacity is likely to provide an explanation for the physiological adaptation of seabirds in the marine environment.

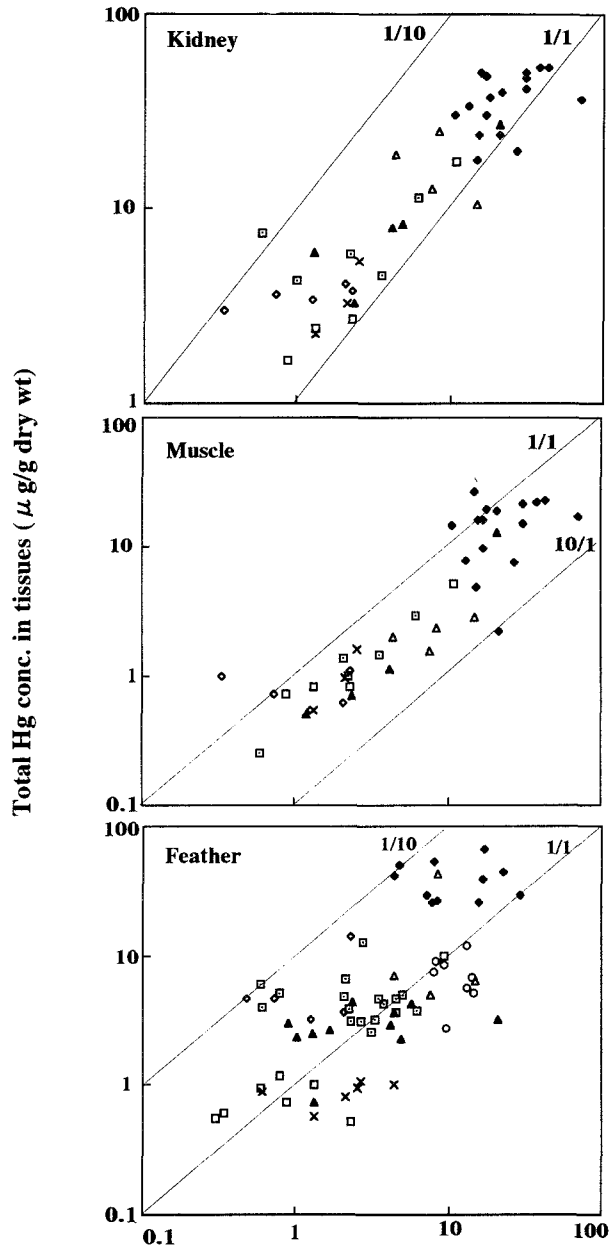

Fig. 7. Relationship between organic mercury in the liver and total mercury in the kidney, muscle, and feather of seabirds (□: oldsquaw; △: royal albatross; ◆: black-footed albatross; △: white-chinned petrel; ⊡: northern fulmar; ▲: brown booby; ◇: herring gull; ×: arctic tern; ○: lysan albatross)

Conclusion

Birds with high mercury levels tended to feed mainly on squid and/or fish. The differences in moulting pattern and demethylation process were also important for the high mercury levels in several seabirds. Particularly, it is noteworthy that the species with a high degree of demethylation exhibited a slow moulting pattern. This indicates that seabirds control the mercury accumulation by excretion through moulting and demethylated metabolism. In this aspect, the birds with low demethylation capac-

ity and slow moulting could be considered critical species towards mercury toxicity.

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