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Risk assessment of trace elements in the stomach contents of Indo-Pacific Humpback Dolphins and Finless Porpoises in Hong Kong waters

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Abstract

The potential health risks due to inorganic substances, mainly metals, was evaluated for the two resident marine mammals in Hong Kong, the Indo-Pacific Humpback Dolphin (*Sousa chinensis*) and the Finless Porpoise (*Neophocaena phocaenoides*). The stomachs from the carcasses of twelve stranded dolphins and fifteen stranded porpoises were collected and the contents examined. Concentrations of thirteen trace elements (Ag, As, Cd, Co, Cr, Cs, Cu, Hg, Mn, Ni, Se, V and Zn) were determined by inductively coupled plasma mass spectrometer (ICP-MS). An assessment of risks of adverse effects was undertaken using two toxicity guideline values, namely the Reference Dose (RfD), commonly used in human health risk assessment, and the Toxicity Reference Value (TRV), based on terrestrial mammal data. The levels of trace metals in stomach contents of dolphins and porpoises were found to be similar. Risk quotients (RQ) calculated for the trace elements showed that risks to the dolphins and porpoises were generally low and within safe limits using the values based on the TRV, which are less conservative than those based on the RfD values. Using the RfD-based values the risks associated with arsenic, cadmium, chromium, copper, nickel and mercury were comparatively higher. The highest RQ was associated with arsenic, however, most of the arsenic in marine organisms should be in the non-toxic organic form, and thus the calculated risk is likely to be overestimated.

Keywords: Heavy metals; Risk quotient; Toxicity reference value; Reference dose

1. Introduction

Hong Kong is located on the southern coast of China, where it is the centre of a rapidly expanding area and is host to the second largest port in the world. Marine ecosystems in Hong Kong and the adjacent Guangdong Province have been the subject of considerable research during the last 10–20 years. A number of studies have been conducted on the dolphin and porpoise populations, but only a small number were related to pollution (Parsons, 1999a; Minh et al., 1999, 2000a,b; Leung et al., 2005; Ramu et al., 2005; Hung et al., 2006).

There are 16 species of dolphins, porpoises and whales that have been recorded in Hong Kong waters. Only the Indo-Pacific Humpback Dolphin, or locally known as Chinese White Dolphin (*Sousa chinensis*), and the Finless Porpoise (*Neophocaena phocaenoides*) are resident marine mammals (Parsons et al., 1995). The two species tend to

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have different distributions in Hong Kong waters. Indo-Pacific Humpback Dolphins are estuarine animals, which can be found in western waters, situated at the mouth of Pearl River, while the porpoises are found in the eastern and southern waters of Hong Kong.

To date, the size of the humpback dolphin population in the Pearl River Estuary is estimated to be 1300 (Jefferson, 2005) and the abundance estimation of finless porpoises is about 217 in Hong Kong waters (http://www.afcd.gov.hk/). Both of them are protected species included in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Many studies showed that humpback dolphins and finless porpoises in Hong Kong are threatened by habitat loss, over-fishing, fast-moving boats, infrastructural projects and pollution. Post-mortem investigations on stranded cetacean carcasses found in Hong Kong waters demonstrated that many accumulated a range of contaminants that may cause adverse health effects (Parsons, 1999a; Minh et al., 1999, 2000a,b; Leung et al., 2005; Ramu et al., 2005; Hung et al., 2006). For example tissue analyses showed that some specimens had high levels of trace metals with the highest mercury levels in dolphins and porpoises at 910 and 390 $\mu g\ g^{-1}$ dw, respectively. Arsenic levels were also very high in dolphins (12.9 $\mu g\ g^{-1}$ dw) and porpoises (40.3 $\mu g\ g^{-1}$ dw) (Parsons, 1999a).

Based on the stomach content of stranded cetaceans, some studies have found that humpback dolphins mainly feed on estuarine fish, including the families Engraulidae, Sciaenidae and Clupeidae (Jefferson, 2000; Barros et al., 2004). The feeding habits of finless porpoises are somewhat different from the dolphins. Their diet consists of fish, crustaceans and cephalopods (Barros et al., 2002). The trace element concentrations in fish collected in western waters of Hong Kong have been measured (Parsons, 1999b; Hung et al., 2004) and the risk to humpback dolphins, due to consuming these species of fish was assessed (Hung et al., 2004). However, there are only a very small number of studies on the trace metal concentrations in the actual stomach content of the cetaceans. In fact, the stomach acts as a very specific sampler collecting the numbers of species, sizes and other characteristics of the biota consumed, and thus the trace metal content of this is particularly relevant in risk assessment.

The main objective of the present study was to measure the trace element concentrations in stomach contents of stranded cetacean carcasses in Hong Kong waters and use these data to evaluate the risk to the humpback dolphins and finless porpoises.

2. Materials and methods

2.1. Sample preparation

The stranded dolphins and porpoise carcasses were collected and dissected by personnel of the HK Cetacean Research Project (HKCRP) funded by the Agricultural, Fisheries and Conservation Department (AFCD) of Hong Kong SAR. The whole stomachs, with adequate contents, were stored at −20 °C. Prior to analysis the stomach contents were removed, stored in pre-washed PVC tubes and freeze-dried (Dura-Dry™, US).

2.2. Analytical method

The dried stomach contents were digested following the methods of Connell et al. (2002) and Hung et al. (2004). The weighed samples were digested in a mixture of 3-D water (2 ml, double-distilled deionized water) and 70% nitric acid (5 ml, trace metal grade, Tedia, USA). The pressure in the digestion tubes was 65 psi and this was continued for 15 min in a microwave oven (CEM, model MDS-2000). After cooling, H_2O_2 (2 ml, 35%, Riedel-de Haën, Germany) was added and the procedure, 65 psi for 15 min, was repeated. The cooled digests were filtered through a disposable syringe filter disc (Macherey-Nagel, pore size 0.45 μm and diameter 25 mm, with cellulose mixed esters as filtering material) equipped with 50 ml plastic syringes and the filtrates were diluted to 25 ml with 3-D water in volumetric flasks. The samples were kept in PVC tubes at 4 °C for subsequent trace element analysis.

Concentrations of trace elements (Ag, As, Cd, Co, Cr, Cs, Cu, Hg, Mn, Ni, Se, V and Zn) were determined using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) (Perkin–Elmer, Elan DRC Plus). The detection limits of Ag, As, Cd, Co, Cr, Cs, Cu, Hg, Mn, Ni, Se, V and Zn were 0.22, 0.68, 0.04, 0.26, 0.21, 0.26, 0.69, 0.21, 0.44, 0.37, 0.49, 0.52 and 0.57 $ng\ g^{-1}$, respectively. All specimens were analyzed in batches which included a procedural blank. Standard reference material (SRM2977, freeze-dried mussel tissue, National Institute of Standards and Technology, USA) were also analyzed using the same method. A good agreement was found between the data generated and those certified by the SRM. The percentage recoveries ranged from 85% to 118%. All the concentrations were expressed in $ng\ g^{-1}$ wet weight (ww) for easier comparison with other studies and calculation in risk assessment, and were not corrected for recovery.

2.3. Risk assessment

Exposure was assessed from plots of the percent cumulative probability against the concentration. The dose-response assessment was carried out using two guideline values namely the Reference Dose (RfD, $mg\ kg^{-1}$ wet weight day^{-1}) commonly used in relation to human health and Toxicity Reference Value (TRV, $mg\ kg^{-1}$ wet weight day^{-1}), used in relation to mammal health. These were used to derive the Maximum Allowable Concentration (MAC) which represents the maximum concentration of each toxicant that can occur in prey items (food taken by dolphin or porpoise) without causing adverse health effects. The MAC based on the RfD (MAC_{RfD}) is derived using the equation for intake of a chemical

$$\text{Intake (mg kg}^{-1}\text{ day}^{-1}) = \frac{\text{CF} \times \text{IR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$$

where, CF is contaminant concentration in fish (mg kg^{-1} ww); IR ingestion rate (kg day^{-1}); EF exposure frequency (day $year^{-1}$); ED exposure duration (years); BW body weight (kg); AT average time (period over which exposure is averaged in days). When

$$\text{Intake} = \text{RfD}, \text{then CF} = \text{MAC}_{\text{RfD}}$$

Thus,

$$\text{RfD} = \frac{\text{MAC}_{\text{RfD}} \times \text{IR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$$

$$\text{MAC}_{\text{RfD}} = \frac{\text{RfD} \times \text{BW} \times \text{AT}}{\text{IR} \times \text{EF} \times \text{ED}}$$

The values substituted into the above equation to calculate the MAC_{RfD} values are summarized in Table 1.

On the other hand, the Toxicity Reference Values (TRV) were derived for the dolphin and porpoise based on NOAELs from mammalian surrogates and a scaling factor based on body weight following the method of Sample et al. (1996):

$$\text{TRV} = \text{NOAEL}_t(\text{BW}_t/\text{BW}_r)^{1/4}$$

where, TRV is the toxicity reference value for receptor species (mg kg^{-1} ww day^{-1}); $NOAEL_t$ the no observable adverse effect level for test species (mg kg^{-1} ww day^{-1}); BW_r the body weight for the receptor species (kg ww); BW_t the body weight for the test species (kg ww).

To account for age (size) differences, TRV and MAC_{TRV} were calculated separately for adult and juvenile humpback dolphins and finless porpoises using their respective body weights. The body weight of adult humpback dolphins and finless porpoises were taken as 185 kg and 60 kg,

Table 1
Values of variables used in calculation of the MAC values for the dolphin and porpoise

Variables	Indo-Pacific Humpback Dolphin	Finless Porpoise
Adult ingestion rate (IR)	9 kg day^{-1} (about 5% of body weight)	3 kg day^{-1} (about 5% of body weight)
Juvenile ingestion rate (IR)	2 kg day^{-1} (about 5% of body weight)	1 kg day^{-1} (about 5% of body weight)
Fraction ingested (FI)	0.9[b]	0.9[b]
Exposure frequency (EF)	365 day $year^{-1}$[b]	365 day $year^{-1}$[b]
Exposure duration (ED)	40 years (assuming life-time exposure)[b]	28 years (assuming life-time exposure)[a]
Adult body weight (BW)	185 kg[b]	60 kg[a]
Juvenile body weight (BW)	40 kg[c]	20 kg[d]
Average time (AT)	14600 days (40 × 365 days)	10220 days (28 × 365 days)

Notes:
[a] Data from www.afcd.gov.hk.
[b] Data from ERM (2000).
[c] Data from estimation from Jefferson (2000).
[d] Data from estimation from Jefferson et al. (2002).

Table 2
RfD, MAC_{RfD}, TRV and MAC_{TRV} values of various trace elements used in the risk assessment of dolphin

Contaminant	RfD (mg kg^{-1} ww day^{-1})	MAC_{RfD} (mg kg^{-1}ww)	Adult TRV (mg kg^{-1} ww day^{-1})	Adult MAC_{TRV} (mg kg^{-1}ww)	Juvenile TRV (mg kg^{-1} ww day^{-1})	Juvenile MAC_{TRV} (mg kg^{-1} ww)
Ag	0.005[a]	0.1	0.04[e]	0.9	0.06[e]	1.2
As	0.0003[a]	0.007	0.01[f]	0.2	0.02[f]	0.4
Cd	0.001[a]	0.02	0.2[f]	4.6	0.3[f]	6
Co	0.06[b]	1.4	1.2[g]	27	1.2[g]	24
Cr	0.003[a]	0.07	570[f]	13000	840[f]	16700
Cs	–	–	–	–	–	–
Cu	0.02[c]	0.5	3.2[f]	72	4.7[f]	93
Hg	0.0007[d]	0.02	0.3[f]	6.2	0.4[f]	8
Mn	0.14[a]	3.2	18[f]	420	27[f]	540
Ni	0.02[a]	0.7	8.3[f]	190	12[f]	250
Se	0.005[a]	0.1	0.04[f]	0.9	0.06[f]	1.2
V	0.003[c]	0.07	0.04[f]	0.9	0.06[f]	1.2
Zn	0.3[a]	6.9	33[f]	760	49[f]	980

Notes:
[a] Obtained from the Integrated Risk Information System, USEPA (IRIS) (http://www.epa.gov/iris).
[b] Obtained from Ontario Ministry of the Environment and Energy (2001).
[c] Obtained from the ATSDR (1995).
[d] Obtained from WHO (1996).
[e] Obtained from USEPA (1999).
[f] Obtained from Sample et al. (1996), incorporated with scaling factor.
[g] Obtained from California Department of Toxic Substances Control (2000).

Table 3
RfD, MAC_{RfD}, TRV and MAC_{TRV} values of various trace elements used in the risk assessment of porpoise

Contaminant	RfD ($mg\ kg^{-1}$ ww day^{-1})	MAC_{RfD} ($mg\ kg^{-1}$ ww)	Adult TRV ($mg\ kg^{-1}$ ww day^{-1})	Adult MAC_{TRV} ($mg\ kg^{-1}$ ww)	Juvenile TRV ($mg\ kg^{-1}$ ww day^{-1})	Juvenile MAC_{TRV} ($mg\ kg^{-1}$ ww)
Ag	0.005[a]	0.1	0.06[e]	1.3	0.07[e]	1.4
As	0.0003[a]	0.007	0.02[f]	0.4	0.03[f]	0.6
Cd	0.001[a]	0.02	0.3[f]	6	0.35[f]	7
Co	0.06[b]	1.3	1.2[g]	27	1.2[g]	24
Cr	0.003[a]	0.07	760[f]	16800	996[f]	19900
Cs	–	–	–	–	–	–
Cu	0.02[c]	0.4	4.2[f]	93	5.5[f]	110
Hg	0.0007[d]	0.02	0.4[f]	8	0.5[f]	9.4
Mn	0.14[a]	3.1	24[f]	540	32[f]	640
Ni	0.02[a]	0.4	11[f]	246	15[f]	290
Se	0.005[a]	0.1	0.06[f]	1.3	0.07[f]	1.4
V	0.003[c]	0.07	0.05[f]	1.1	0.07[f]	1.4
Zn	0.3[a]	6.7	44[f]	983	58[f]	1160

Notes:
[a] Obtained from the Integrated Risk Information System, USEPA (IRIS) (http://www.epa.gov/iris).
[b] Obtained from Ontario Ministry of the Environment and Energy (2001).
[c] Obtained from the ATSDR (1995).
[d] Obtained from WHO (1996).
[e] Obtained from USEPA (1999).
[f] Obtained from Sample et al. (1996), incorporated with scaling factor.
[g] Obtained from California Department of Toxic Substance Control (2000).

respectively (Hung et al., 2006). The body weight of juveniles (using 2 year-old animals as examples) of humpback dolphins and porpoises were estimated to be 40 kg (based on data in Jefferson (2000)) and 20 kg (based on data in Jefferson et al. (2002)), respectively.

The Maximum Allowable Concentration based on TRV (MAC_{TRV}) was derived in a similar way to the MAC_{RfD}, thus

$$MAC_{TRV} = \frac{TRV \times BW \times AT}{IR \times EF \times ED}$$

The RfD, TRV, calculated MAC_{RfD} and MAC_{TRV} values are summarized in Tables 2 and 3.

For risk characterization, the results obtained from the exposure assessment and dose-response assessment were integrated to estimate the risk. The risk quotient (RQ) was calculated as concentration of a specific trace element in stomach content divided by the relevant MAC_{RfD} or MAC_{TRV}. Risk assessment on Cs was not performed as neither RfD nor TRV are available for this element.

3. Results and discussion

3.1. Trace element concentrations

The concentrations of various trace elements in the stomach content of Indo-Pacific Humpback Dolphins and Finless Porpoises are summarized in Tables 4 and 5, respectively. There is a large range of concentrations for individual elements, for example, humpback dolphins have

Table 4
Trace element concentrations ($ng\ g^{-1}$ ww) in stomach content samples of Indo-Pacific Humpback Dolphins

No.	Specimen	Sex	Ag	As	Cd	Co	Cr	Cs	Cu	Hg	Mn	Ni	Se	V	Zn
1	SC00-01/08	F	15	42	10	17	630	21	36400	41	2800	3800	430	65	21100
2	SC01-11/02	F	4	360	59	42	430	11	1200	46	3900	2400	300	50	11100
3	SC00-26/08	M	10	81	13	5	440	20	9700	48	540	520	500	16	19800
4	SC00-06/07	F	7	43	3	4	300	16	10000	32	630	200	440	22	13400
5	SC01-06/02	M	18	220	13	160	4900	74	1900	73	17300	7500	420	800	22700
6	SC00-23/07	M	4	61	40	7	370	16	10600	26	1300	1500	350	57	24200
7	SC01-30/07	M	3	62	27	9	1200	20	5300	27	800	75	320	42	26100
8	SC01-03/06	M	7	64	47	43	530	47	8700	32	2800	2400	330	410	30200
9	SC01-28/06	M	6	210	4	160	4600	18	2400	28	9900	9800	82	270	19300
10	SC02-08/02	M	4	400	9	31	780	24	680	30	4000	580	220	120	8800
11	SC03-08/01	?	3	88	4	9	160	34	360	34	630	190	300	30	6900
12	SC02-22/03	M	3	420	9	26	160	12	620	29	4100	320	170	140	16800
Mean			7	170	20	43	1200	26	7300	37	4000	2500	320	170	18300
Range			3–18	42–420	3–59	4–160	160–4900	11–74	360–36400	26–73	540–17300	75–9800	82–500	16–800	6900–30200

Table 5
Trace element concentrations (ng g^{-1} ww) in stomach content samples of finless porpoises

No.	Specimen	Sex	Ag	As	Cd	Co	Cr	Cs	Cu	Hg	Mn	Ni	Se	V	Zn
1	NP01-09/12	M	6	200	46	23	1400	20	1100	240	1900	830	280	71	16700
2	NP01-20/03	M	39	160	430	9	350	30	6100	350	2500	420	1000	25	38500
3	NP00-26/12	M	15	410	68	21	1400	31	3600	340	2300	770	540	55	27500
4	NP02-21/04	M	4	51	130	8	340	20	2500	160	630	300	210	12	14500
5	NP01-12/04	M	42	210	160	8	510	15	3500	520	930	280	580	37	18600
6	NP00-25/12	F	4	290	3	55	1300	8	950	25	11100	1400	200	180	18000
7	NP01-15/06	?	5	390	19	41	630	29	5300	38	580	530	660	200	22700
8	NP00-23/06	?	7	130	8	9	190	13	8500	98	510	210	360	23	21700
9	NP00-27/09	F	4	280	6	37	160	12	2900	13	12200	780	200	120	12400
10	NP00-28/12	M	3	230	9	12	100	11	780	19	2700	190	190	27	7760
11	NP00-05/09	M	4	78	55	22	330	22	5900	120	3400	500	380	180	16300
12	NP00-09/11	M	3	290	12	15	160	14	1900	34	1800	200	200	56	16300
13	NP01-24/05	M	5	280	12	35	210	9	1700	19	3300	870	180	56	17400
14	NP01-13/10A	?	9	260	21	68	680	33	5100	33	11500	1800	200	280	17500
15	NP00-02/11	M	3	220	4	36	530	5	550	12	4200	840	110	33	12000
Mean			10	230	66	27	550	18	3360	140	4000	660	350	90	18500
Range			3–42	51–410	3–430	8–68	100–1400	5–33	550–8500	12–520	510–12200	190–1800	110–1000	12–280	7760–38500

a range of 42–420 As, 3–59 Cd and 360–36400 ng g^{-1} ww Cu while the finless porpoises have 51–410 As, 3–430 Cd and 550–8500 ng g^{-1} ww Cu. Perhaps this reflects the foraging patterns of these mammals resulting in varying levels of exposure to trace elements via consumption of food fish in the ambient estuarine and marine environment of the Pearl River Estuary and the surrounding areas.

Humpback dolphins generally inhabit the western waters of Hong Kong, while the finless porpoises can be found in southern and eastern waters. However, statistical analyses showed that there were no significant differences in the concentrations of individual elements between the stomach contents of humpback dolphins and finless porpoises. This suggests that the source of the trace elements may be widespread, and that the concentrations of trace elements in the ambient marine and estuarine waters may be relatively consistent.

Trace element concentrations in fish prey species of the Indo-Pacific Humpback Dolphin, from the northwestern waters of North Lantau, have been reported previously (Hung et al., 2004). In general, the concentrations reported by Hung et al. (2004) were similar to those recorded in this study. However, the concentrations of As and Cd in the stomach contents were lower than the concentrations in fishes reported in Hung et al. (2004). These fish samples were collected in the area around the contaminated mud pits located in the northwestern waters of Lantau Island. Perhaps the lower levels found in stomach contents were due to the dolphins and porpoises consuming food fish in waters with lower levels of trace elements.

The trace element levels in liver, kidney and blubber of the Indo-Pacific Humpback Dolphin and Finless Porpoise have previously been reported by Parsons (1999a). The concentrations of Cr, Cu and Ni in humpback dolphins' tissues and Cr in porpoises' tissues reported by Parsons (1999a) were lower than those in the stomach content of these species observed in the present study. However, in general, the tissue concentrations of dolphin and porpoise reported by Parsons (1999a) were higher than the stomach content concentrations reported in this study. These apparent differences may possibly be attributed to the varying degrees of uptake, assimilation, and excretion for different trace elements by the cetaceans.

3.2. Assessment of risk of adverse effects

The procedure adopted in the risk assessment was essentially the same as that described in Hung et al. (2004). Plots of the percent cumulative probability, on a probabilistic scale, against the concentrations of the various elements on a logarithmic scale were made for each element. For exposure evaluation, the concentrations corresponding to the 5th, 50th and 95th cumulative percentiles were calculated from the linear regression equations. These three concentrations represent the lowest, middle and highest concentrations and so provide a thorough evaluation of the range of exposure concentrations through the stomach contents.

In this study, the body weight for adults and juveniles were used to calculate the TRV and MAC_{TRV}. It is noted that the values for adults were always lower than their corresponding values for juveniles for both humpback dolphins and porpoises. On this basis, an assessment which based on TRV and MAC_{TRV} for adults would be sufficiently conservative for the protection of juvenile dolphins and porpoises.

The calculated risk quotients (RQs) based on MAC_{RfD} and MAC_{TRV} using exposure data corresponding to the 5th, 50th and 95th percentiles of humpback dolphin (Tables 6 and 7) and porpoise (Tables 8 and 9) are presented. A typical plot of percent cumulative probability against trace element concentrations in stomach content

Table 6
Risk quotient (RQ) calculated for the measured contaminants based in MAC_{RfD} using 5th, 50th and 95th percentile data of Indo-Pacific Humpback Dolphin

Analyte	RQ 5% (TRV)				RQ 50% (TRV)				RQ 95% (TRV)			
	<1	1–10	10–100	>100	<1	1–10	10–100	>100	<1	1–10	10–100	>100
Ag	X				X				X			
As		X					X				X	
Cd	X				X					X		
Co	X				X				X			
Cr		X				X					X	
Cu	X					X					X	
Hg		X				X				X		
Mn	X				X					X		
Ni	X					X					X	
Se		X				X				X		
V	X					X				X		
Zn		X				X				X		

Table 7
Risk quotient (RQ) calculated for the measured contaminants based in MAC_{TRV} using 5th, 50th and 95th percentile data of Indo-Pacific Humpback Dolphin

Analyte	RQ 5% (TRV)				RQ 50% (TRV)				RQ 95% (TRV)			
	<1	1–10	10–100	>100	<1	1–10	10–100	>100	<1	1–10	10–100	>100
Ag	X				X				X			
As	X				X					X		
Cd	X				X				X			
Co	X				X				X			
Cr	X				X				X			
Cu	X				X				X			
Hg	X				X				X			
Mn	X				X				X			
Ni	X				X				X			
Se	X				X				X			
V	X				X				X			
Zn	X				X				X			

Table 8
Risk quotient (RQ) calculated for the measured contaminants based in MAC_{RfD} using 5th, 50th and 95th percentile data of finless porpoise

Analyte	RQ 5% (RfD)				RQ 50% (RfD)				RQ 95% (RfD)			
	<1	1–10	10–100	>100	<1	1–10	10–100	>100	<1	1–10	10–100	>100
Ag	X				X				X			
As		X					X				X	
Cd	X					X					X	
Co	X				X				X			
Cr		X				X					X	
Cu		X				X					X	
Hg	X					X					X	
Mn	X				X					X		
Ni	X					X				X		
Se	X					X				X		
V	X				X					X		
Zn		X				X				X		

samples for the dolphin and porpoise, with corresponding MAC_{RfD} and MAC_{TRV} values is given in Fig. 1 using manganese as an example.

The risk quotient analysis based on MAC_{RfD}, used in human health investigations, showed a large range of RQs reflecting the large range in concentrations, see

Table 9
Risk quotient (RQ) calculated for the measured contaminants based in MAC_{TRV} using 5th, 50th and 95th percentile data of finless porpoise

Analyte	RQ 5% (TRV)				RQ 50% (TRV)				RQ 95% (TRV)			
	<1	1–10	10–100	>100	<1	1–10	10–100	>100	<1	1–10	10–100	>100
Ag	X				X				X			
As	X				X					X		
Cd	X				X				X			
Co	X				X				X			
Cr	X				X				X			
Cu	X				X				X			
Hg	X				X				X			
Mn	X				X				X			
Ni	X				X				X			
Se	X				X				X			
V	X				X				X			
Zn	X				X				X			

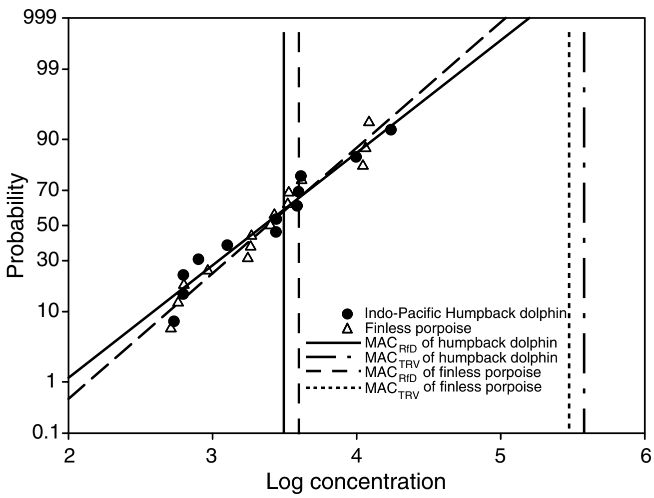

Fig. 1. Plots of percent cumulative probability (probabilistic scale) against concentrations of manganese in stomach content samples, with corresponding MAC_{RfD} and MAC_{TRV} values of humpback dolphin and finless porpoise.

Tables 6 and 8. Arsenic (As) had the highest RQ in all cases, and this is similar to the finding by Hung et al. (2004). The RQ values for Cr, Cu and Ni in humpback dolphin were relatively high ranging from 10 to 100, while Cd, Cr, Cu and Hg in finless porpoise also had RQs in the ranges of 10–100 (Tables 6 and 8). The RQ values for Co and Ag were smaller than unity even when the 95th percentile data were used for both dolphin and porpoise, suggesting that these two metals are probably of low toxicological concern.

The RQs based on the MAC_{TRV}, used to evaluate mammal health, can now be compared with the outcomes above. All RQs, with the exception of As, were lower than 1 which indicated a generally negligible health risk (Tables 7 and 9) for the humpback dolphin and porpoise. The RQs of As were greater than 1 only when the 95th percentile data were used. This finding shows that risks are relatively high only when the highest concentrations occur.

Two guideline values were used, the RfD and TRV. The RfD is commonly used for human health risk assessment and it is derived using the relevant NOAEL divided by a safety factor to give a conservative value for toxic effects. On the other hand the TRV were derived from the NOAEL of terrestrial mammals by applying relevant scaling factors relating to body weights but without the use of safety factors (Sample et al., 1996), and thus can be considered to give a less conservative value. It is noteworthy that the TRV values are derived from data on terrestrial mammals and it is conceivable that marine mammals may have a different tolerance to elements in seawater than terrestrial mammals.

Arsenic (As) was found to have the highest RQs (1–10) with the humpback dolphin and finless porpoise in the MAC_{TRV}-based risk assessments only at the 95 percentile level of concentration. It should be noted that the derivation of TRV was based on the most toxic form of arsenic [inorganic arsenite (As III)]. In this study, the analytical procedure did not discriminate different As species, and provided a value for total As. Some studies have shown that arsenite rarely accounts for more than 20% of total arsenic in seawater, and inorganic arsenic generally represents below 10% of total arsenic in marine biota (Neff, 1997). As a result, most of the arsenic found in stomach content should be in the non-toxic organic form. This means that the risk due to As may have been overestimated, and that there is probably a low level of risk due to As at all concentrations for both mammals.

Cd, Cr, Cu and Ni had MAC_{RfD}-based RQs of between 10 and 100 in one or both mammals at the highest percentile (95%) concentrations. However, the MAC_{TRV}-based RQs of all of these elements were smaller than unity at all concentrations. Mercury (Hg) showed a relatively high RQ in finless porpoise (10 to 100). Hg is highly toxic and also known to be bioaccumulated in marine organisms. Thus, risk due to Hg may require further investigation.

4. Conclusions

The results of the present investigation show that the risks due to trace elements to Indo-Pacific Humpback Dolphin and Finless Porpoise are generally low and within safe limits using toxicity guideline values derived from terrestrial mammals. However if the more conservative guideline values used for human health evaluations are used there are several areas of potential concern including Cr, Cu, Ni, Cd and Hg. It is probable that the TRV values represent a more likely scenario for adverse health effects since these are derived from terrestrial mammals, and marine mammals are likely to be more resistant to seawater borne substances than terrestrial mammals. Arsenic consistently displayed a high RQ but the chemical form of this element is likely to be the low toxicity organic form, and thus this element is probably not of immediate concern.

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