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Paco Bustamante, Claire Garrigue, Ludovic Breau, Florence Caurant, Willy Dabin, et al.. Trace elements in two odontocete species (*Kogia breviceps* and *Globicephala macrorhynchus*) stranded in New Caledonia (South Pacific). *Environmental Pollution*, 2003, 124 (2), pp.263-271. 10.1016/S0269-7491(02)00480-3. hal-00186634

HAL Id: hal-00186634

<https://hal.science/hal-00186634>

Submitted on 10 Nov 2007

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Trace elements in two odontocete species (*Kogia breviceps* and *Globicephala macrorhynchus*) stranded in New Caledonia (South Pacific).

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ABSTRACT : liver, muscle and blubber tissues of two short-finned pilot whales (*Globicephala macrorhynchus*) and two pygmy sperm whales (*Kogia breviceps*) stranded on the coast of New Caledonia have been analysed for 12 trace elements (Al, Cd, Co, Cr, Cu, Fe, organic and total Hg, Mn, Ni, Se, V, and Zn). Liver was shown to be the most important accumulating organ for Cd, Cu, Fe, Hg, Se, and Zn in both species, *G. macrorhynchus* having the highest Cd, Hg, Se and Zn levels. In this species, concentrations of total Hg are particularly elevated, reaching up to 1452 $\mu\text{g}\cdot\text{g}^{-1}$ dwt. Only a very low percentage of the total Hg was organic. In both species, the levels of Hg are directly related to Se in liver. Thus, a molar ratio of Hg:Se close to 1.0 was found for all specimens, except for the youngest *K. breviceps*. Our results suggest that *G. macrorhynchus* have a physiology promoting the accumulation of high levels of naturally occurring toxic elements. Furthermore, concentrations of Ni, Cr and Co are close to or below the detection limit in the liver and muscles of all specimens. This suggests that mining activity in New Caledonia, which typically elevates the levels of these contaminants in the marine environment, does not seem not to be a significant source of contamination for these pelagic marine mammals.

Keywords : Heavy metals ; Cadmium ; Mercury ; Nickel ; Marine Mammals ; Pacific Ocean

INTRODUCTION

Heavy metals generally occur at very low concentrations in oceans (Bryan 1984). Nevertheless, most of marine organisms concentrate trace elements at higher concentrations than those occurring in their environment. This process, currently described as bioaccumulation, concerns toxic elements such as Cd or Hg, as well as essential ones such as Cu, Fe, Se, or Zn. Slight variations of heavy metal concentrations in the environment of marine organisms could lead to a significant increase of their metal burdens. Enrichment of sea water in heavy metals may occur naturally by local environmental processes, such as volcanism or upwellings. In addition to this natural origin, human activities can lead to increases of trace element concentrations in coastal waters, subsequently leading to an increase of metal burdens in biota.

In New Caledonia, mining activities plus strong natural erosion due to tropical rainfall have resulted in enrichment of several metals in coastal waters (mainly Co, Cr, Fe and Ni), and consequently in the coral reef food webs (Monniot et al. 1994). These authors reported high metal burdens in several species of filter-feeding ascidians from shallow waters. However, the impact of metal contamination does not appear to be limited to coastal waters and, in fact, high levels of Co, Cr and Ni have also been reported in the tissues of a cephalopod living in deeper waters, the nautilus, *Nautilus macromphalus* (Bustamante et al. 2000).

Current literature on heavy metal concentrations in New Caledonian marine lower trophic level organisms is scarce (e.g. Monniot et al. 1994; Bustamante et al. 2000), and no data for marine mammals have been published to date. In this work, baseline information is presented for the concentrations of 12 trace elements in the tissues and organs of two odontocetes species, i.e., pygmy sperm whale, *Kogia breviceps* (de Blainville, 1838), and short-finned pilot whale, *Globicephala macrorhynchus* (Gray, 1846) for which very few information on trace elements are available. These marine mammals give the opportunity to investigate the

impact of mining activities on high trophic level organisms stranded in New Caledonia. It also provides information on the bioaccumulation and detoxification processes of Cd and Hg in marine mammals from a tropical zone, toxic elements which are currently reported to raise the question of physiological damages in the tissues of top marine predators.

MATERIALS AND METHODS

Sampling and sample preparation

In spring 1997, two short-finned pilot whales (*Globicephala macrorhynchus*) and two pygmy sperm whales (*Kogia breviceps*) stranded on the coasts of New Caledonia. These animals were autopsied shortly after death. Stomach contents were collected and stored in 90% ethanol for later diet analyses. Teeth were extracted for ageing and skin samples were collected for genetic analysis. Tissues and organs (liver, blubber and muscle) were sampled for heavy metal and radionuclides analyses (Garrigue et al. 2000). Separated tissue samples were placed in decontaminated glass vessels and stored at -20°C . They were then freeze-dried, finely ground and stored in plastic vials.

The two stranded *G. macrorhynchus* were probably part of a bigger pod observed in the vicinity of the stranding location on the day of stranding. This species is commonly encountered outside of the lagoon by long liners in both nearshore and pelagic environments but there is no evidence that they are resident in the area. In fact, seasonal inshore to offshore movements are related to the distribution of squid they feed on (Olson and Reily 2001).

Little is known on the status of *K. breviceps* in New Caledonia as they are very discrete animals, rarely observed alive. Most of the information on this species comes from stranded

animals which have been documented earlier in New Caledonia (Robineau and Rancurel 1981; Sylvestre 1988).

Age determination

Teeth were used for age determination, following the recommendations of Neilsen (1972) and Perrin and Myrick (1980). Teeth taken up from the lower jaw were cleaned, fixed and stored in 70% glycerined alcohol. Before sectioning and staining, teeth were decalcified with DC3 (Labonor©). Sections were then examined to count the growth layer groups (GLGs) assuming 1 GLG equals 1 years, as described by Perrin and Myrick (1980). Three series of several independent readings were done for each tooth section according to Hohn and Fernandez (1999). All readings were recorded to the nearest whole year and age was expressed as mean \pm SD for each individual.

Stomach contents analysis

Stomach contents were washed and the contained elements were sorted by type. Fish species were determined from the otoliths by J. Rivaton from the laboratory of marine biology of IRD (Nouméa, New Caledonia). Cephalopod species were determined from the beaks by Dr R. Young from the University of Hawaii.

Metal analysis

Metal analyses were performed by inductively coupled plasma atomic emission spectrophotometry (ICP-AES) for Al, Co, Cr, Cu, Fe, Mn, Ni, V and Zn, by atomic

absorption spectrophotometry (AAS) for Cd, Cu, Se and Zn, and with an Advanced Mercury Analyser (AMA) for total and organic Hg **after extraction**.

For ICP-AES measurements, 2 aliquots of approx. 500 mg of each **homogenised** dry sample were digested in Teflon containers with 4 ml of 65% HNO₃ and 1 ml of 30% H₂O₂ using a microwave digester (ANTON-PAAR, Perkin Elmer). The digested contents were made up to 25 ml with Milli-Q quality water. Elements were analysed by ICP-AES with an OPTIMA 3200 DV, Perkin-Elmer. Multicomponent Spectral Fitting Models were used to correct for spectral interference between elements.

For AAS measurements, 2 aliquots of approx. 300 mg of each homogenised dry sample were digested with 3.5 ml of 65% HNO₃ at 60°C for 3 d. The digested contents were then diluted to 10 ml in Milli-Q quality water. Cd, Cu, Se and Zn were assayed using flame and graphite furnace atomic absorption spectrophotometer Varian 250 Plus with deuterium background correction.

For AMA measurements, aliquots ranging from 10 to 50 mg of dried material were analysed directly for total Hg in a Advanced Mercury Analyser spectrophotometer (Altec AMA 254). Hg determination involved evaporation of Hg by progressive heating until 800°C was reached and then held under oxygen atmosphere for 3 min, and subsequent amalgamation on a Au-net. Afterwards, the net was heated to liberate the collected mercury, subsequently measured by UV atomic absorption spectrophotometry. The same procedure was performed for the analysis of organic Hg after extraction adapted from Uthe et al. 1972. Organic Hg was extracted from 2 aliquots of approx. 500 mg of each homogenised dry sample using 2 ml of acidic sodium bromide (30% NaBr in 4N H₂SO₄), 4 ml of cupric sulfate (2.5% CuSO₄ in milli-Q quality water) and 10 ml of toluene under agitation for 10 min in glass flasks. The organic phase was then separated and used for the analysis in the AMA.

Quality control was assured using dogfish liver DOLT-2 (NRCC) and dogfish muscle DORM-2 (NRCC) as reference materials for AAS and AMA, and dogfish muscle DORM-1 (NRCC) for ICP-AES. These standards were treated and analysed under the same conditions as the samples. The results were in good agreement with the certified values (Table 1). Detection limits ($\mu\text{g}\cdot\text{g}^{-1}$) were 0.004 for Cd, 0.5 for Cu, 3 for Zn, 0.8 for Se, 0.005 for total Hg and 0.2 for organic Hg for AAS and AMA analyses. For ICP-AES analyses, detection limits were 0.006 for Al, 0.040 for Co, 0.013 for Cr, 0.005 for Cu, 0.051 for Fe, 0.002 for Mn, 0.010 for Ni, 0.009 for V and 0.008 for Zn ($\mu\text{g}\cdot\text{g}^{-1}$). Metal concentrations in tissues are reported in $\mu\text{g}\cdot\text{g}^{-1}$ dry wt.

RESULTS

Main features, age and diet

The main features of the 4 specimens sampled, one male and one female *G. macrorhynchus* and one male and one female *K. breviceps*, are reported in Table 2, with the prey species identified from their corresponding stomach contents and their ages. Considering their ages, the two *G. macrorhynchus* may have been sexually matured as sexual maturity occurred at 9 years for females and between 13 and 16 for males (Olson and Reilly, 2001). Considering *K. breviceps*, the size of sexual maturity have been documented to be 2.7m to 3.0m for males and 2.6 to 2.8m for females of (Leatherwood et al., 1983). Furthermore, *K. breviceps* appears to reach sexual maturity between 3 and 5 years old (Plön, in prep.). In the light of this data the two *K. breviceps* presented in this paper may have been sexually matured.

All the animals with the exception of the male *K. breviceps* were already stranded when samples were collected. This last one was first alive, but it has been euthanased after the

failure of its refloat. The autopsies didn't provide any evident reasons for the death of the animals. Parasites were only found in great quantity in the male *K. breviceps*, with a stomach full of *Anisakis simplex* (Nematodes). This specimen could have suffered of a parasitose, stranded individuals from this species being frequently heavily infected by intestinal nematodes (McAlpine, 2002).

On the other hand, the female *G. macrorhynchus* was probably pregnant before the stranding as part of a foetus was found in its vicinity. This female may have been fasting as its stomach was empty (Table 2).

Metal analysis

Heavy metal and organic mercury concentrations in the liver, muscle and blubber of *G. macrorhynchus* and *K. breviceps* are presented in Table 3. Co, Cr and Ni concentrations in all tissues and organs fall below the detection limit or close to it (i.e. in liver). Among these tissues, liver is the most important accumulating organ for Cd, Cu, Fe, Hg, Se, and Zn and to a lesser extent for Mn and V. However, the two *G. macrorhynchus* exhibit higher hepatic levels for Cd, Cu, Hg, Se and Zn than *K. breviceps* while both species have similar hepatic levels of Mn and V. Fe is the only metal having higher concentrations in the liver of *K. breviceps* than in the one of *G. macrorhynchus*.

In muscle, Mn in *G. macrorhynchus* and V in both mammals are below the detection limits. The remaining trace elements were within the same order of concentration in the muscle of both species (Table 3). The only exception was Hg, where concentrations were 5 times higher in *G. macrorhynchus* muscle compared to *K. breviceps*.

Blubber has generally low trace element concentrations. However, Cr exhibits the highest concentrations among the three tissues (Table 3). Despite its strong affinity to lipids, organic Hg concentrations in blubber were an order of magnitude lower than in liver and muscle.

Figure 1 shows the hepatic concentrations of inorganic Hg and Se of marine mammals in relation to age together with the inorganic Hg:Se molar ratio for each individual. In both species, hepatic inorganic Hg is directly related to hepatic Se. Consequently, a molar ratio close to 1.0 is found in all specimens, except for the youngest *K. breviceps* (6 years old) for which this ratio was 0.13 (Figure 1). Nevertheless, both species exhibit very different ratio organic:total Hg in their tissues (Figure 2) with *K. breviceps* showing a higher percentage of organic Hg than *G. macrorhynchus* in liver (aver. 13% vs 0.5 %) and in muscle (aver. 75 % vs 14 %).

DISCUSSION

Trace element levels

Heavy metal concentrations in the tissues of marine mammals are globally well documented but they concern mainly species having strong interactions with man, i.e. hunted for meat consumption, by-caught during fishing or living in coastal areas. Furthermore, very few studies have investigated trace elements such as Co, Cr, Ni or V although they are potentially toxic, probably because these trace elements are not bioaccumulated in large amounts in mammalian tissues (Thompson 1990). Nevertheless, such elements can be used as tracers of contamination when an enrichment due to anthropogenic activities occurs. In Alaska, Mackey et al. (1996) have shown an increase of V in the tissues of pinnipeds and cetaceans. **The**

bioaccumulation of V in biota and its transfer to the top marine predators has been related to the contamination of sea water by oil residues in this area. Similarly, the consequence of intense mining activities in New Caledonia must be monitored by the measurement of the concentrations of Ni and its associated elements, mainly Co and Cr, in the food webs around the island. Analysis in the tissues of the short-finned pilot whales *Globicephala macrorhynchus* and the pygmy sperm whales *Kogia breviceps* have not revealed any increase of concentrations for these three metals compared to other marine mammals species from various areas (Table 4). With the exception of Cr in the blubber of the male *G. macrorhynchus* ($2.51 \mu\text{g}\cdot\text{g}^{-1}$ dwt), concentrations remained close to or below the detection limits. Considering that these pelagic animals could have preyed on species living around the island as suggested by the examination of their full stomach, our results suggest that these metals are not easily transferred in the food web of these pelagic odontocetes. To assess the impact of mining activities on marine mammals, further studies should be conducted on more coastal species known to be resident of the impacted area, such as the bottlenose dolphin (*Tursiops truncatus*) or the dugong (*Dugong dugon*) that spend all their life in the waters of the New Caledonian lagoon.

Most of the studies on the bioaccumulation of trace elements in marine mammals have focused on toxic Cd and Hg, which are well bioaccumulated in mammalian tissues (Thompson 1990). Nevertheless, numerous rare species have been poorly investigated and there is a lack of data for *G. macrorhynchus* and *K. breviceps*. Table 5 shows the paucity of information reported for these two species. The present study provides new information on metal concentrations in these marine mammals. The four odontocetes stranded in New Caledonia exhibited very high levels of Cd and Hg in liver, reaching 464 and 1452 $\mu\text{g}\cdot\text{g}^{-1}$ dwt, respectively. However, *G. macrorhynchus* displayed much higher concentrations of Cd and Hg than *K. breviceps* (Table 3).

Both species occupy a high and similar trophic levels (4.3 and 4.4 for *G. macrorhynchus* and *K. breviceps*, respectively), assessed by stable isotope analysis (Pauly et al. 1998). They mainly prey upon squid although this may be implemented by a large proportion of fish for *G. macrorhynchus* (around 40%) and a lower one for *K. breviceps* (around 20%) in certain areas (Pauly et al. 1998). The concentrations of Hg in the liver of *G. macrorhynchus* sampled in New Caledonia suggest that fish constitute an important prey items for this species as fish are considered to be the main Hg source for marine top predators (Law et al. 1992). This was confirmed by the analysis of stomach contents showing several fish species in the diet of *G. macrorhynchus* (Table 2). However, no fish remains were found in the stomach contents of *K. breviceps* but its diet included several crustaceans species which are known to have very low Hg contents (Cossa et al. 1990).

Similar exposures to Cd would occur for both species considering the high dietary intakes due to cephalopod consumption (Bustamante et al. 1998) that represent 60% and 75% of the diet of *G. macrorhynchus* and *K. breviceps*, respectively (Pauly et al. 1998). Nevertheless, *G. macrorhynchus* had hepatic Cd concentrations of one order of magnitude higher than *K. breviceps* (Table 3). It appears from the scarce data available in the literature that *K. breviceps* generally have lower Cd concentrations than *G. macrorhynchus* (Table 5). This suggests that diet does not explain alone the high concentrations of Cd in the tissues of *G. macrorhynchus* and that a particular physiology promoting the accumulation of naturally occurring Cd could be envisage for this species.

Detoxification processes

Extremely high levels of toxic Hg and Cd may trigger cellular and physiological damages of the target organs, especially kidney (Gallien et al. 2001). Despite the lack of the main storage organ for Cd analyses (i.e. kidney), Cd concentrations encountered here in liver suggest even

higher concentrations in kidney as it is always the case in marine mammals (Aguilar et al. 1999). Renal dysfunction has been linked to Cd concentrations in liver exceeding $20 \mu\text{g}\cdot\text{g}^{-1}$ ww (approx. $100 \mu\text{g}\cdot\text{g}^{-1}$ dwt) (Honda 1985, Fujise et al. 1988). *G. macrorhynchus* had Cd concentrations in liver far higher than that limit (i.e. 225 and $464 \mu\text{g}\cdot\text{g}^{-1}$ dwt), while the livers of *K. breviceps* were clearly below that limit (Table 3). Thus, Cd detoxification processes should be particularly efficient in the liver and kidney of *G. macrorhynchus* to support such high concentrations and needs to be investigated further.

Marine mammals are exposed to methyl Hg through fish consumption, but only a small fraction of the total Hg in liver and muscle of *G. macrorhynchus* was found to be organic Hg, i.e. <1% and <15% of the total Hg, respectively (Fig. 2). This is far below the percentage of organic Hg to total Hg that is usually found in these tissues of adult marine mammals, which generally ranges from 3 to 20% for liver and from 70 to 95 % for muscle (Caurant et al. 1996, Wagemann et al. 1998). Gaskin et al. (1974) also reported values ranging from 2 to 17 % for organic Hg in the liver of *G. macrorhynchus* from the Lesser Antilles, but muscle had only 42 to 60% of total Hg in the organic form. Therefore, organic Hg concentrations in liver and muscle of *G. macrorhynchus* from New Caledonia are relatively similar to those from Lesser Antilles (Gaskin et al. 1974). Apparently, the low fraction of hepatic organic Hg appear to be due to very high total Hg concentrations. However, such a low organic fraction in muscle of *G. macrorhynchus* from New Caledonia remains questionable. It has been suggested that residual mercury could be mobilised and concentrated from muscle and blubber in other tissues prior to death in *G. macrorhynchus* from the Cumberland Islands (Stoneburner 1978). This author explained that a stress period, viz. fast, could lead to such remobilization. The very low percentages of organic Hg in blubber support this speculation.

It is noteworthy that *K. breviceps* preferentially feeding on cephalopods and shrimp (Table 2), had concentrations of organic Hg in their tissues similar to that of *G. macrorhynchus*.

Cephalopods and shrimp displayed lower methyl Hg contents than fish, i.e. from 29 to 55% vs 53 to 94%, respectively (Cappon & Smith 1982). Compared to *G. macrorhynchus*, higher percentages of organic Hg in the tissues of *K. breviceps* related to lower total Hg contents in liver could be explained by a lower rate of hepatic demethylation. Low percentages of methyl Hg in liver have been reported for many marine mammals species (e.g. Itano et al. 1984, Wagemann et al. 1998). This supports the idea of continuous demethylation of methyl Hg occurring in liver throughout the animal's life span, subsequently leading to the formation of mercuric selenide (HgSe) granules (Pelletier 1985, Cuvin-Aralar & Furness 1991, Nigro & Leonzio 1996). HgSe granules (tiemannite) have been identified in the liver of seabirds, marine mammals and humans (Martoja & Berry 1980, Pelletier 1985, Hansen et al. 1989, Nigro & Leonzio 1996). Moreover, many studies also reported that Hg and Se are correlated in a 1:1 molar ratio as in HgSe (Koeman et al. 1973, Nielsen & Dietz 1990, Law et al. 1997, Wagemann et al. 1998). *G. macrorhynchus* and *K. breviceps* from New Caledonia had a Hg:Se molar ratio close to 1 and a low percentage of organic Hg in liver (Fig. 1 & 2). This suggests the presence of tiemannite granules as a result of demethylation of organic Hg in liver. However, the youngest *K. breviceps*, a 6 years old male (Table 2), had a low hepatic Hg:Se ratio due to low total Hg concentrations. This specimen also exhibited an elevated percentage of hepatic organic Hg (Fig. 2). Palmisano et al. (1995) have shown that demethylation of Hg by Se is efficient reaching a threshold Hg concentration of $100 \mu\text{g}\cdot\text{g}^{-1}$ ww (approx. $500 \mu\text{g}\cdot\text{g}^{-1}$ dw) in the liver of the dolphin *Stenella coeruleoalba*. Although this threshold should be different from one species to another, it clearly appears that the young *K. breviceps* had Hg concentrations far below such a threshold.

CONCLUSION

The present study provides **new information on trace elements concentrations in the tissues of** two rare marine mammals species from a tropical area. Very low Ni, Co and Cr concentrations in the tissues of *G. macrorhynchus* and *K. breviceps* suggest that industrial extracting activities in New Caledonia does not represent a significant source of contaminants for these two particular species. On the other hand, very high Cd and Hg concentrations in the liver of these marine mammals were related to cephalopod and fish consumption. Interspecific differences in the bioaccumulation, i.e. highest Cd and Hg concentrations in *G. macrorhynchus*, remain questionable and should be related to the physiology of this species.

Acknowledgements. We are particularly grateful to Richard Young from the University of Hawaii for cephalopod determination and to Jacques Rivaton from the IRD of Nouméa for fish determination. We also thanks the four anonymous reviewers for their helpful comments on this work.

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Table 1. Comparison of trace elements concentrations ($\mu\text{g}\cdot\text{g}^{-1}$ dry wt) of certified standards from the NRCC determined in the present study with certified values.

Metals	DOLT-2 (n=6)		DORM-2 (n=3)		DORM-1 (n=3)	
	Certified values	Present study	Certified values	Present study	Certified values	Present study
Al	-	-	-	-	-	13.1 \pm 2.1
Cd	20.8 \pm 0.5	21.4 \pm 0.6	0.043 \pm 0.008	0.042 \pm 0.012	-	-
Co	-	-	-	-	0.049 \pm 0.014	< QL
Cr	-	-	-	-	3.60 \pm 0.40	3.45 \pm 0.17
Cu	25.8 \pm 1.1	26.9 \pm 1.3	2.34 \pm 0.16	2.28 \pm 0.24	5.22 \pm 0.33	5.24 \pm 0.05
Fe	-	-	-	-	63.6 \pm 4.9	66.7 \pm 1.4
Total Hg	2.14 \pm 0.28	2.13 \pm 0.02	4.64 \pm 0.26	4.50 \pm 0.16	-	-
Organic Hg	0.693 \pm 0.053	0.759 \pm 0.018	4.47 \pm 0.32	4.38 \pm 0.28	-	-
Mn	-	-	-	-	1.32 \pm 0.26	1.11 \pm 0.02
Ni	-	-	-	-	1.20 \pm 0.30	0.97 \pm 0.08
Se	6.06 \pm 0.49	5.48 \pm 0.13	1.40 \pm 0.09	1.31 \pm 0.15	-	-
Zn	85.8 \pm 2.5	83.6 \pm 3.4	25.6 \pm 2.3	26.2 \pm 2.1	21.3 \pm 1.0	21.1 \pm 1.3

Table 2. Characteristics of the odontocetes and preys identified in their stomach contents. Age is the mean \pm SD of 3 counting of growth layer groups.

Species	Sex	Length (m)	Age	Prey identified in the stomach content
<i>Globicephala macrorhynchus</i>	♂	5.4	14 \pm 1	Fishes : <i>Bathyclupea malayana</i> (Bathyclupeidae) <i>Antigoniia sp.</i> (Caproidae) <i>Synagrops sp.</i> (Acropomatidae) <i>Diaphus sp.</i> (Myctophidae) <i>Cubiceps sp.</i> (Nomeidae) <i>Chlorophthalmus sp.</i> (Clotophthalmidae) Cephalopods : <i>Stenoteuthis sp.</i> (Ommastrephidae) 3 unidentified species (Ommastrephidae) <i>Moroteuthis sp.</i> (Onychoteuthidae) <i>Lycoteuthis sp.</i> (Lycoteuthidae) <i>Histioteuthis sp.</i> (Histioteuthidae) 5 unidentified species (Histioteuthidae)
	♀	3.5	12 \pm 2	Empty stomach
<i>Kogia breviceps</i>	♂	3.1	6 \pm 1	Shrimps : <i>Pasiphea sp.</i> (Pasiphaeidae) <i>Gnathophausia ingens</i> (Mysidacea) <i>Meningodora sp.</i> (Oplophoridae) Cephalopods : <i>Histioteuthis sp.</i> (Histioteuthidae) <i>Enoploteuthis sp.</i> (Enoploteuthidae) 2 unidentified species
	♀	3.0	19 \pm 3	Shrimps : <i>Pasiphea sp.</i> (Pasiphaeidae) <i>Gnathophausia ingens</i> (Mysidacea) <i>Meningodora sp.</i> (Oplophoridae) Cephalopods : <i>Taonius sp.</i> (Cranchidae) Histioteuthidae Enoploteuthidae Octopoteuthidae

Table 3. Age and metal concentrations ($\mu\text{g}\cdot\text{g}^{-1}$ dwt) in the tissues of odontocetes from the New Caledonia.

Tissue	Age	Al	Cd	Co	Cr	Cu	Fe	Total-Hg	Organic-Hg	Mn	Ni	Se	V	Zn
<i>Globicephala macrorhynchus</i> ♂	14 ± 1													
Liver		1.38 ± 0.45	225.3 ± 0.4	< dl	< dl	37.4 ± 0.3	1472 ± 7	1411 ± 24	11.7 ± 0.4	7.1 ± 0.2	< dl	627 ± 43	0.06	135.7 ± 0.6
Muscle		2.62 ± 0.69	0.79 ± 0.03	< dl	< dl	0.8 ± 0.1	347 ± 29	32.8 ± 2.0	4.41 ± 0.09	< dl	< dl	9 ± 1	< dl	61.1 ± 2.4
Blubber		1.53 ± 0.14	0.95 ± 0.03	< dl	2.51 ± 0.01	0.4 ± 0.1	187 ± 8	11.0 ± 0.8	0.47 ± 0.05	0.17 ± 0.01	< dl	4 ± 1	< dl	21.3 ± 0.3
<i>G. macrorhynchus</i> ♀	12 ± 2													
Liver		1.07 ± 0.11	464.4 ± 5.4	0.04	< dl	51.0 ± 1.3	1535 ± 17	1452 ± 79	1.70 ± 0.01	6.8 ± 0.2	< dl	758 ± 39	0.10	113.3 ± 2.1
Muscle		0.88 ± 0.26	1.48 ± 0.03	< dl	< dl	1.5 ± 0.1	622 ± 78	27.3 ± 1.1	3.29 ± 0.06	< dl	< dl	6 ± 1	< dl	49.8 ± 1.4
Blubber		1.15 ± 0.00	0.84 ± 0.01	< dl	0.32 ± 0.08	0.2 ± 0.1	18 ± 2	3.20 ± 0.22	0.21 ± 0.02	< dl	< dl	3 ± 0	< dl	17.3 ± 1.3
<i>Kogia breviceps</i> ♂	6 ± 1													
Liver		2.11 ± 0.29	28.8 ± 0.8	< dl	< dl	8.1 ± 0.1	2503 ± 11	7.86 ± 0.14	1.25 ± 0.12	5.2 ± 0.2	< dl	21 ± 1	0.10	52.3 ± 1.6
Muscle		6.58 ± 0.17	0.41 ± 0.01	< dl	0.03	1.7 ± 0.2	977 ± 18	6.07 ± 0.17	4.65 ± 0.01	0.26 ± 0.01	< dl	6 ± 1	< dl	42.9 ± 0.7
<i>K. breviceps</i> ♀	19 ± 3													
Liver		17.0 ± 0.5	47.5 ± 1.3	0.05	< dl	17.5 ± 0.9	3120 ± 84	77.3 ± 0.7	7.03 ± 0.06	5.0 ± 0.1	< dl	25 ± 1	0.68	54.3 ± 0.8
Muscle		3.60 ± 0.33	0.57 ± 0.04	< dl	< dl	0.9 ± 0.0	820 ± 12	5.16 ± 0.13	3.75 ± 0.11	0.12 ± 0.02	< dl	3 ± 0	< dl	67.1 ± 0.9

dl : detection limit.

wet : dry wt ratio are 4.5, 4.0 and 1.6 for liver, muscle and blubber, respectively.

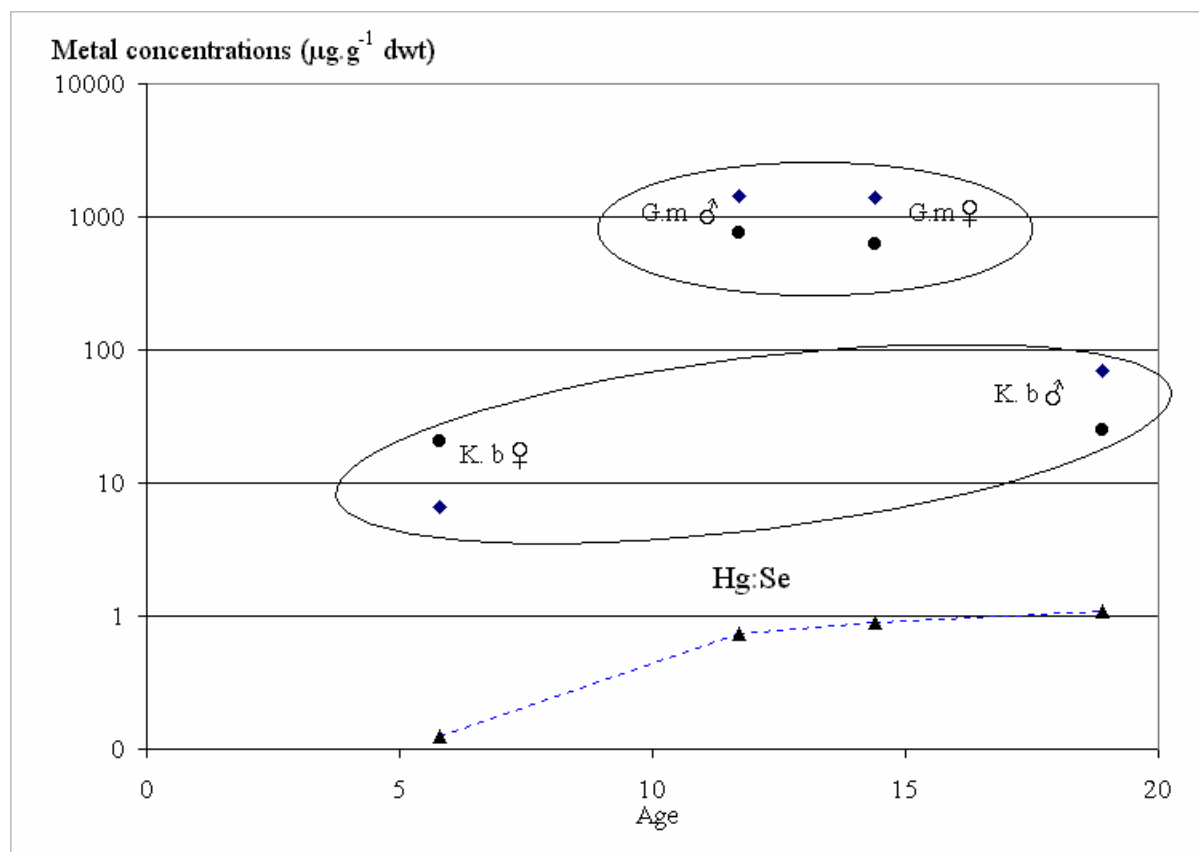


Figure 1. Concentrations of inorganic Hg (◆) and Se (●) together with Se:Hg molar ratio (▲) in *G. macrorhynchus* and *K. breviceps* from New Caledonia.

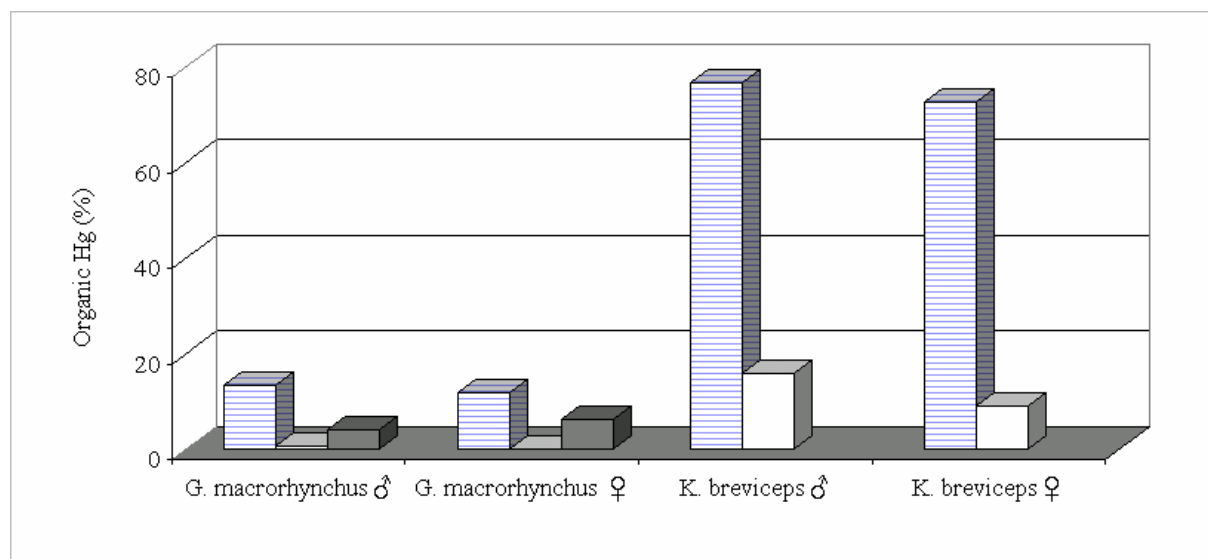


Figure 2. Percentage of organic Hg in the muscle (striped), liver (white) and blubber (grey) of *G. macrorhynchus* and *K. breviceps* from New Caledonia.

Table 4. Heavy metal concentrations ($\mu\text{g}\cdot\text{g}^{-1}$ wwet) in the liver of odontocete species from various areas.

Species	Locality	N	Cd	Co	Cr	Cu	Fe	Total-Hg	Organic-Hg	Mn	Ni	Se	Zn	Authors
<i>Globicephala melas</i>	Northwest Atlantic Ocean	9	7.88 ± 3.61	0.012 ± 0.003	-	2.7 ± 1.0	356 ± 221	40.30 ± 38.81	-	2.53 ± 0.51	-	11.73 ± 9.94	39 ± 7	Mackey et al. 1995
<i>G. melas</i>	Northeast Atlantic Ocean	1	0.1	-	0.25	4.7	2680	0.74	-	-	0.31	2.1	45	Law et al. 2001
<i>Grampus griseus</i>	Mediterranean Sea	1	6.00	-	0.28	-	-	1002	14.70	-	-	266.4	-	Storelli et al. 1999
<i>G. griseus</i>	"	1	8.42	-	0.41	-	-	478.3	7.35	-	-	113.2	-	Storelli et al. 1999
<i>G. griseus</i>	Northeast Atlantic Ocean	1	0.2	-	0.26	5.2	337	2.6	-	-	0.71	4.6	37	Law et al. 2001
<i>Lagenorhynchus acutus</i>	Northwest Atlantic Ocean	4	0.423 ± 0.294	0.013 ± 0.029	-	6.3 ± 2.2	179 ± 100	10.36 ± 10.09	-	3.67 ± 0.53	-	5.31 ± 2.98	41.6 ± 9.9	Mackey et al. 1995
<i>Mesoplodon bidens</i>	Northeast Atlantic Ocean	1	20	-	1.7	19	172	322	-	-	1.0	133	83	Law et al. 2001
<i>M. densirostris</i>	"	1	6.2	-	0.63	5.6	-	248	-	-	0.75	98	41	Law et al. 1997
<i>Phocoena phocoena</i>	Northwest Atlantic Ocean	6	0.444 ± 0.281	0.006 ± 0.003	-	8.9 ± 4.0	388 ± 116	9.86 ± 15.17	-	4.49 ± 0.93	-	2.04 ± 1.19	28 ± 5	Mackey et al. 1995
<i>Stenella coeruleoalba</i>	Mediterranean Sea	6	1.75 ± 1.27	-	0.03 ± 0.02	7.73 ± 2.22	307 ± 93	189.2 ± 28.6	8.82 ± 3.70	3.19 ± 1.48	-	80.3 ± 12.7	24.5 ± 7.3	Cardellicchio et al. 2000
<i>Physeter macrocephalus</i> ^a	North Sea	6	19.1 ± 8.9	-	0.02 ± 0.02	1.7 ± 0.6	458 ± 70	14.5 ± 9.2	0.34 ± 0.16	-	0.12 ± 0.10	3.6 ± 2.6	21 ± 3	Holsbeck et al. 1999
<i>Ziphius cavirostris</i>	Mediterranean Sea	1	18.49	-	0.12	-	-	259.3	9.85	-	-	110.6	-	Storelli et al. 1999

^a: Values recalculated from dry wt.

Table 5. Heavy metal concentrations ($\mu\text{g}\cdot\text{g}^{-1}$ wwet) in the liver of *G. macrorhynchus* and *K. breviceps* from various areas.

Species	Locality	N	Cd	Co	Cr	Cu	Fe	Total-Hg	Organic-Hg	Mn	Ni	Se	Zn	Authors
<i>Globicephala macrorhynchus</i>														
	Australia	5	0.4-22.0	-	-	-	-	-	-	-	-	-	-	Kemper et al. 1994
	Caribbean Sea	5	-	-	-	-	-	88.7 ± 67.9	3.46 ± 0.20	-	-	-	-	Gaskin et al. 1974
	Cumberland Island	4	13.90 ± 3.98	-	-	-	-	231.0 ± 172.1	-	-	-	44.18 ± 19.32	-	Stoneburner 1978
	New Caledonia	2	50.1-102.3	0.01	< dl	8.7-12.7	294-307	313-323	0.38-2.59	1.51-1.57	< dl	146-162	35.3-37.0	Present study
<i>Kogia breviceps</i>														
	Argentina	1	7.6	-	-	10.3	-	11.7	-	-	-	-	163.2	Marcovecchio et al. 1990
	Australia	1	14.3	-	-	-	-	1.52	-	-	-	-	-	Kemper et al. 1994
	England	1	3.2	-	0.57	9.5	1450	14	-	-	0.68	0.18	21	Law et al. 2001
	Florida	-	0.22-7.60	-	0.84-4.13	2.10-144.44	-	-	-	0.80-4.06	-	-	10.09-15.04	Odell & Asper 1976
	New Caledonia	2	6.3-10.8	0.01	< dl	1.9-4.1	501-624	1.7-17.2	0.28-1.56	1.11-1.15	< dl	4.5-5.7	16.9-18.1	Present study
	South Africa	4	-	-	-	-	-	0.9 ± 0.8	-	-	-	-	28.5 ± 13.7	Henry & Best 1999
	South Africa	7	-	-	-	-	-	6.1 ± 5.6	-	-	-	-	21.9 ± 4.7	Henry & Best 1999

