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Mercury, organic-mercury and selenium in small cetaceans in Taiwanese waters

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Abstract

Total Hg ($\sum$Hg), organic-Hg (O-Hg) and Se bioaccumulations in small cetaceans distributed in Taiwanese waters of the Taiwan Strait and the southwestern Pacific have been investigated for the first time. The results could represent the baseline metal concentrations of marine mammals in the southwestern Pacific, where volcanic activities are possibly the major source of mercury to the environments. Muscle samples of four species of small cetaceans were collected from animals accidentally caught by tuna-longline fisheries from 1994 through 1995. In total, 53 pantropical spotted dolphins, *Stenella attenuata*, nine spinner dolphins, *S. longirostris*, five bottlenose dolphins, *Turiops truncatus* and four Risso's dolphins, *Grampus giseus* were analyzed. In addition, two stranded pantropical spotted dolphins were investigated. Cold vapour AAS and ICP-MS were used in the analysis of Hg and Se, respectively. Significant species difference was found in the four species of small cetaceans. Among them, the pantropical spotted dolphin showed the highest mean concentration (mg/kg wet wt.) of both $\sum$Hg (3.64 ± 2.19) and O-Hg (2.79 ± 1.23), whereas the Risso's dolphin had the highest mean concentrations of Se (1.77 ± 1.29). There was no significant sex difference with respect to metal bioaccumulation in the samples of *S. attenuata*. Significant correlations between body length (BL) and $\sum$Hg, as well as O-Hg concentrations were observed in pantropical spotted (Sa) and spinner dolphins (Sl). The linear relationships were Sa: $\sum\text{Hg} = -8.290 + 0.066\text{BL}$, $r = 0.421$; Sl: $\sum\text{Hg} = -2.735 + 0.025\text{BL}$, $r = 0.875$; Sa: $\text{O-Hg} = -3.723 + 0.036\text{BL}$, $r = 0.408$; and Sl: $\text{O-Hg} = -3.017 + 0.025\text{BL}$, $r = 0.870$. However, a demethylation phenomenon that decreasing the percentage of O-Hg coupled with increasing levels of Se was observed when the $\sum$Hg concentrations in the muscle tissues of dolphins reached 4 mg/kg wet wt.

Keywords: Pantropical spotted dolphin (*Stenella atteunuata*); Spinner dolphin (*S. longirostris*); Bottlenose dolphin (*Turiops truncatus*); Risso's dolphin (*Grampus giseus*); Background levels; Taiwan

1. Introduction

The Kuroshio Current flows through the eastern coast of Taiwan all year round, and resulting disturbance of the waters makes them rich in plankton, which then attracts many marine creatures feeding in this area. Meanwhile, migratory marine organisms, such as dolphins and tuna, chase their prey in the current, thereby creating a flourishing tuna fishery in the eastern and southwestern waters. Due to such nature, dolphins are most often found among tuna cruising in the sea, which frequently leads to their getting entangled in fishing nets. Not until 1994, however, had such an abundance of small-toothed cetacean ever been studied in Taiwan. The Cetacean Research Team was consequently established in the Department of Zoology at National Taiwan University, and these entangled dolphins, therefore, became their research specimens. Once landed in the fishing ports, the carcasses of the accidentally caught cetaceans were handed over to police authorities so that they could be used by researches for investigative purposes. This marked the first time that the bioaccumulation of contaminants in the small cetaceans of Taiwan had ever been studied.

The toothed cetacean, inhabitants of the highest trophic levels of a marine ecosystem due to the food chain effect and their long longevity, bioaccumulate the

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greatest amount of various pollutants, such as organochlorines and mercury (Kemper et al., 1994; Aguilar et al., 1993; Leonzio et al., 1992; Andre et al., 1990). Generally, they are considered the end point of the biogeochemical cycle of mercury in the biological phase of a marine ecosystem (Becker, 2000; Bargagli et al., 1998; Becker and Bigham, 1995). Besides Taiwanese waters, the accumulation of mercury and other heavy metals in marine mammals has been examined in many areas and in various species (e.g. Siebert et al., 1999; Parsons, 1999; Holsbeek et al., 1998; Wagemann et al., 1996; Wood and Van Vleet, 1996; Noda et al., 1995; Law et al., 1991; Andre et al., 1991; Marcovecchio et al., 1990; Morris et al., 1989; Fujise et al., 1988). Therefore, it is worthwhile to use all of these findings as diagnostic and comparative tools to understand the status of marine pollution in Taiwanese waters (Marcovecchio et al., 1994; Miyazaki, 1994; Viale, 1994; Fujise et al., 1988). Moreover, by gaining a better understanding of the bioaccumulation pattern in the marine mammal, we may well be able to gain insight into the transfer and fate of mercury in the biogeochemical cycle.

2. Materials and methods

From 1994 to 1995, we collected samples of small cetaceans from police-detained dolphins which had accidentally been captured by tuna-angling fisheries around Taiwanese waters, mainly from Penghu, Suao, Chengkung, Tungkang, Kaohsiung and Yunlin (Fig. 1). The samples included 53 pantropical spotted dolphins (*Stenella atteunuata*), four Risso's dolphins (*Grampus giseus*), nine spinner dolphins (*S. longirostris*) and five bottlenose dolphins (*Turiops truncatus*). In addition, two stranded pantropical spotted dolphins were also investigated in this study. As accurately as possible, the sizes of the samples were recorded for total length (cm) and for body weight (kg). Then 0.5–1 kg of muscle tissue at the flank under the dorsal fin was taken and frozen at −20 °C for further analysis.

After thawing of samples, the outer-most layer of tissue was cut off to eliminate any contamination that may have occurred during field sampling. At this stage all of the equipment used had obviously been acid-washed and was ultra-clean. The samples were then cut into small cubes, homogenized and stored in small vials and refrozen at −20 °C for further investigation.

The analysis of total mercury employed the method established in previous studies (Chen and Chou, 2000; Uthe et al., 1970, 1972). Briefly, 0.2–0.5 g of the homogenized flesh muscle tissues were weighed and placed into the 75 ml graduated test tubes. One ml of nitric acid (HNO_3), 4 ml of sulfuric acid (H_2SO_4) and 15 ml of potassium permanganate ($KMnO_4$) were used for wet digestion. Once the digestion was completed, each

Fig. 1. Map showing the sampling sites of the cetaceans studied here.

sample was made up to 25 ml of volume. By using 2% of tin(II) chloride dihydrate ($SnCl_4$) as a reductant, the measurement of Hg concentration was performed by cold vapour of an atomic absorption spectrophotometer (cold vapour AAS, Hitachi Z-8200 and HFS-2).

The organic-mercury extract method was adopted from Shum et al. (1979). First, acetone was used to remove lipid. Then, 5 ml 3 M potassium bromide (KBr), with 10 ml 0.1 M copper sulfate ($CuSO_4$) as an extracting agent, was added to 0.3–0.5 g of homogenized flesh muscle in 40 ml conical graduated centrifuge tubes. The extractant was put into 20 ml centrifuge tubes and extracted with toluene again and the upper organic phase was taken into another 20 ml centrifuge tubes. Finally, the organic phase of Hg was then extracted back to 1 ml 0.005 M sodium persulfate ($Na_2S_2O_3$) and this 1 ml $Na_2S_2O_3$ extractant was transferred into a 75 ml test tube. Then, once again the Hg digestion procedure was performed, as previously stated, and the Hg concentration was also measured using cold vapour AAS method.

For the analysis of Se, approximately 1 g of homogenized flesh muscle was weighed and put into a 50 ml conical flask to which 10 ml nitric acid was added for acid digestion. When the tissue was completely dissolved, it was gradually heated to 120 °C on a hot plate until the vapour and acid flume inside the flask turned clear. After the excess acid had evaporated, the sample was washed with 1 M HNO_3 and filtrated through Whatman No. 540 filter paper. Finally, the filtrated digests were quantified into 25 ml volumetric flasks. This sample was then ready for analysis using inductively coupled plasma mass spectrometry (ICP-MS Perkin–Elmer Eln 500).

Each sample was analyzed at least in duplicate and measured at least twice. Regent blanks were inserted in every 20th sample to detect any alien contaminant. In addition, the duplicates of the standard reference material (DORM-2, Dog fish muscle purchased from the National Research Council of Canada) were analyzed simultaneously in each digesting process. All chemical reagents used in this study were GR grade from Merck Company Ltd. The instrumental detection limits of $\sum$Hg, O-Hg and Se were calculated based on three standard deviation of blank after a series of analyses. They were 1, 2 and 1 ng/ml, respectively. Our analytical results of DORM-2 were $Hg = 4.69 \pm 0.25$ ($n = 20$), $O\text{-}Hg = 4.39 \pm 0.43$ ($n = 20$) and $Se = 1.51 \pm 0.19$ ($n = 4$) mg/kg dry wt. Compared with the certified values of DORM-2, i.e. $Hg = 4.64 \pm 0.26$, $O\text{-}Hg = 4.47 \pm 0.32$ and $Se = 1.40 \pm 0.09$ mg/kg dry wt., the recovery rates in this study were within $100 \pm 10\%$.

The statistical analysis was performed using SAS software, including Student's *t*-test, linear regression, ANOVA (one-way analysis of variance, $p < 0.05$) and ANCOVA (analysis of covariance, $p < 0.01$). The Duncan's multiple-range test was also adopted to detect differences in metal concentrations among the four species ($p < 0.05$) (SAS, 1988).

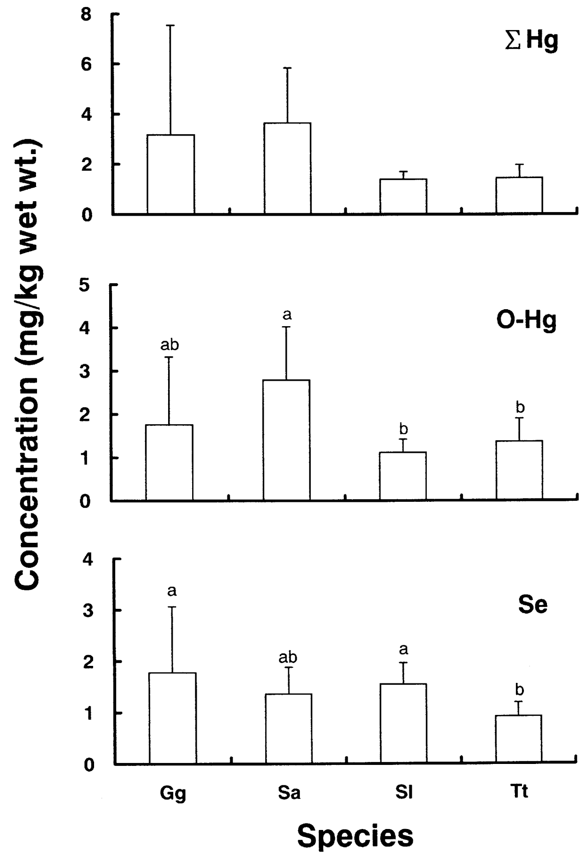

Fig. 2. Means and standard deviations of $\sum$Hg, O-Hg and Se concentrations (mg/kg wet wt.) of muscle tissues in four species of cetaceans. Gg: Risso's dolphin, *G. giseus*; Sa: pantropical spotted dolphin, *S. atteunuata*; Sl: spinner dolphin, *S. longirostris*; and Tt: bottlenose dolphin, *T. truncatus*. The symbols a, ab, b and c above the vertical bars show the results of Duncan's multiple-range test and indicate that there is no significant difference with same italic letter.

3. Results

Significant species differences in terms of concentrations of $\sum$Hg, O-Hg and Se in muscle tissues were obvious among the four species of small cetaceans (Fig. 2). For one, *S. attenuata* showed the highest means of both $\sum$Hg (3.64 ± 2.21 mg/kg wet wt.) and O-Hg (2.81 ± 1.24 mg/kg wet wt.). Its O-Hg value was significantly higher than that of the spinner and bottlenose dolphins. On the other hand, the *G. giseus* had the highest mean Se concentration (1.77 ± 1.29 mg/kg wet wt.) and differed significantly from *T. truncatus*. The lowest mean $\sum$Hg (1.39 ± 0.30 mg/kg wet wt.) and mean O-Hg (1.13 ± 0.32 mg/kg wet wt.) concentrations were apparent in *S. longirostris* while the lowest mean Se concentration (0.92 ± 0.27 mg/kg wet wt.) was found in *T. truncatus* (Fig. 2).

No significant sex difference with regard to metal bioaccumulation was observed in males and females of *S. attenuata* (Student's *t*-test, $p > 0.05$). Compared with the by-catch samples, the two stranded samples (one male and one female) did not show any elevated metal levels (Tables 1 and 2).

Significant correlations between body length and metal concentrations of $\sum$Hg and O-Hg were noted in both *S. attenuata* and *S. longirostris* (Fig. 3). However, the linear relationship between the female and male *S. attenuata* was not significant (ANCOVA, $p > 0.05$). Therefore, it was combined as Sa: $\sum Hg = -8.290 + 0.066BL$, $r = 0.421$; Sl: $\sum Hg = -2.735 + 0.025BL$, $r = 0.875$; Sa: $O\text{-}Hg = -3.723 + 0.036BL$, $r = 0.408$; and Sl: $O\text{-}Hg = -3.017 + 0.025BL$, $r = 0.870$ (Fig. 3). A good correlation between body length and Se concentrations was only found in *S. longirostris* ($Se = -1.268 + 0.017BL$) , but this was not the case with *S. attenuata* (Fig. 3).

Organic-mercury in both *S. attenuata* and *S. longirostris* significantly correlated with total mercury. However, two regression lines were noted in *S. attenuata,* whereas only one was fitted in the case of the *S. longirostris* (Fig. 4). In *S. attenuata,* the turning point was at 4 mg/kg of $\sum$Hg. A comparison of the regression

Table 1
Means and standard deviations of body length (BL), total mercury (∑Hg), organic-mercury (O-Hg) and selenium (Se) concentrations (mg/kg wet wt.) in males and females by-catch Pantropical spotted dolphins, *S. attenuata*, as well as stranded Pantropical spotted dolphins

Source	Sex	No.	BL (cm)	∑Hg	O-Hg	Se
Stranded in Penghu, September 1995	Male	1	150	0.55	0.54	0.88
Stranded in Penghu, October 1995	Female	1	191	5.58	2.11	0.64
By-catch in Suao, Yunlin and Tungkang	Male	21	179 (160–205)	3.46 ± 1.92 (1.27–8.23)	2.81 ± 1.46 (1.07–7.53)	1.35 ± 0.43 (0.76–2.55)
By-catch in Suao, Yunlin, Tungkang and Chengkung	Female	32	180 (158–242)	3.76 ± 2.38 (1.05–12.03)	2.77 ± 1.09 (1.05–4.87)	1.36 ± 0.58 (0.90–4.19)

Table 2
Means and standard deviations of total mercury (∑Hg), organic-mercury (O-Hg) and selenium (Se) concentrations (mg/kg wet wt.) in the muscle tissues of various small dolphins all over the world

Species	Region	∑Hg	O-Hg	Se	Reference
Grampus griseus	Taiwan Strait & SW Pacific	3.17 ± 4.36 (0.71–9.70)	2.00 ± 1.42 (0.97–4.05)	1.77 ± 1.29 (0.78–3.63)	This study
	Mediterranean, Italy	(26.52–30.87)	(15.0–15.7)	(6.5–17.3)	Storelli et al. (1998)
Lagenorhynchus albirostris	Newfoundland, NW Atlantic	0.41 ± 0.11 (0.175–0.65)	–	0.48 ± 0.23 (0.30–1.20)	Muir et al. (1988)
Phocoena phocoena	Cardigan Bay, W. Wales*	(0.22–1.1)	–	–	Morris et al. (1989)
	North and Baltic Sea, Germany*	3.5 ± 14.4 (0.2–108)	0.9 ± 0.9 (0.1–5.3)	–	Siebert et al. (1999)
Phocoenoides dalli	Northwestern Pacific, Japan	(NA–1.13)	–	–	Fujise et al. (1988)
Stenella attenuata	Taiwan Strait & SW Pacific	3.64 ± 2.21 (1.05–12.0)	2.81 ± 1.24 (1.05–7.53)	1.36 ± 0.52 (0.76–4.19)	This study
	Australian waters	(0.82–1.01)	–	–	Kemper et al. (1994)
	Eastern tropical Pacific	2.27 (0.1–9.17)	–	–	Andre et al. (1991)
S. coeruleoalba	Cardigan Bay, W. Wales*	0.56	–	–	Morris et al. (1989)
	Atlantic, France (1972–1980)*	3.76 (1.50–12.00)	–	–	Andre et al. (1990)
	Kawana & Taiji, Japan	7.02 (0.46–15.7)	–	–	Honda et al. (1983)
	Taiji & Kii Peninsula, Japan	(2.05–22.2)	–	(0.47–4.99)	Itano et al. (1985)
	Mediterranean, France (1973–1974)*	8.13 (1.91–23)	–	–	Viale (1994)
	Mediterranean, Italy*	9.2 (1.6– 42.1)	–	2.6 (1.0–13.8)	Leonzio et al. (1992)
	Mediterranean, France (1988–1990)*	11.2 (1.85–38.9)	–	–	Augier et al. (1993)
	Mediterranean, France (1972–1980)*	28.3 (1.00–81.2)	–	–	Andre et al. (1990)
S. longirostris	Taiwan Strait & SW Pacific	1.39 ± 0.30 (0.84–1.76)	1.13 ± 0.32 (0.59–1.60)	1.54 ± 0.41 (1.01–2.40)	This study
Tursiops truncatus	Taiwan Strait & SW Pacific	1.44 ± 0.53 (0.73–2.05)	1.41 ± 0.61 (0.73–2.27)	0.78 ± 0.47 (0.08–1.37)	This study
	Cardigan Bay, W. Wales*	0.68	–	–	Morris et al. (1989)
	Australian waters	(0.22–0.77)	–	–	Kemper et al. (1994)
	Mediterranean, Italy*	9.5 (1.2–73.0)	–	2.1 (1.1–12.1)	Leonzio et al. (1992)

The asterisk (*) indicates stranded specimens. The number in brackets indicate the range of values.

line established for the ∑Hg < 4 mg/kg wet wt. for *S. attenuata* with that of *S. longirostris* shows that there was no significant difference between them (ANCOVA, $p > 0.01$) (Fig. 4).

When the ∑Hg concentrations of the four species of small cetaceans were sorted in ascending sequence, the trend that emerged demonstrating that the percentage of O-Hg decreased to below 85% while the total Hg reached ≈4 mg/kg wet wt. in both females and males (Fig. 5).

Noteworthy too is that the percentage of O-Hg was negatively correlated to the concentration of Se when the ∑Hg concentrations were greater than 4 mg/kg wet wt.; by contrast, when the ∑Hg concentrations were

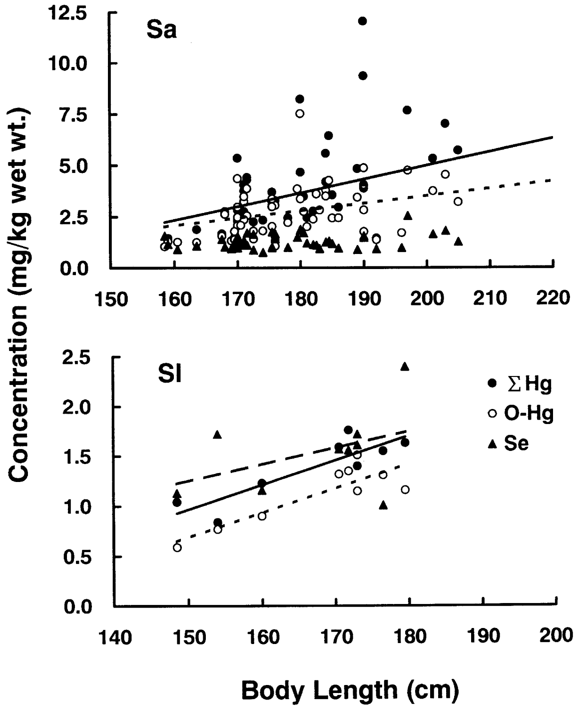

Fig. 3. Relationships between BL and ∑Hg, O-Hg and Se concentrations in the muscle tissues of *S. atteunuata* (Sa) and *S. longirostris* (Sl) accidentally caught in Taiwanese waters.

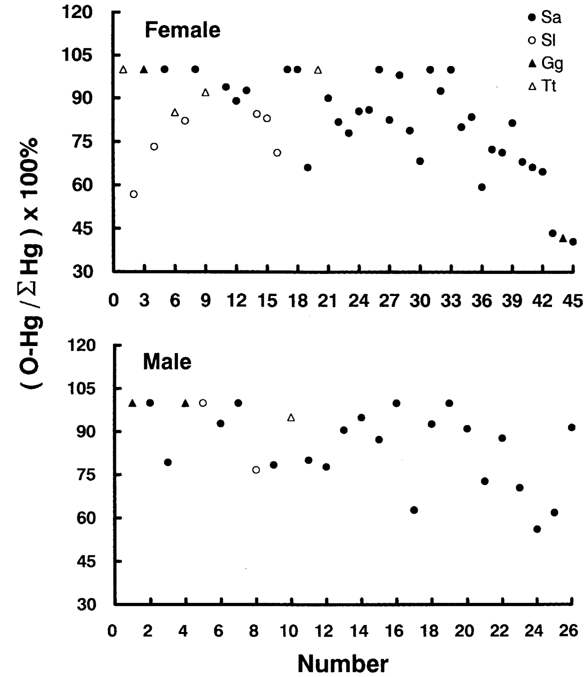

Fig. 5. Distribution of the percentage of O-Hg (O-Hg/∑Hg%) plotted in ascending order of the ∑Hg concentrations of males and females in the four species of small cetaceans. (The original data are listed in Tables 3 and 4.)

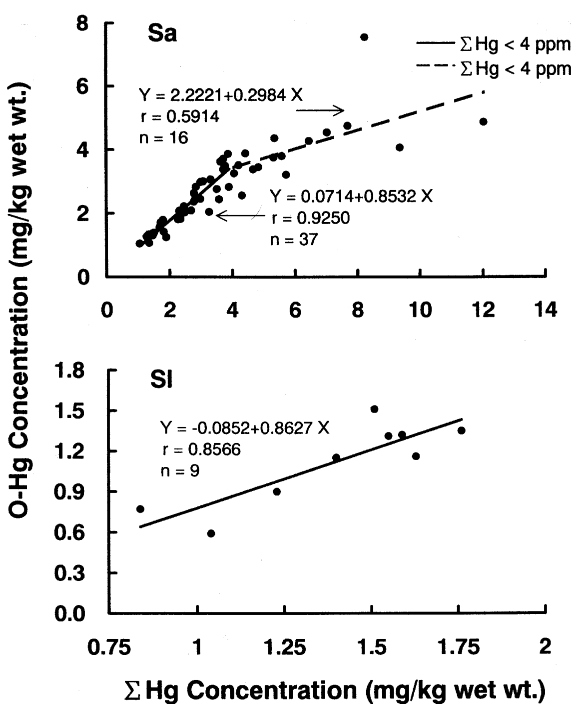

Fig. 4. Linear relationships between ∑Hg and O-Hg concentrations (mg/kg wet wt.) in the muscle tissues of *S. atteunuata* (Sa) and *S. longirostris* (Sl) accidentally caught in Taiwanese waters.

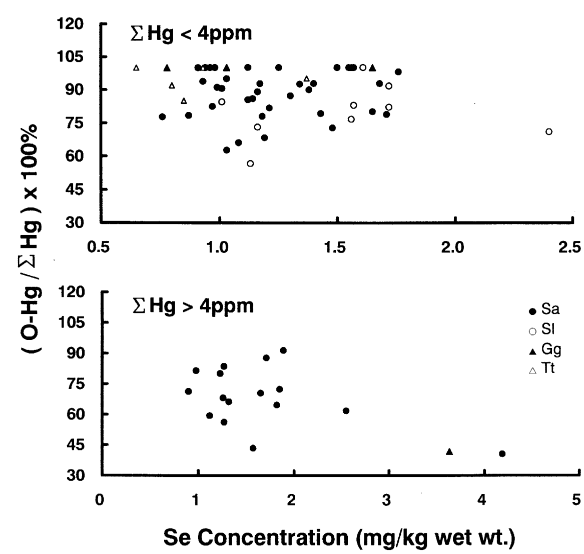

Fig. 6. Relationships between the Se concentrations (mg/kg wet wt.) and O-Hg/∑Hg% in the two groups of dolphins based on whether the ∑Hg concentration was more or less than 4 mg/kg wet wt. in the muscle tissues.

less than 4 mg/kg wet wt., the negative correlation was no longer found in the muscle tissues of the dolphin samples (Fig. 6).

4. Discussion

The factors influencing the species differences with respect to ∑Hg, O-Hg and Se concentrations in the four species of dolphins include age, feeding habits, availability of food, the amount of food-intake and habitat. The *T. truncatus* examined in this study were between 197 and 247 cm in length. They were in the young stage of bottlenose dolphins, which means they witnessed the shortest exposure time. Accordingly, they had the lowest metal bioaccumulations among the four species.

The length of *G. griseus* ranged from 179 to 272 cm. They were also in the young stage of Risso's dolphins. They had different feeding habits from the other three species in that they ate more cephalopod and crustacean than the other species (Mr. M.-C. Wang, personal communication).

The size of *S. longirostris* and *S. attenuata* examined in this study covered the ranges of 148–180 cm (167 $\pm$ 11 cm) and 158–205 cm (178 $\pm$ 11 cm), respectively, and the samples included both young and mature individuals. Although their ages and growth rates were unknown,the larger size of *S. attenuata* may consumed more food than *S. longirostris* thus, they would have taken in more

Table 3
List of the total Hg ($\sum$Hg), organic-Hg (O-Hg) and Se concentrations (mg/kg wet wt.) as well as the percentage of O-Hg (O-Hg%) in the females of four species of dolphins based on the ascending order of ($\sum$Hg)

No.	Species Code	Site	BL (cm)	BW (kg)	Age (year)	$\sum$Hg	O-Hg	O-Hg%	Se
1	Tt	SU	198.5	91.0	–	0.73	0.73	100	0.65
2	Sl	TG	154.0	–	–	0.84	0.77	92	1.72
3	Gg	SU	180.5	74.0	–	0.84	0.84	100	1.65
4	Sl	TG	148.5	37.0	–	1.04	0.59	57	1.13
5	Sa	TG	158.5	–	–	1.05	1.05	100	1.57
6	Tt	SU	247.0	–	–	1.21	1.03	85	0.85
7	Sl	SU	160.0	–	–	1.23	0.90	73	1.16
8	Sa	TG	169.0	48.4	–	1.33	1.33	100	0.94
9	Tt	SU	244.0	–	–	1.38	1.27	92	0.80
10	Sl	TG	173.0	48.2	–	1.40	1.15	82	1.72
11	Sa	SU	192.0	63.0	8	1.46	1.37	94	0.93
12	Sa	TG	159.0	–	–	1.46	1.30	89	1.16
13	Sa	TG	169.5	54.0	–	1.50	1.39	93	1.17
14	Sl	CY	176.5	48.4	–	1.55	1.31	85	1.01
15	Sl	CY	170.5	53.0	–	1.59	1.32	83	1.57
16	Sl	TG	179.5	48.0	–	1.63	1.16	71	2.40
17	Sa	SU	190.0	–	4	1.78	1.78	100	1.56
18	Sa	TG	169.5	54.0	–	1.79	1.79	100	1.25
19	Sa	TG	163.5	51.0	–	1.89	1.25	66	1.08
20	Tt	SU	232.0	149.0	–	2.05	2.05	100	0.93
21	Sa	SU	170.0	47.0	3	2.30	2.07	90	1.38
22	Sa	TG	181.0	50.0	–	2.47	2.02	82	1.21
23	Sa	SU	170.5	–	–	2.68	2.09	78	1.18
24	Sa	SU	171.0	60.0	6	2.76	2.36	86	1.12
25	Sa	SU	182.0	–	3	2.78	2.39	86	1.14
26	Sa	SU	183.0	–	5	2.83	2.83	100	0.94
27	Sa	SU	186.0	–	5	2.97	2.45	82	0.97
28	Sa	TG	175.5	–	–	3.06	3.00	98	1.76
29	Sa	SU	180.5	–	–	3.50	2.76	79	1.71
30	Sa	SU	185.0	–	6	3.57	2.44	68	1.19
31	Sa	SU	242.0	–	–	3.71	3.71	100	0.96
32	Sa	YL	171.0	–	–	3.77	3.49	93	1.34
33	Sa	SU	179.5	–	9	3.86	3.86	100	1.50
34	Sa	SU	171.0	–	5	4.06	3.25	80	1.23
35	Sa	SU	184.0	–	6	4.20	3.51	84	1.27
36	Sa	SU	171.5	56.0	4	4.31	2.56	59	1.12
37	Sa	SU	180.0	65.0	5	4.67	3.38	72	1.85
38	Sa	SU	189.0	–	–	4.84	3.45	71	0.90
39	Sa	TG	170.0	53.8	–	5.35	4.36	82	0.98
40	Sa	SU	184.0	–	6	5.58	3.80	68	1.26
41	Sa	SU	184.5	–	5	6.45	4.27	66	1.32
42	Sa	SU	203.0	–	10	7.02	4.54	65	1.82
43	Sa	SU	190.0	–	11	9.36	4.06	43	1.57
44	Gg	SU	272.0	249.7	–	9.70	4.05	42	3.63
45	Sa	SU	190.0	51.0	15	12.03	4.87	40	4.19

Tt: *T. truncatus*; Sl: *S. longirostris*; Gg: *G. giseus*; and Sa: *S. atteunuata*. SU: *Suao*; TG: *Tungkang*; CY: *Chengkung* and YL: *Yunlin*. '–' means the data is unavailable.

$\sum$Hg and O-Hg. Moreover, the coastal–offshore migratory habit of *S. attenuata* could be another factor that caused this species to have greater exposure to higher doses of anthropogenic contaminants. Of course, the difference in dietary composition could also have been a major factor affecting the mercury bioaccumulation of organisms living in the same ecosystem (Monteiro et al., 1998).

The effect of gender in the bioaccumulation of $\sum$Hg, O-Hg and Se in small cetaceans in this study coincided closely with findings in other studies; however, they contradicted the findings of Andre et al. (1991) who found that the females of *S. attenuata* contained higher Hg concentrations than did the males.

According to some previous studies, stranded dolphins usually contain more elevated Hg concentrations than do by-catch dolphins (Table 2). In this study, we had only two stranded samples, and they revealed no specific elevated metal levels. The small size of the sample here may account for this discrepancy with other research findings.

It is widely accepted that $\sum$Hg and O-Hg concentrations are positively correlated to the size of dolphins (Leonzio et al., 1992; Andre et al., 1991; Honda et al., 1983). The results in this study once again confirm this trend.

Our results indicated that the accumulations of $\sum$Hg in the muscle tissues of the small cetacean reached a turning point at about 4 mg/kg wet wt. Before reaching this point, the amount of O-Hg in the muscle tissue of the dolphin seemed increase at the rate of about 85% accompanying with the increase of $\sum$Hg. It would have then slowed down to only 30% when the $\sum$Hg in the muscle was over 4 mg/kg wet wt. It seems that demethylation was activated at the point, at which the lengths of the dolphins were BL = 185 and 273 cm in *S. attenuata* and *S. longirostris* respectively according to the regression lines established in Fig. 3.

Demethylation in the cetacean included the formation of metallothioneins and insoluble tiemannite. From the original data presented in Tables 3 and 4, the higher Se concentrations were found in samples with elevated $\sum$Hg but low O-Hg%. This clearly shows that the formation of tiemannite was particularly active when the concentrations of $\sum$Hg in the muscle were greater than 4 mg/kg wet wt. It might be reasonable to assume that the protective mechanism of tiemannite has a similar function to the liver of dolphin in the study of Palmisano et al. (1995).

The Hg bioaccumulated in the toothed cetaceans represent the total exposure and the degree environmental degradation (Viale, 1994). In this study, the

Table 4
List of the total Hg ($\sum$Hg), organic-Hg (O-Hg) and Se concentrations (mg/kg wet wt.) as well as the percentage of O-Hg (O-Hg%) in the males of four species of dolphins based on the ascending order of $\sum$Hg

No.	Species code	Site	BL (cm)	BW (kg)	Age (year)	$\sum$Hg	O-Hg	O-Hg%	Se
1	Gg	SU	179.0	87.0	–	0.71	0.71	100	0.78
2	Sa	TG	160.5	47.0	–	1.27	1.27	100	0.91
3	Sa	SU	176.0	–	4	1.35	1.07	79	1.43
4	Gg	CY	233.5	164.4	–	1.44	1.44	100	1.03
5	Sl	SU	173.0	35.0	–	1.51	1.51	100	1.61
6	Sa	TG	167.5	–	–	1.68	1.56	93	1.40
7	Sa	YL	196.0	–	–	1.71	1.71	100	0.98
8	Sl	YL	171.8	–	–	1.76	1.35	77	1.56
9	Sa	YL	172.5	–	–	1.81	1.42	78	0.87
10	Tt	SU	197.0	–	–	1.85	1.76	95	1.37
11	Sa	YL	172.5	–	–	2.26	1.81	80	1.65
12	Sa	SU	174.0	–	2	2.34	1.82	78	0.76
13	Sa	TG	178.0	48.0	–	2.45	2.22	91	1.01
14	Sa	SU	168.0	51.5	4	2.77	2.63	95	1.03
15	Sa	TG	170.0	58.0	–	2.84	2.48	87	1.30
16	Sa	SU	170.0	56.0	4	2.98	2.98	100	1.55
17	Sa	TG	175.5	51.0	–	3.25	2.04	63	1.03
18	Sa	SU	176.0	61.8	3	3.30	3.06	93	1.68
19	Sa	SU	182.5	–	3	3.62	3.62	100	1.12
20	Sa	SU	175.5	–	3	3.71	3.38	91	0.99
21	Sa	SU	190.0	68.0	7	3.89	2.83	73	1.48
22	Sa	SU	171.5	–	–	4.42	3.88	88	1.71
23	Sa	SU	201.0	–	–	5.32	3.75	75	1.65
24	Sa	SU	205.0	–	12	5.72	3.21	56	1.27
25	Sa	SU	197.0	–	–	7.68	4.75	62	2.55
26	Sa	SU	180.0	–	14	8.23	7.53	91	1.89

Tt: *T. truncatus*; Sl: *S. Longirostris*; Gg: *G. giseus*; and Sa: *S. atteunuata*. SU: *Suao*; TG: *Tungkang*; CY: *Chengkung* and YL: *Yunlin*. '–' means the data is unavailable.

mean $\sum$Hg concentration of *S. attenuata* was 1.5 and 3.0 times higher than these in the eastern Pacific and Australian waters (Kemper et al., 1994; Andre et al., 1991), respectively. Meanwhile, the Hg concentration in *T. truncates* found in this study is also two to three folds of the Australian bottlenose dolphin. However, these Hg concentrations in muscles were only one-eighth to one-third of the stranded dolphins off the Mediterranean coasts of Italy and France, and in the Atlantic (Storelli et al., 1998; Augier et al., 1993; Leonzio et al., 1992; Andre et al., 1991) (Table 2). It seems that the Hg levels of the small-toothed cetaceans in Taiwanese waters did not revealed a highly elevated concentrations. Taiwan is mountainous volcanic island, and is well industrialized with dense population. Either natural emissions from actively volcanic activities (Andersen and Depledge, 1997) or anthropogenic pollution could introduce mercury into the aquatic environments. Nevertheless, in the coastal waters of Taiwan, no observation of mercury pollution has ever been reported. So far, we suggest that the metal concentrations determined in this study could represent the present the baseline metal concentrations of marine mammals in the southwestern Pacific Ocean at present.

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