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Trace element concentrations in the tissues of cetaceans from Hong Kong's territorial waters

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Summary

There have been few studies of trace elements in cetaceans from Chinese waters despite considerable potential for contamination by this class of pollutant. Between 1993 and 1996, blubber, liver and/or kidney tissues were collected from 11 Indo-Pacific hump-backed dolphins (*Sousa chinensis*) and 20 finless porpoises (*Neophocaena phocaenoides*) stranded in Hong Kong. These tissues were analysed for 12 trace elements (As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Se, Sn and Zn). In general, concentrations of trace elements were similar to those of other cetacean populations and were deemed not to be of any toxicological significance. However, concentrations of mercury in the liver tissues of certain individuals were at levels which could constitute a health risk to the animals (up to 906 $\mu g\, g^{-1}$ dry weight). Cadmium, mercury and selenium were observed to bio-accumulate with age, whereas concentrations of copper were highest in neonatal nimals.

Keywords: trace elements, trace metals, pollution, Indo-Pacific hump-backed dolphin, *Sousa chinensis*, finless porpoise, *Neophocaena phocaenoides*, Hong Kong

Introduction

Hong Kong's territorial waters are seriously polluted; approximately 2000 million litres of sewage are pumped into these waters daily (Chan & Yung 1995). This, coupled with the millions of tonnes of sewage and industrial pollutants carried down the Pearl River from the Shenzhen Special Economic Zone and from other areas of southern China, means that the marine environment is subjected to substantial contamination. Most pollution-based studies in Hong Kong have concentrated upon analysing trace metal levels (Rainbow 1993), which may be partly due to the fact that the Environmental Protection Department of the Hong Kong Government uses such data as an indicator of adverse anthropogenic influences. There are high levels of trace element contamination in Hong Kong's waters, particularly in Victoria Harbour (Phillips 1979, 1985; Phillips *et al.* 1982*a, b*; Chan 1988, 1995; Phillips & Rainbow 1988; Chan *et al.* 1990), with an estimated daily input of two tonnes of trace metals (Lam 1994).

Two species of cetacean are present year-round in Hong Kong's territorial waters: the Indo-Pacific hump-backed dolphin, *Sousa chinensis,* and the finless porpoise, *Neophocaena phocaenoides* (Parsons *et al.* 1995). *Sousa chinensis* is consistently recorded from the waters to the north of Lantau Island, notably from shallow areas around the islands of Sha Chau, Lung Kwu Chau and Chek Lap Kok (Parsons *et al.* 1995; Jefferson 1996). This local pattern of distribution coincides with three potential sources of trace element pollution, namely contaminated-mud pits to the east of Sha Chau, the new airport platform and associated works at Chek Lap Kok, and over 12 000 sewage outfalls (EPD 1996). By the year 2000, the three main sewage outfalls in this area will be discharging wastewater at a rate of 384 000 $t\, d^{-1}$ (Hoffmann 1995; Fig. 1).

N. phocaenoides is reported from the waters to the south of Lantau and Hong Kong islands and in the eastern waters of the New Territories, a habitat which is relatively less polluted in comparison to the area inhabited by *S. chinensis*. It has been suggested that high levels of pollution could compromise these two populations of cetacean (Parsons & Porter 1995). The current study was initiated in order to begin an assessment of whether or not trace element pollution did indeed pose a threat to the conservation of Hong Kong's cetaceans. The aims of this present study were to investigate whether cetaceans in Hong Kong exhibited substantial levels of trace element contamination, to determine differences in contaminant burdens between the species and also to investigate whether trace elements bio-accumulate in these two species.

Materials and methods

Samples of liver, kidney and blubber tissue were collected from stranded cetacean carcasses (Table 1; Fig.1) using standard protocols (Geraci & Lounsbury 1993). Tissue samples were initially excised with a stainless steel scalpel with exposed surfaces later being removed by a sharpened, acid-washed, plastic knife. The samples were placed in Tekmar whirlpacks and frozen at −20 °C until sample prep-

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Table 1 Dates of stranding and stranding locations of cetaceans sampled for trace element analysis. Body length details: 'c' denotes a measurement converted from a curvilinear length. Animal annotated N.T. did not have a body length measurement taken, as the carcass was too badly decomposed (decomposition category 4; Geraci & Lounsbury 1993) and was no longer intact.

Date stranded	*Stranding location*	*Sex*	*Age (yr)*	*Body length(cm)*
Sousa chinensis				
25–05–93	Tai Kwai Wan, Cheung Chau	–	1	140[c]
27-01-94	Tung Chung, Lantau Island	Male	*c.* 1	144
28–04–94	Castle Peak, Tuen Mun, New Territories	Male	-	> 250
19–10–94	Tai A Chau, Soko Islands	Male	-	N.T.
23–12–94	Yam O, Lantau Island	Male	-	211[c]
11–02–95	Tai O, Lantau Island	Male	11	247
02–04–95	Chek Lap Kok	Male	14	234
28–05–95	Shui Hau, Tong Fuk, Lantau Island	Male	6	205
15–06–95	Soko Islands	Male	<1	101.5
02–09–95	Tong Wan Beach, Cheung Chau	Male	2.5	189
14–09–95	Butterfly Beach, Tuen Mun, New Territories	Female	17+	255
Neophocaena phocaenoides				
06–05–93	Mui Wo, Lantau Island	Female	5	133[c]
22–12–93	Shek Kwu Chau	Female	<1	71
30–07–94	Tai A Chau, Soko Islands	Female	–	155
04–11–94	Clearwater Bay, Sai Kung, New Territories	–	4.5	137
16–12–94	Clearwater Bay, Sai Kung, New Territories	Female	<1	82
15–03–95	Tai A Chau, Soko Islands	Male	<1	104.5
02–11–95	Clear Water Bay, Sai Kung, New Territories	Female	<1	83
29–11–95	Chek Lap Kok	Male	6	155
15–12–95	Sai Kung, New Territories	Male	<1	76
25–12–95	Port Shelter, Sai Kung, New Territories	Female	2	143
08–01–96	Clearwater Bay, Sai Kung, New Territories	Male	3–5	138
11–01–96	Cheung Chau	Male	10	168
13–01–96	Shek O, Hong Kong Island	Female	13	150
14–01–96	Shek O, Hong Kong Island	Male	<1	86
15–01–96	Aberdeen Harbour, Hong Kong Island	Female	<1	87
23–01–96	Tai A Chau, Soko Islands	Male	<1	67
08–03–96	Tung Ah Pui, Tai Tam, Hong Kong Island	Female	4–5	137
09–03–96	Tung Wan, Cheung Chau	Female	<1	94
12–03–96	Shek O, Hong Kong Island	Male	2–4	128
25–04–96	Cheung Sha, Lantau Island	Male	<1	84

aration could be carried out. The tissues were macerated and homogenized with a small amount of double-distilled water in a Seward 80 stomacher. The homogenates were then re-frozen for 24 hours before being freeze-dried in a Hetosicc FD3 freeze-drier. Dried samples were weighed and digested in 5 ml of 69% HNO_3 for 24 hours at room temperature, and for a second 24 hours at 100 °C. Three blanks, standard reference materials (bovine liver, Standard Reference Material 1577b; US National Institute of Standards and Technology) and duplicate samples were prepared for every batch of 30 samples analysed. Digests were filtered through Whatman 44 ashless filter paper and made up to 50 ml with double deionized distilled water.

Trace element concentrations in the digests were determined with a Perkin-Elmer 400 Induction-Coupled Plasma Atomic Emission Spectrometer (ICPAES) which was fitted with a Perkin-Elmer AS-90 automated sampler. Concentrations were calibrated with Perkin-Elmer PE pure standard solutions and cross-calibrated by comparison values obtained using a Graphite Furnace Atomic Emission Spectrophotometer upon standard materials and samples. The mean percentage compliances of the determined trace element concentrations with certified values for the standard reference materials (which allows the efficiency of the extraction technique to be determined), are summarized in Table 2. For statistical comparison of the results, Pearson's rank correlation and Welch's t-test were utilized upon normalized (log transformed) data.

Results

Overall, trace element concentrations were shown to be the greatest in the liver, with a slightly lower level in kidney tissue, and the lowest concentration in the blubber layer (Tables 3–4). Concentrations were significantly higher in the liver than the kidney for a variety of elements, notably arsenic, copper and molybdenum (Table 5). Detectable concentrations of mercury were only recorded in liver tissue and one kidney sample. Concentrations of copper, molybdenum, selenium and zinc were significantly higher in liver tissue than in

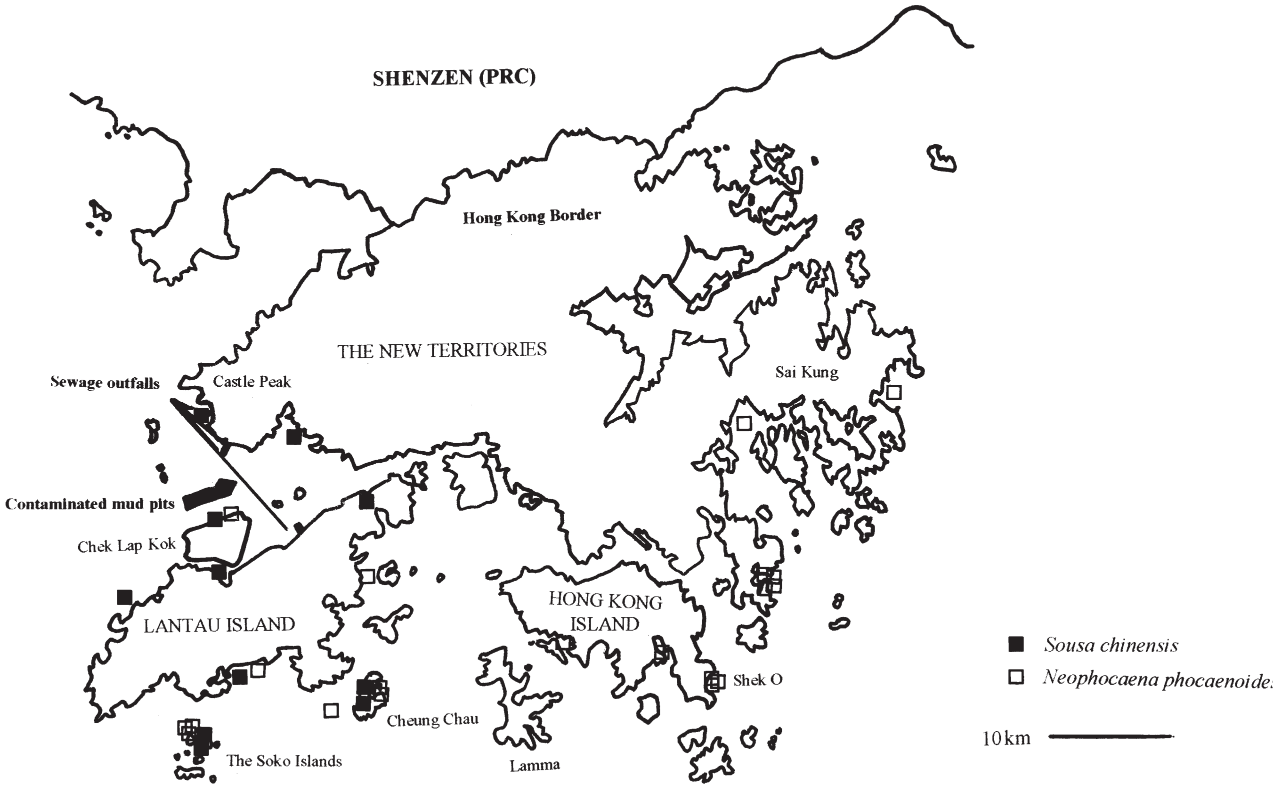

Figure 1 Map of Hong Kong showing the approximate stranding locations of the cetaceans which were sampled in the present study and local sources of trace element pollution.

Table 2 Efficiency of the element extraction technique when used upon Standard Reference Materials (bovine liver 1577b). The table lists the percentage of the SRM certified value obtained when the SRM digests were analysed.

	As	*Cd*	*Co*	*Cu*	*Pb*	*Mo*	*Se*	*Zn*
Mean percentage compliance with certified value	83	100	100	94	94	84	95	93

blubber tissue (Table 5). Moreover, concentrations of copper, selenium, tin and zinc were higher in the kidney than in blubber (Table 5).

Mean concentrations of cadmium in the kidney (*S. chinensis*: 12.08 $\mu g\,g^{-1}$ dry weight; *N. phocaenoides*: 3.40 $\mu g\,g^{-1}$ dry weight) were greater than those of the liver (*S. chinensis*: 2.18 $\mu g\,g^{-1}$ dry weight; *N. phocaenoides*: 0.62 $\mu g\,g^{-1}$ dry weight) and values were below detection limits in the blubber of both species.

When comparing the two species, a significant difference in concentrations ⩽was only observed for molybdenum; concentrations of this element in liver tissues were higher in hump-backed dolphins than in finless porpoises ($t = 2.33$; $p < 0.05$).

The concentrations of several trace elements were shown to exhibit a positive correlation with the length of the animal. In this study, significant positive correlations between the total body length of *N. phocaenoides* and the level of cadmium were discerned in both liver ($r = 0.705$; $p < 0.01$) and kidney tissues ($r = 0.871$; $p < 0.01$); and also for mercury ($r = 6.15$; $p < 0.05$) and tin ($r = 0.532$; $p < 0.05$) in liver tissue. Levels of copper in liver from *N. phocaenoides* were shown to be negatively correlated with length, with highest concentrations being identified in neonates ($r = -0.609$; $p < 0.05$). This was also the case for copper ($r = -0.984$; $p < 0.001$) and arsenic ($r = -0.927$; $p < 0.05$) in blubber from *S. chinensis*.

There was a significant correlation between the concentration of mercury and selenium in liver tissue of both species (*S. chinensis*: $r = 0.859$; $p < 0.01$ and *N. phocaenoides*: $r = 0.690$; $p < 0.05$), which is probably due to the role of selenium in the detoxification of mercury, as discussed later. Selenium in the liver was also correlated with cadmium concentration (both species: $r = 0.6744$; $p < 0.05$), which may reflect the fact that both of these elements accumulate with age (Thompson 1990; Law 1996), as opposed to a detoxification mechanism such as that found in the case of mercury (Joiris *et al.* 1991). A direct relationship between levels of trace element concentration and age was noted for lead and zinc in finless porpoise tissues (liver: $r = 0.559$; $p < 0.05$ and blubber: $r = 0.524$; $p < 0.05$, respectively).

Discussion

Arsenic

In comparison to other trace elements, little research has been carried out on arsenic contamination of cetacean tissues.

Table 3 Trace element concentrations recorded from the tissues of Indo-Pacific hump-backed dolphins (*Sousa chinensis*) stranded in Hong Kong (μg g^{-1} dry weight).

Date	*Tissue*	*As*	*Cd*	*Co*	*Cr*	*Cu*	*Hg*	*Mo*	*Ni*	*Pb*	*Se*	*Sn*	*Zn*
25–05–93	Liver	<0.9	<0.9	<0.9	<0.9	7.81	<0.9	<0.9	<0.9	1.74	13.02	<0.9	62.5
	Kidney	5.07	2.53	<0.8	<0.8	11.83	<0.8	<0.8	0.84	4.22	7.60	1.69	73.5
	Blubber	<0.9	<0.9	<0.9	<0.9	1.16	<0.9	<0.9	1.16	4.65	<0.9	<0.9	9.30
27–01–94	Liver	<0.89	<0.89	<0.89	<0.89	15.13	<0.89	0.89	0.89	<0.89	1.78	<0.89	99.7
	Kidney	<0.9	0.91	<0.9	<0.9	23.61	<0.9	<0.9	0.91	<0.9	5.45	<0.9	102
	Blubber	18.32	<1.0	<1.0	<1.0	1.02	<1.0	<1.0	1.02	<1.0	<1.0	<1.0	2.04
28–04–94	Liver	0.83	23.17	<0.8	<0.8	30.62	906	0.83	0.83	6.62	131	<0.8	58.8
	Kidney	6.77	84.1	<0.9	<0.9	11.60	35.77	<0.9	<0.9	0.97	21.27	<0.9	75.4
	Blubber	<0.85	<0.85	0.87	<0.85	0.87	<0.85	0.87	<0.85	3.47	15.64	3.47	18.24
19–10–94	Blubber	1.34	<0.9	<0.9	2.68	2.68	<0.9	<0.9	<0.9	12.05	4.69	1.34	14.73
23–12–94	Liver	<0.36	<0.36	<0.36	<0.36	11.58	<0.36	0.72	0.36	<0.36	4.70	8.32	121
	Blubber	<0.35	<0.35	<0.35	<0.35	0.35	<0.35	<0.35	<0.35	3.51	3.16	0.70	9.82
11–02–95	Liver	<0.9	<0.9	<0.9	<0.9	5.98	<0.9	1.00	<0.9	6.98	1.99	1.99	70.8
	Kidney	10.54	0.70	<0.7	<0.7	7.03	<0.7	<0.7	<0.7	1.41	6.32	2.81	53.4
	Blubber	<0.9	<0.9	1.11	2.22	<0.9	<0.9	1.11	<0.9	3.33	1.11	1.11	5.55
02–04–95	Liver	9.39	<0.78	<0.78	<0.78	14.09	<0.78	0.78	<0.78	3.13	<0.78	7.04	78.3
	Kidney	12.12	1.51	<0.76	<0.76	9.85	<0.76	0.76	0.76	7.57	11.36	0.76	59.8
	Blubber	2.80	<0.3	0.40	1.60	0.40	<0.3	0.40	<0.3	3.20	2.00	<0.3	2.00
28–05–95	Liver	<0.9	<0.9	<0.9	<0.9	0.93	<0.9	0.93	<0.9	4.64	<0.9	1.85	24.13
	Kidney	7.81	<0.87	<0.87	<0.87	9.55	<0.87	<0.87	0.87	<0.87	16.50	8.68	234
15–06–95	Liver	<0.65	<0.65	<0.65	0.65	5.86	<0.65	<0.65	<0.65	7.82	6.51	<0.65	74.9
02–09–95	Liver	2.15	<0.7	<0.7	<0.7	23.61	<0.7	0.72	<0.7	8.59	5.72	<0.7	243
	Kidney	5.47	1.82	<0.9	<0.9	14.59	<0.9	<0.9	<0.9	<0.9	11.85	2.73	121
14–09–95	Liver	12.94	0.81	<0.8	<0.8	13.37	552	1.62	0.81	<0.8	66.3	8.90	79.3
	Kidney	<0.9	5.05	<0.9	<0.9	10.10	<0.9	<0.9	<0.9	13.13	<0.9	<0.9	64.6
	Blubber	<0.46	<0.46	<0.46	<0.46	0.46	<0.46	<0.46	0.92	<0.46	<0.46	<0.46	11.98
Range													
Liver	min	<0.36	<0.36	<0.36	<0.36	<0.93	<0.36	<0.65	<0.65	<0.36	<0.78	<0.65	24.13
n = 10	max	12.94	23.17	<0.9	0.65	30.62	906	1.62	0.89	8.59	131	8.90	243
Kidney	min	<0.9	<0.7	<0.7	<0.7	7.03	<0.7	<0.7	<0.7-	<0.87	<0.9	<0.9	53.4
n = 8	max	12.12	84.1	<0.9	<0.9	23.61	35.77	0.76	0.91	13.13	21.27	8.68	234
Blubber	min	<0.35	<0.3	<0.35	<0.35	<0.35	<0.3	<0.35	<0.3-	<0.46	<0.46	<0.3	2.00
n = 8	max	18.32	<1.0	1.11	2.68	2.68	<1.0	1.11	1.16	12.05	15.64	3.47	18.24

Concentrations of arsenic recorded from cetaceans are generally low, usually <1μg g^{-1} wet weight. Pilot whales have been recorded with levels of up to 2.9 μg g^{-1} wet weight (Muir *et al.* 1988). By comparison, much higher concentrations were reported here in at least some samples; up to 18.3 μg g^{-1} dry weight in *S. chinensis* and up to 40.3 μg g^{-1} dry weight in *N. phocaenoides*.

Marine fish have been shown to have high levels of arsenic within their tissues, sometimes reaching concentrations of >100 μg g^{-1} wet weight (Bohn 1975). Typically, arsenic levels in Hong Kong fish are high (up to 417.3 μg g^{-1} dry weight) and large quantities of ingested arsenic may explain the elevated concentrations seen in Hong Kong's cetaceans (Parsons 1998*a* in press). Much of this arsenic would, however, be likely to be present as organic forms, which are relatively non-toxic (Coulson *et al.* 1935; Phillips 1990).

Cadmium

As in previous studies (Thompson 1990; Law 1996), higher concentrations of cadmium were recorded from cetacean kidneys than from the liver, with even lower concentrations determined in blubber tissue. The high concentrations found in the kidneys of Hong Kong's cetaceans are likely to be associated with metallothioneins (Underwood 1977; Leland & Kuwabara 1985; Laurwerys 1990).

Moreover, cadmium is known to accumulate with age in dolphins (Honda *et al.* 1983), a pattern which was also apparent in this study. Hansen *et al.* (1990) showed that cadmium

Table 4 Trace element concentrations recorded from the tissues of finless porpoises (*Neophocaena phocaenoides*) stranded in Hong Kong ($\mu g\,g^{-1}$ dry weight).

Date	*Tissue*	*As*	*Cd*	*Co*	*Cr*	*Cu*	*Hg*	*Mo*	*Ni*	*Pb*	*Se*	*Sn*	*Zn*
06–05–93	Liver	40.25	<0.9	<0.9	<0.9	5.03	<0.9	<0.9	<0.9	7.04	6.04	6.04	66.4
22–12–93	Liver	<0.9	<0.9	<0.9	<0.9	138	<0.9	<0.9	<0.9	<0.9	11.8	<0.9	97.8
	Kidney	<0.69	<0.69	<0.69	<0.69	11.0	<0.69	0.69	<0.69	8.96	<0.69	<0.69	48.9
	Blubber	<0.62	<0.62	<0.62	<0.62	0.62	<0.62	<0.62	1.24	<0.62	<0.62	0.62	17.39
30–07–94	Blubber	<0.66	<0.66	<0.66	0.66	0.66	<0.66	<0.66	<0.66	0.66	<0.66	<0.66	26.9
04–11–94	Blubber	1.54	<0.77	<0.77	0.77	0.77	<0.77	<0.77	<0.77	3.86	6.95	<0.77	12.35
16–12–94	Liver	11.41	<0.88	<0.88	<0.88	29.9	<0.88	0.88	<0.88	<0.88	1.76	2.63	81.7
	Kidney	<0.9	<0.9	<0.9	<0.9	12.95	<0.9	<0.9	1.00	2.99	8.97	<0.9	83.7
15–03–95	Liver	5.00	<0.9	<0.9	1.00	38.0	<0.9	1.00	2.00	7.00	<0.9	1.00	116
	Kidney	<0.9	<0.9	<0.9	<0.9	7.89	<0.9	<0.9	<0.9	5.26	5.26	<0.9	50.9
	Blubber	5.00	<0.5	<0.5	<0.5	0.56	<0.5	<0.5	<0.5	7.78	2.78	<0.5	7.78
02–11–95	Liver	1.12	<0.37	<0.37	<0.37	37.1	<0.37	0.37	<0.37	2.62	2.25	<0.37	151
	Kidney	<0.77	<0.77	<0.77	<0.77	19.98	<0.77	<0.77	0.77	<0.77	8.45	2.31	61.5
	Blubber	<0.79	<0.79	<0.79	<0.79	<0.79	<0.79	0.79	<0.79	8.74	11.12	<0.79	7.15
29–11–95	Blubber	4.18	<0.84	<0.84	<0.84	<0.84	<0.84	<0.84	0.84	0.84	5.02	<0.84	6.69
15–12–95	Kidney	3.71	<0.9	1.86	0.93	13.93	<0.9	0.93	0.93	7.43	13.93	4.64	43.6
25–12–95	Liver	15.87	<0.59	<0.59	<0.59	11.17	<0.59	0.59	0.59	1.18	12.34	1.18	40.5
	Kidney	7.92	1.76	<0.88	<0.88	8.80	<0.88	0.88	<0.88	4.40	14.96	1.76	55.4
08–01–96	Blubber	<0.71	<0.71	<0.71	<0.71	0.71	<0.71	<0.71	0.71	<0.71	<0.71	<0.71	10.60
11–01–96	Liver	<0.9	1.86	<0.9	<0.9	12.42	123	<0.9	<0.9	<0.9	21.11	1.24	47.8
	Kidney	<0.9	9.25	<0.9	<0.9	4.62	<0.9	<0.9	<0.9	<0.9	5.20	<0.9	34.1
	Blubber	2.82	<0.9	<0.9	<0.9	<0.9	<0.9	<0.9	<0.9	<0.9	4.23	<0.9	2.82
13–01–96	Liver	<0.9	2.86	<0.9	0.95	42.9	385	1.90	<0.9	13.33	76.2	0.95	142
	Kidney	4.02	18.10	<0.9	1.01	36.2	<0.9	2.01	6.03	5.03	33.2	7.04	12.07
	Blubber	<0.9	<0.9	<0.9	<0.9	1.87	<0.9	<0.9	0.93	1.87	<0.9	<0.9	48.6
14–01–96	Liver	<0.67	<0.67	<0.67	<0.67	58.8	<0.67	<0.67	0.67	<0.67	3.34	<0.67	273
	Kidney	<0.9	<0.9	<0.9	<0.9	5.56	<0.9	<0.9	<0.9	1.39	<0.9	<0.9	41.7
	Blubber	<0.9	<0.9	<0.9	<0.9	0.90	<0.9	<0.9	<0.9	9.92	2.71	<0.9	5.41
15–01–96	Liver	3.67	<0.9	<0.9	<0.9	26.53	<0.9	<0.9	<0.9	<0.9	2.86	<0.9	359
	Kidney	0.63	<0.63	<0.63	0.63	74.8	<0.63	1.90	2.53	5.70	8.24	4.43	113
	Blubber	10.80	<0.9	<0.9	<0.9	<0.9	<0.9	0.98	0.98	<0.9	<0.9	<0.9	5.89
23–01–96	Liver	<0.9	<0.9	<0.9	<0.9	199	<0.9	<0.9	<0.9	<0.9	<0.9	<0.9	131
	Kidney	7.11	<0.71	<0.71	<0.71	9.25	<0.71	<0.71	0.71	<0.71	<0.71	<0.71	54.1
	Blubber	<0.6	<0.6	0.62	<0.6	0.62	<0.6	<0.6	<0.6	6.81	<0.6	0.62	10.5
08–03–96	Liver	<0.9	2.64	<0.9	<0.9	88.8	<0.9	<0.9	<0.9	<0.9	15.8	<0.9	476
	Kidney	1.57	19.6	<0.78	<0.78	15.66	<0.78	0.78	<0.78	3.13	<0.78	<0.78	91.6
	Blubber	<0.9	<0.9	<0.9	<0.9	<0.9	<0.9	<0.9	<0.9	5.82	<0.9	<0.9	8.31
09–03–96	Liver	<0.9	<0.9	<0.9	<0.9	84.8	<0.9	<0.9	<0.9	<0.9	1.34	<0.9	155
	Kidney	20.13	<0.8	<0.8	<0.8	9.63	<0.8	<0.8	0.88	<0.8	2.63	0.88	53.4
	Blubber	<0.9	<0.9	<0.9	7.01	1.00	<0.9	1.00	<0.9	8.01	<0.9	<0.9	6.01
12–03–96	Liver	<0.9	1.98	<0.9	<0.9	24.73	<0.9	0.99	1.98	4.95	0.99	1.98	88
	Kidney	3.99	2.28	<0.57	<0.57	4.56	<0.57	<0.57	0.57	0.57	2.28	2.28	34.8
	Blubber	28.7	<0.9	<0.9	<0.9	0.95	<0.9	<0.9	<0.9	4.77	<0.9	<0.9	28.64
25–04–96	Liver	12.92	<0.7	<0.7	<0.7	30.9	<0.7	<0.7	<0.7	0.72	6.46	<0.7	165
	Kidney	<0.7	<0.7	<0.7	0.78	7.80	<0.7	<0.7	0.78	4.68	15.59	1.56	55.4
	Blubber	<0.9	<0.9	<0.9	<0.9	1.09	<0.9	<0.9	1.09	<0.9	11.94	4.34	1.09
Range													
Liver	min	<0.67	<0.37	<0.37	<0.37	5.03	<0.37	0.37	<0.37	<0.67	<0.9	<0.37	40.5
n=15	max	40.25	2.86	<0.09	1.00	199	385	1.90	2.00	13.33	76.2	6.04	476
Kidney	min	<0.66	<0.63	<0.57	<0.57	4.56	<0.57	<0.57	<0.69	<0.77	<0.69	<0.69	12.07
n=15	max	20.13	19.6	1.86	1.01	74.8	<0.9	2.01	6.03	8.96	33.2	7.04	113
Blubber	min	<0.6	<0.5	<0.5	<0.5	0.79	<0.5	<0.5	<0.5	<0.62	<0.6	<0.05	1.09
n=16	max	28.7	<0.9	0.62	7.01	1.87	<0.9	1.00	1.24	9.92	11.94	4.34	48.6

Table 5 The results of statistical comparisons between trace metals concentrations determined in liver, kidney and blubber tissues.

Metal	*Differences in trace element concentrations*	*Species*	*t value*	
As	liver > kidney	*S. chinensis*	2.13	$p < 0.05$
Cu	liver > kidney	*N. phocaenoides*	3.63	$p < 0.01$
	liver > blubber	*S. chinensis*	7.02	$p < 0.001$
		N. phocaenoides	12.59	$p < 0.001$
	kidney > blubber	*S. chinensis*	10.99	$p < 0.001$
		N. phocaenoides	10.59	$p < 0.001$
Mo	liver > kidney	*S. chinensis*	4.18	$p < 0.001$
	liver > blubber	*S. chinensis*	2.33	$p < 0.05$
Se	liver > blubber	*N. phocaenoides*	2.24	$p < 0.05$
	kidney > blubber	*S. chinensis*	2.35	$p < 0.05$
		N. phocaenoides	2.06	$p < 0.05$
Sn	kidney > blubber	*N. phocaenoides*	2.38	$p < 0.05$
Zn	liver > blubber	*S. chinensis*	7.47	$p < 0.001$
		N. phocaenoides	9.54	$p < 0.001$
	kidney > blubber	*S. chinensis*	7.74	$p < 0.001$
		N. phocaenoides	6.81	$p < 0.001$

levels were correlated with selenium concentrations in the livers of minke whales, beluga whales and narwhals from Greenland. This is also the case in the Hong Kong species studied here, although, as discussed previously, this correlation may be the result of accumulation with age rather than a reflection of any detoxification system.

Cetaceans from other regions of the world have been found with high burdens of cadmium despite dwelling in areas far removed from sources of contamination. For example, Wagemann *et al.* (1983) found narwhals with tissue concentrations of cadmium of up to 205 $\mu g\,g^{-1}$ wet weight. This accumulation of cadmium is often the result of ingesting high levels of the element in food. Hong Kong's hump-backed dolphins live in close proximity to contaminated-mud pits which contain extremely high levels of cadmium (CES & Binnies 1994). Uptake of cadmium through eating contaminated fish from the area may be substantial (Parsons 1998*a*).

Although the concentrations of cadmium found in this study are higher than levels reported in dolphins reported from Great Britain, they are much lower than levels reported in similar species from other Asian countries (Table 6). For example, Lee and Mok (1995) reported mean cadmium concentrations in the liver tissues of Taiwanese *Tursiops* sp., *Stenella longirostris* and *Stenella attenuata* of 16.43 $\mu g\,g^{-1}$ dry weight, which is almost eight times higher than the mean concentrations recorded in the livers of Hong Kong's hump-backed dolphins.

It should be noted that background levels of cadmium in the marine environment, as well as other trace elements, can vary from region to region as the result of differences in local geology, and high contaminant loads may, therefore, not be entirely due to increased levels of pollution. In Hong Kong, however, there is an undeniably high degree of cadmium pollution.

Cadmium has widespread toxic effects on the mammalian body. High cadmium levels can lead to depressed growth, kidney damage, cardiac enlargement, hypertension, foetal deformity and cancer (Mertz 1987; Merian 1991). In humans, cadmium concentrations above 200–400 $\mu g\,g^{-1}$ in kidney tissue can lead to renal damage (Piotrowski & Coleman 1980). Fujise *et al.* (1988) noted that renal dysfunction can occur in cetaceans when hepatic concentrations exceed 20 $\mu g\,g^{-1}$ wet weight. The cadmium concentrations in the tissues of Hong Kong's resident cetaceans were well below these critical levels, with maximum kidney and liver concentrations being 21.03 $\mu g\,g^{-1}$ and 7.7 $\mu g\,g^{-1}$ wet weight, respectively (84.1 $\mu g\,g^{-1}$ and 23.2 $\mu g\,g^{-1}$ dry weight).

Copper

Copper is an essential element and concentrations of copper are regulated in the mammalian body. In adult cetaceans, copper concentrations are typically 3–30 $\mu g\,g^{-1}$ (Law *et al.* 1991). Wagemann *et al.* (1983) and Honda *et al.* (1983) showed that copper concentrations in cetaceans are negatively correlated with body length, as was the case with the finless porpoises sampled in this study. No mention has been made previously of a similar negative correlation for copper concentrations in blubber, as was apparent with Hong Kong's hump-backed dolphins.

In general, copper concentrations recorded from Hong Kong's resident cetaceans were comparable to the levels found in small cetacean species from other regions of the world (Table 6).

Lead

The toxic effects of lead upon the mammalian physiology include anaemia, renal damage, hypertension, cardiac disease, immuno-suppression (through antibody inhibition) and neurological damage (Mertz 1987). Lead levels in cetaceans are usually low (<1 $\mu g\,g^{-1}$) and concentrations recorded in small cetaceans from Taiwan (1.32 $\mu g\,g^{-1}$ dry weight; Lee & Mok 1995) were lower than those seen in Hong Kong. The latter varied up to 13.13 $\mu g\,g^{-1}$ dry weight in *S. chinensis* and to 13.33 $\mu g\,g^{-1}$ dry weight in *N. phocaenoides* (Tables 3 & 4). Law *et al.* (1992) attributed similarly elevated concentrations of the element (up to 4.3 $\mu g\,g^{-1}$ wet weight, or approximately 14 $\mu g\,g^{-1}$ dry weight) in small cetaceans from parts of the UK to alkyl lead contamination, a compound which is added to gasoline as an 'anti-knocking' agent. Parsons (in press) describes high concentrations of lead in potential dolphin prey species (up to 511 $\mu g\,g^{-1}$ dry weight) caught from areas of high dolphin abundance. Elevated concentrations of lead in cetacean tissues may, thus, have been absorbed via their diet.

The correlation between lead concentration and age, noted here for finless porpoises, has also been reported for striped dolphins (Honda *et al.* 1983). In that study, there was a rapid increase in lead concentrations in calves during the first year, which the authors attributed to lead transfer from

Table 6 A comparison between trace element concentrations recorded from the tissues of Hong Kong's resident cetaceans and cetaceans from other areas of the world. NA = a specific element was not analysed in the particular study; n.d. = concentrations that were not detectable. All concentrations are expressed as wet weight values μg g^{-1}. The concentrations from this current study and those asterisked have been converted to wet weight values for comparative purposes.

Species	*Region*	*Tissue*	*As*	*Cd*	*Co*	*Cr*	*Cu*	*Hg*	*Mo*	*Ni*	*Pb*	*Se*	*Zn*	*Reference*
Tursiops truncatus	USA	Liver	NA	n.d.	NA	NA	0.08–28	n.d.–110	NA	NA	n.d.–3.2	NA	16–210	Geraci 1989
Tursiops truncatus	USA	Liver*	NA	n.d.–0.5	NA	NA	2.0–70	NA	NA	NA	NA	NA	24–216	Wood & van Vleet 1996
		Kidney*	NA	n.d.–1.6	NA	NA	1.8–8.4	NA	NA	NA	NA	NA	22–44	
Phocoena sinus	Gulf of California	Liver	NA	0.06	< 0.09	< 0.33	16.7	NA	NA	< 0.12	0.5	NA	30.6	Villa-R. *et al.* 1993
		Kidney	NA	2.9	< 0.08	< 0.3	2.9	NA	NA	0.12	< 0.5	NA	17.8	
Phocoena phocoena	UK	Liver	NA	< 0.06–1.2	NA	< 0.04–2.0	6.5–160	0.6–190	NA	< 0.6	< 0.6–4.3	NA	25–87	Law *et al.* 1991, 1992
Delphinus delphis	UK	Liver	0.51–2.6	< 0.02–1.2	NA	< 0.5–1.6	4.2	11	NA	< 0.7	1.0	NA	26	Law *et al.* 1991, 1992
Stenella coeruleoalba	Mediterranean	Liver*	NA	NA	NA	NA	NA	20.4–568	NA	NA	NA	NA	NA	Augier *et al.* 1993
		Kidney*	NA	NA	NA	NA	NA	3.29–99	NA	NA	NA	NA	NA	
Physter macrocephalus	Netherlands	Liver	0.71	30	NA	0.79	2.3	34	NA	0.39	0.11	11	34	Law *et al.* 1996
Phocoena phocoena	Norway	Liver	NA	NA	NA	NA	NA	0.84–5.42	NA	NA	NA	1.58–4.81	NA	Teigen *et al.* 1993
		Kidney	NA	NA	NA	NA	NA	0.48–1.06	NA	NA	NA	2.84–4.83	NA	
Phocoena phocoena	Poland	Liver*	NA	0.08–0.11	NA	< 0.03	5.31–18.0	NA	NA	< 0.03	0.08–0.31	NA	28.8–43.2	Szefer *et al.* 1994
		Kidney*	NA	0.05–0.69	NA	< 0.03	2.9–4.68	NA	NA	< 0.03	< 0.03–1.87	NA	26.8–33.2	
Platanista gangetica	India	Liver*	NA	< 0.02–0.05	NA	NA	2.82–120	NA	NA	0.14–1.02	0.21–0.51	NA	19.2–63	Kannan *et al.* 1993
		Kidney*	NA	< 0.01–1.6	NA	NA	3.25–16.5	NA	NA	0.16–0.75	0.2–0.55	NA	16.5–35	
Stenella coeruleoalba	Japan	Liver	NA	< 0.1–11.1	NA	NA	3.6–15.2	1.7–485	NA	0.05–0.49	0.03–0.64	NA	26.5–109	Honda *et al.* 1983
		Kidney	NA	< 0.1–69.6	NA	NA	1.5–6.1	0.09–17.6	NA	NA	0.01–0.71	NA	22.8–41.2	
Delphinus delphis	Australia	Liver	NA	0–11	NA	NA	NA	33–72.1	NA	NA	0–3.00	NA	NA	Kemper *et al.* 1994
		Kidney	NA	0–32.6	NA	NA	NA	NA	NA	NA	0–0.47	NA	NA	
Tursiops truncatus	Australia	Liver	NA	0–10	NA	NA	NA	0.14–10.18	NA	NA	0.05–1.00	NA	NA	Kemper *et al.* 1994
		Kidney	NA	0–25.5	NA	NA	NA	NA	NA	NA	1.00	NA	NA	
Neophocaena phocaenoides	East China Sea	Liver	NA	0–6.22	0.02–0.06	NA	8.07–45.51	0.06–9.69	NA	0–0.57	0.11–0.87	0.35–78.91	31.8–105.8	Zhou *et al.* 1994
		Kidney	NA	0.01–17.03	0.02–0.07	NA	3.50–17.50	0.01–2.29	NA	0–0.23	< 0.08–2.35	0.17–8.80	18.9–50.1	
Neophocaena phocaenoides	Hong Kong	Liver	< 0.3–12.08	< 0.3–0.86	< 0.3	< 0.3	1.51–59.61	< 0.3–115	< 0.3–0.57	< 0.3–0.60	< 0.3–4.00	< 0.3–22.85	12.16–143	This study
		Kidney	< 0.25–5.03	< 0.25–4.89	< 0.25–0.46	< 0.25–	1.14–18.69	< 0.25	< 0.25–0.50	< 0.25–1.51	< 0.25–2.24	< 0.25–8.30	3.03–28.19	
Sousa chinensis	Hong Kong	Liver	< 0.3–3.88	< 0.3–6.95	< 0.3	< 0.3	0.28–9.19	< 0.3–272	< 0.3–0.49	< 0.3–0.37	< 0.3–2.58	< 0.3–39.23	7.24–72.98	This study
		Kidney	< 0.25–3.03	< 0.25–21.0	< 0.25	< 0.25	1.76–5.90	< 0.25–8.94	< 0.25–0.19	< 0.25	< 0.25–3.28	< 0.25–5.32	13.35–58.61	

the mother to the calf during lactation. Despite the fatty nature of blubber, there were surprisingly high levels of lead detected in this type of tissue in the Hong Kong samples. This tends to suggest that lead may be present in an organically-bound form. If this were the case, it would explain why the lactating females in Honda *et al.* (1983) had lead contaminating their secreted lipids.

Mercury

Mercury is one of the most frequently studied trace elements in cetacean tissues, mainly due to its toxicological significance: mercury poisoning results in neurological damage (Mertz 1987; Merian 1991). Mercury contamination in cetaceans from industrialized regions can be high. In Japan, mercury levels of up to 485 $\mu g\,g^{-1}$ wet weight (or approximately 1600 $\mu g\,g^{-1}$ dry weight) have been recorded from striped dolphins (Honda *et al.* 1983). The Mediterranean contains some of the most highly contaminated animals, with levels of up to 13 156 $\mu g\,g^{-1}$ dry weight (Leonzio *et al.* 1992), which was recorded from a bottlenose dolphin from the Tyrrhenian Sea.

In the oldest animals sampled here, mercury concentrations were high (up to 906 $\mu g\,g^{-1}$dry weight). The mean liver concentration for finless porpoises recorded in this study was over two hundred times higher than noted by Zhou *et al.* (1994) for the same species in the East China Sea (Table 6). Although not as great as those recorded from Japan and the Mediterranean, the mercury concentrations detected in this study were nonetheless high enough to cause damage to the internal organs of contaminated individuals (Wagemann & Muir 1984; Rawson *et al.* 1993). However, the method of trace metal determination used in this present study (ICPAES) is not the optimum method for determining mercury concentrations and may underestimate the degree of mercury contamination. The actual concentrations of this element in the cetacean tissues sampled may thus be higher than those shown in Tables 3 and 4. Even if the true concentrations are not higher, the concentrations reported in this study still show that mercury poisoning is a threat to Hong Kong's local cetaceans.

Cobalt, molybdenum, chromium and nickel

Cobalt concentrations were below detection levels in most of the tissues examined in this study. The toxic effects of cobalt contamination in cetacean tissues have rarely been studied, therefore one cannot assess the toxicological impact of the element. However, as concentrations are lower than detection limits, cobalt is probably not of toxicological significance with respect to Hong Kong's cetaceans. This is also the case for the element molybdenum.

The toxicity of chromium depends on the valency of the compound involved; while some are either non-toxic or not easily absorbed when ingested, others are toxic and even carcinogenic (Mertz 1987; Merian 1991). However, the chromium concentrations determined in this study were generally low (i.e. mostly <1 $\mu g\,g^{-1}$ dry weight), and were orders of magnitude lower than the levels of the element recorded from Taiwanese cetaceans (53.3 $\mu g\,g^{-1}$ dry weight; Lee & Mok 1995). Even if the valency of the chromium present was such that it could potentially be toxic, the low chromium concentrations noted in Hong Kong mean that chromium is unlikely to constitute a health risk to cetaceans.

Nickel levels were also low in all of the samples tested in this study. The element is relatively non-toxic and, thus, levels in Hong Kong's cetaceans are of no toxicological significance.

Selenium

Selenium is believed to be involved in the detoxification of mercury in marine mammals, with levels and uptake of the two elements often being correlated with each other (Koeman *et al.* 1973, 1975; van de Ven *et al.* 1979; Itano *et al.* 1984; Caurant *et al.* 1994). Such a correlation was also observed in this study. Correlations have also been found between the age of marine mammals and selenium concentration (Koeman *et al.* 1975; Reijnders 1980), a trend likewise shown in Hong Kong's cetaceans. The correlations and tissue concentrations determined in this study could be the result of the sequestering of mercury as mercuric selenide in liver and kidney tissue, as a means of detoxifying high concentrations of accumulated mercury in older animals (Martoja & Berry 1980; Joiris *et al.* 1991).

Tin

Until recently, little research had been carried out on tin within cetacean tissues. This is surprising, since there is a large body of literature on tin, in particular involving tributyltin and its toxic effects on marine invertebrates. Tributyltin is also known to disrupt the immune system of terrestrial mammals (Seinen & Willems 1976; Vos *et al.* 1984).

In Hong Kong, tributyltin is often used as an anti-fouling paint on the hulls of ships and, as the territory is one of the largest ports in the world, contamination from this substance is particularly pertinent. Butyltin has, therefore, been a relatively well researched and discussed topic in the territory (Lau 1991; Ko *et al.* 1995). In Hong Kong, tributyltin is banned as an anti-fouling agent on boats smaller than 25 m, but is still used widely on larger vessels. The Urmston Road shipping channel and several dry dock facilities are present in the area of greatest hump-backed dolphin abundance. Finless porpoises have, moreover, been recorded frequently from the waters of Sai Kung in the New Territories, where substantial quantities of tributyltin have been documented (Ko *et al.* 1995). Thus, Hong Kong's populations of finless porpoises and hump-backed dolphins both inhabit areas of potentially high tributyltin contamination.

Iwata *et al.* (1994) investigated butyltins in cetaceans and reported relatively high concentrations in finless porpoises from Japanese waters (MBT 64–210 $ng\,g^{-1}$; DBT $<$5–74 $ng\,g^{-1}$; TBT 31–460 $ng\,g^{-1}$ wet weight), but much lower concentrations in a finless porpoise from the South China Sea (MBT $<$14 $ng\,g^{-1}$; DBT $<$1 $ng\,g^{-1}$; TBT 6.7 $ng\,g^{-1}$). The method used in the present study measures total tin concentration and does not discriminate between organic and inorganic tin. The concentrations of tin noted in Hong Kong's cetaceans (up to 2670 ng g^{-1} wet weight or 8900 ng g^{-1} dry weight) suggest that there could be high levels of butyltin in the tissues of these animals. The correlation seen between finless porpoise length and tin concentration implies the accumulation of this element over time in this species. Iwata *et al.* (1995) noted that finless porpoises in Japan accumulated butyltins and that part of this accumulation was due to a dietary intake. Considering the potential for such poisoning in Hong Kong, the contamination of Hong Kong's cetaceans and their prey by butyltins should be considered a research priority.

Zinc

Concentrations of zinc in the livers of marine mammals are typically in the range of 20–100 $\mu g\, g^{-1}$ wet weight (Law *et al.* 1991, 1992), and Hong Kong's cetaceans are no exception (7.24–143 $\mu g\, g^{-1}$ wet weight or 24.1–476 $\mu g\, g^{-1}$ dry weight). The correlation between zinc in blubber tissue and porpoise age suggests that this element accumulates in such tissues over time. Zinc is, however, relatively non-toxic. The levels of zinc contamination and the degree of zinc accumulation in Hong Kong's small cetaceans are thus of little import.

Conclusions

Most of the trace element concentrations reported from the tissues of Hong Kong's cetaceans were comparable to the levels seen in cetaceans from other industrialized areas. Only mercury was present in levels high enough to be of immediate concern to individual animals. However, there is a considerable potential for butyltin contamination in Hong Kong's cetaceans and research should be conducted to assess the threat from this metal compound as soon as possible.

Low salinity and high temperature can act synergistically to increase trace element toxicity in marine organisms (McLusky *et al*. 1986). Certain trace metals form inorganic complexes in seawater and this complexation reduces as salinity decreases and causes the release of a more toxic free metal ion. Considering that both species of cetaceans living in Hong Kong's waters dwell in a tropical estuary, this synergy could be an important consideration. The number of cetacean mortalities reported from Hong Kong's waters are high (Parsons 1998*b*), and the sizes of the local populations are relatively small. Whilst trace element concentrations are not extreme enough to cause direct poisoning in most cases, the concentrations reported in this study may combine with other factors such as organochlorine pollutants (Parsons & Chan 1998), stress, low food supply and habitat loss to undermine the health and further decrease the viability of Hong Kong's cetaceans.

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