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A note on concentrations of metals in cetaceans from southern Africa

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ABSTRACT

Concentrations of zinc, copper, cadmium, mercury and lead were measured by atomic absorption spectrophotometry in samples of the brain, kidney , liver and muscle tissue from 178 individuals of 323 different cetacean species (4 right whales - *Eubalaena australis*, 2 pygmy right whales - *Caperea marginata*, 3 minke whales - *Balaenoptera acutorostrata*, 3 Bryde's whales - *B. edeni*, 1 humpback whale - *Megaptera novaeangliae*, 1 sperm whale - *Physeter macrocephalus*, 11 pygmy sperm whale - *Kogia breviceps*, 6 dwarf sperm whales - *K. simus*, 1 southern bottlenose whale - *Hyperoodon planifrons*, 1 Cuvier's beaked whale - *Ziphius cavirostris*, 9 Blainville's beaked whales - *Mesoplodon densirostris*, 5 strap-tooth whales - *M. layardii*, *2 True's beaked whales* - *M. mirus*, 3 long-finned pilot whales - *Globicephala melas*, 30 Risso's dolphins - *Grampus griseus*, 12 bottlenose dolphins - *Tursiops truncatus*, 5 striped dolphins - *Stenella coeruleoalba*, 1 pantropical spotted dolphin - *S. attenuata*, 1 hump-backed dolphin - *Sousa chinensis*, 21 dusky dolphins - *Lagenorhynchus obscurus*, 1 hourglass dolphin - *L. cruciger*, 12 Heaviside's dolphins - *Cephalorhynchus heavisidii* and 43 common dolphins - *Delphinus delphis*). All but the hourglass dolphin were strandings or animals taken incidental to fishing operations or under scientific permit in coastal waters of South Africa or Namibia. Highest concentrations of Zn, Cu and Hg were generally found in the liver and of Cd in the kidney. Comparisons of animals pre-and post puberty indicated accumulation of hepatic mercury in the pygmy sperm whale, Risso's dolphin, dusky dolphin and common dolphin. Loss of a metal (zinc) after puberty was only shown in the common dolphin. No individual analyses exceeded proposed (human) tolerance limits for hepatic mercury and hepatic or renal cadmium.

KEYWORDS: SOUTH AFRICA; POLLUTION; METALS; RIGHT WHALE; PYGMY RIGHT WHALE; MINKE WHALE; BRYDE'S WHALE; HUMPBACK WHALE; SPERM WHALE; PYGMY SPERM WHALE; DWARF SPERM WHALE; SOUTHERN BOTTLENOSE WHALE; CUVIER'S BEAKED WHALE; BLAINVILLE'S BEAKED WHALE ; STRAP-TOOTHED WHALE; TRUE'S BEAKED WHALE; LONG-FINNED PILOT WHALE; RISSO'S DOLPHIN; BOTTLENOSE DOLPHIN; STRIPED DOLPHIN; SPOTTED DOLPHIN; HUMPBACK DOLPHIN; DUSKY DOLPHIN; HOURGLASS DOLPHIN; HEAVISIDE'S DOLPHIN; COMMON DOLPHIN.

INTRODUCTION

This note stems from a general survey of the incidence of metals in marine organisms in South African waters carried out between 1982 and 1990. Cetaceans were considered especially interesting because of their position at the top of the food chain and the consequent expectation that contaminant levels might be relatively high. However, legal and logistical constraints meant that access to material was mainly opportunistic depending on the natural

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occurrence of strandings and the accidental entanglements of individuals in fishing gear. As a consequence, sample sizes vary greatly among species, and for no one species were sufficient individuals analysed for a detailed examination of the effects of sex, age and locality on contaminant levels (Aguilar *et al.*, 1999). Nevertheless, this represents the first such survey for cetaceans in the sub-region, and has value as a baseline study against which future developments might be measured.

Five metals have been analysed in this paper; zinc, copper, cadmium, mercury and lead. The first two are usually classified as essential metals and the remainder as non-essential metals (Bowles, 1999).

MATERIALS AND METALS

Samples for metal analysis were taken from 178 cetaceans of 23 species (Table 1 and Appendix Table 1). All but three animals were obtained between 1982 and 1990. Of the specimens, 127 were stranded on the coastline, 24 entangled in fishing gear and 5 collected at sea under special permit in the waters of South Africa or Namibia. An hourglass dolphin specimen was also collected at sea under special permit in the southwestern Atlantic, and one common dolphin was found unlabelled in the freezer.

Most samples of brain tissue ($n = 170$) were taken through the foramen magnum, and so probably consisted of cerebellum. Muscle tissue ($n = 173$) was removed from the core of one of the dorsal muscle fillets, liver tissue ($n = 167$) from the apex of one of the lobes and kidney tissue ($n = 166$) from the centre of one of the kidneys. All samples were placed in acid-washed polystyrene containers and kept frozen at −20°C until analysis.

Individual cetaceans were assigned into relative age categories, as follows:

(1) calf - still suckling;
(2) juvenile - weaned but sexually immature;
(3) sub-adult - sexually mature but physically immature;
(4) adult - both sexually and physically mature.

Criteria for sexual maturity (and thus immaturity) in females included the presence of an active lactating mammary gland, a corpus luteum or corpus albicans in the ovaries or a foetus. Sexual maturity in males was determined from the size of the testes. An individual was judged physically mature if the epiphyses of the fourth or fifth anterior thoracic vertebrae were fused to their centra: otherwise they were adjudged to be physically immature.

In total, 21 calves, 67 juveniles, 55 sub-adults and 35 adults were sampled. To increase the sample size for analyses of trend in metal concentration with age, calves and juveniles have been combined as 'immature' and sub-adults and adults as 'mature'.

Analyses of metal concentrations were carried out by atomic adsorption spectrophotometry. For the analysis of copper, zinc, cadmium and lead, 2g wet weight of tissue were added to 25ml of concentrated nitric acid and allowed to stand overnight. The resulting digest was gently evaporated almost to dryness. A further 25ml of a 4:1 mixture of concentrated nitric acid and perchloric acids was added to the residue of the first digestion and again slowly evaporated almost to dryness. The final residue was dissolved in 10% nitric acid. This solution was aspirated into a *Varian Spectra* 10 atomic absorption spectrophotometer (AAS) which was set up for each metal according to the instrument manufacturer's recommendations.

The analytical method used for mercury was that of Evans *et al.* (1986) in which wet tissue was treated with concentrated nitric acid and allowed to stand overnight. The acid was then slowly heated to a temperature of 125°C over a period of three hours and then reflexed for

Table 1

Summary of cetaceans from southern Africa sampled for metal analysis.
Key: F = female, M = male, ? = unknown; I = incidental catch, P = special permit catch, S = stranding, C = calf, J = juvenile, SA = subadult, A = adult.

Common name	Latin name	Sample				Origin				Age category				Weight		Length	
		F	M	?	Total	I	P	S	?	C	J	SA	A	Yes	No	Yes	No
Southern right whale	*Eubalaena glacialis*	2	2	0	4	0	0	4	0	4	0	0	0	1	3	4	0
Pygmy right whale	*Caperea marginata*	1	1	0	2	0	0	2	0	0	1	0	1	2	0	2	0
Minke whale	*B. acutorostrata*	2	1	0	3	0	0	3	0	1	1	1	0	1	2	3	0
Bryde's whale	*B. edeni*	1	2	0	3	0	0	3	0	1	2	0	0	1	2	3	0
Humpback whale	*Megaptera novaeangliae*	1	0	0	1	0	0	1	0	1	0	0	0	0	1	1	0
Sperm whale	*Physeter macrocephalus*	0	1	0	1	0	0	1	0	0	0	0	1	0	1	1	0
Pygmy sperm whale	*Kogia breviceps*	7	4	0	11	0	0	11	0	2	2	2	5	9	2	11	0
Dwarf sperm whale	*Kogia simus*	3	3	0	6	0	0	6	0	0	2	3	1	5	1	6	0
Southern bottlenose whale	*Hyperoodon planifrons*	1	0	0	1	0	0	1	0	0	0	1	0	0	1	1	0
Cuvier's beaked whale	*Ziphius cavirostris*	1	0	0	1	0	0	1	0	0	1	0	0	0	1	1	0
Blainville's beaked whale	*Mesoplodon densirostris*	5	4	0	9	0	0	9	0	1	1	0	7	4	5	9	0
Strap-toothed whale	*Mesoplodon layardii*	4	1	0	5	0	0	5	0	1	0	0	4	4	1	5	0
True's beaked whale	*Mesoplodon mirus*	1	0	1	2	0	0	2	0	0	2	0	0	1	1	2	0
Long-finned pilot whale	*Globicephala melas*	2	1	0	3	0	0	3	0	0	1	1	1	1	2	3	0
Risso's dolphin	*Grampus griseus*	14	16	0	30	0	0	30	0	3	6	19	2	21	9	30	0
Bottlenose dolphin	*Tursiops truncatus*	4	8	0	12	0	0	12	0	4	3	2	3	10	2	11	1
Striped dolphin	*Stenella coeruleoalba*	2	3	0	5	0	0	5	0	0	2	2	1	5	0	5	0
Pantropical spotted dolphin	*Stenella attenuata*	1	0	0	1	0	0	1	0	0	0	1	0	1	0	1	0
Hump-backed dolphin	*Sousa chinensis*	1	0	0	1	0	0	1	0	0	0	0	1	1	0	1	0
Dusky dolphin	*Lagenorhynchus obscurus*	14	7	0	21	13	2	6	0	2	10	7	2	20	1	20	1
Hourglass dolphin	*Lagenorhynchus cruciger*	1	0	0	1	0	1	0	0	0	1	0	0	1	0	1	0
Heaviside's dolphin	*Cephalorhynchus heavisidii*	4	7	1	12	2	7	3	0	1	4	5	2	11	1	11	1
Common dolphin	*Delphinus delphis*	21	22	0	43	9	16	17	1	1	27	11	4	43	0	43	0

a further four hours. The final digest was diluted with water and analysed using a *Varian* vapour generation accessory (VGA-76) linked to the *Varian Spectra* 10 AAS and fed by a *Varian* PSC-55 sample changer. The reducing agent, 25% w/v stannous chloride in 20% w/v hydrochloric acid was added at a rate and under conditions only slightly modified from those recommended by Evans *et al.* (1986). The limit quantification LOQ, defined in Zak *et al.* (1983) as the concentration above which quantitative results can be obtained with a specified confidence, in this case ±30% in the measured value at 99% confidence level, was calculated for copper as 0.1μg/g, zinc as 0.05μg/g, cadmium as 0.2μg/g, lead as 0.4μg/g, and mercury as 0.1μg/g.

All metal concentrations quoted are in μg/g wet mass. Figures following ± (and all error bars on the Figures) refer to one standard deviation of the mean.

A total of 2,354 analyses was carried out, 491 of brain, 655 of kidney, 644 of liver and 564 of muscle tissue (Table 2). Analyses for zinc, copper and mercury were similar in number (534, 656 and 577 respectively), whereas fewer analyses were completed for cadmium (355) and lead (132). Three lead analyses from brain tissue have been excluded from the results presented because they originated from animals killed by a gunshot to the head: lead concentrations recorded for these individuals (25.9, 95.2 and 164μg/g) were 7-46 times higher than the next highest concentration recorded for the brain.

Table 2

Numbers of analyses of each heavy metal carried out for each tissue, in cetaceans from southern Africa.

	Metal					
Tissue	Zinc	Copper	Cadmium	Mercury	Lead	Total
Brain	131	165	34	130	31	491
Kidney	163	164	142	147	39	655
Liver	168	165	134	151	26	644
Muscle	172	162	45	149	36	564
Total	634	656	355	577	132	2,354

RESULTS

Distribution between tissues

Given the high individual variability in contaminant levels, only individuals in which all four tissues were analysed have been examined in order to determine the relative contaminant loads between tissues. The results for zinc, copper, cadmium and mercury are shown in Table 3.

The highest concentrations of zinc were found in the liver of 84.9% of the individuals for which all four tissues were examined. Some 13% had their highest concentration in the kidney, and very few (0.6 and 1.5% respectively) in the brain or muscle.

The liver was also the site of the highest concentrations of copper in most (85.7%) individuals, followed by the kidney (8.2%) and the brain (6.1%). The two *Kogia* species formed an exception, in that the highest copper concentration most frequently occurred in the brain (53.8%), followed by the liver (46.2%).

Cadmium levels were highest in the kidney of 73.9% of individuals, followed by the liver (21.7%) and muscle (4.4%).

Mercury levels were highest in the liver of 85% of individuals, with relatively few animals (3.5, 4.2 and 6.7% respectively) having their highest levels in the kidney, brain or muscle.

Table 3

Frequency with which the highest concentrations of heavy metals were found in the brain, kidney, liver or muscle of cetaceans off southern Africa.

Tissue	Zinc	%	Copper	%	Cadmium	%	Mercury	%
Brain	1.0	0.6	9.0	6.1	0.0	0.0	5.25	4.8
Kidney	21.0	13.0	12.0	8.2	17.0	73.9	3.75	3.5
Liver	137.5	84.9	126.0	85.7	5.0	21.7	91.75	85.0
Muscle	2.5	1.5	0.0	0.0	1.0	4.4	7.25	6.7
Total	162.0		147.0		23.0		108.0	

Owing to the relatively few lead analyses carried out it is not possible to present a similar analysis for this metal. The average lead concentrations recorded for each tissue, however, varied little, from 1.07 ± 0.75µg/g in brain to 1.37 ± 0.79µg/g in liver, 2.05 ± 3.10 in kidney and 2.42 ± 3.56µg/g in muscle.

Relationship between metal concentration and maturity status

There were only six species (all odontocetes) for which a sufficient number of samples had been analysed to investigate possible changes in metal concentration with the age of the individual. These were the pygmy sperm whale and the Risso's, bottlenose, dusky, Heaviside's and common dolphins. Even in these cases, the number of individuals sampled (11-40) was only sufficient for an examination on a gross scale, i.e. between immature (calves plus juveniles) and mature (sub-adults plus adults) animals of both sexes combined, and only for four metals (zinc, copper, cadmium and mercury). Comparisons were confined to those tissues in which the highest concentrations of each metal were usually found, i.e. the liver for zinc, copper and mercury and the kidney for cadmium (Table 4).

Mean values were compared using a two-tailed Mann-Whitney U test. Significantly higher hepatic values of mercury in mature individuals were found for the pygmy sperm whale and the Risso's, dusky and common dolphins. Significantly higher renal values of

Table 4

Comparison of concentrations of hepatic zinc, copper, mercury and renal cadmium in immature and mature individuals of six cetaceans in southern African waters. All concentrations are expressed in µg/g wet weight.

		Hepatic zinc		Hepatic copper		Renal cadmium		Hepatic mercury	
Species	Maturity	No.	Mean ±SD	No.	Mean ± SD	No.	Mean ± SD	No.	Mean ± SD
Pygmy sperm whale	Immature	4	28.5 ± 13.7	4	18.3 ± 21.9	3	2.4 ± 1.2	3	0.9 ± 0.8
	Mature	7	21.9 ± 4.7	7	3.0 ± 1.2	7	15.1 ± 10.7	6	6.1 ± 5.6[1]
Risso's dolphin	Immature	9	34.6 ± 40.9	9	4.2 ± 1.7	6	9.2 ± 1.9	8	2.3 ± 4.6
	Mature	20	28.1 ± 13.0	20	5.7 ± 2.7	20	24.1 ± 16.1[2]	20	45.6 ± 32.2[3]
Bottlenose dolphin	Immature	7	49.7 ± 23.2	7	19.4 ± 16.2	4	7.8 ± 7.0	7	2.5 ± 3.4
	Mature	5	39.9 ± 21.1	5	5.4 ± 1.4	5	9.1 ± 4.8	4	71.0 ± 104.3
Dusky dolphin	Immature	12	18.1 ± 8.1	12	5.1 ± 3.5	10	3.5 ± 1.8	12	1.3 ± 1.1
	Mature	8	34.4 ± 23.0	8	6.5 ± 4.1	8	8.3 ± 5.0[2]	8	7.7 ± 9.2[1]
Heaviside's dolphin	Immature	5	43.0 ± 23.3	5	9.7 ± 2.4	4	8.4 ± 8.3	4	0.6 ± 0.4
	Mature	7	45.9 ± 18.1	7	11.4 ± 4.2	7	11.0 ± 7.3	6	6.2 ± 9.7
Common dolphin	Immature	26	40.2 ± 19.7	26	7.5 ± 3.8	23	4.0 ± 3.3	25	5.3 ± 5.5
	Mature	14	26.8 ± 10.1[1]	14	6.0 ± 2.4	13	8.6 ± 5.3[3]	13	22.0 ± 16.2[3]

[1]Significant at 5% level. [2]Significant at 2% level. [3]Significant at 1% level (or less).

cadmium were found in mature Risso's, dusky and common dolphin individuals. The only significant reduction in the concentration of a metal with age occurred in the common dolphin where hepatic zinc levels were lower in mature animals.

Inter-specific variation in metal concentrations

Appendix Figs 1 - 5 (hereafter simply referred to as 'Figs 1 - 5') show the mean concentrations recorded for each metal for each tissue for each age category of each species. Comparisons between species are complicated by the small sample sizes, high individual variability and correlation with age (at least in some species and metals).

For the five species where three or more adults were examined, hepatic zinc levels averaged between about 20 and 50μg/g (Table 5), with renal levels equivalent or only slightly less. Inspection of Fig. 1 fails to suggest any consistent trend in concentration with age between species. Although there are indications of a trend for some species (minke whale, dwarf sperm whale, striped dolphin and dusky dolphin) sample sizes precluded statistical analysis apart from the significant link reported for the common dolphin in Table 4. Few adult baleen whales were examined. High zinc concentrations were recorded in the liver of right (88.1 ± 47.7μg/g) and Bryde's (87.0μg/g) whale calves and in an adult pygmy right whale (191μg/g).

Table 5

Concentrations of four metals for cases where samples for three or more physically mature specimens were analysed. Concentrations are expressed in μg/g wet mass. Figures following ± refer to one standard deviation of the mean.

Species	Hepatic Zn	Hepatic Cu	Hepatic Hg	Renal Cd
Dwarf sperm whale	22.6 ± 5.4	2.8 ± 1.3	7.2 ± 5.6	20.82 ± 8.4
Blainville's beaked whale	22.7 ± 7.5	5.0 ± 2.0	46.9 ± 26.2	32.3 ± 17.8
Strap-toothed whale	49.7 ± 20.2	8.7 ± 1.7	93.8 ± 57.1	76.9 ± 39.1
Bottlenose dolphin	39.0 ± 20.5	4.6 ± 0.4		11.0 ± 5.2
Common dolphin	19.3 ± 5.1	3.9 ± 0.9	34.4 ± 15.0	7.6 ± 2.3

Concentrations of copper in the liver of adults of the same five odontocetes averaged between about 3 and 9μg/g (Table 5). Inspection of Fig. 2 also fails to suggest any consistent age related change in concentration levels between species. As for zinc, high hepatic copper concentrations were recorded in right (169.5 ± 104.3) and Bryde's (118.0) whale calves and in an adult pygmy right whale (100μg/g).

Concentrations of cadmium in the kidneys of adults of the same species were highly variable (from around 7 to 77 μg/g) as shown in Table 5. A general tendency for concentrations to increase with age is apparent from Fig. 3 (and was demonstrated statistically for three species as shown in Table 4). Renal cadmium values for baleen whale calves and juveniles were low (0.15 – 0.5 μg/g). The value for the adult pygmy right whale however was 46.8 μg/g, similar to some of the odontocetes.

Inspection of Fig. 4 shows a clear indication for mercury concentrations in the liver to increase with age in several species, and such an increase has been statistically demonstrated in Table 4 for four species. In the four species for which there were analyses from three or more adults, average mercury concentrations were highly variable (from around 7 to 94 μg/g) as shown in Table 5. All the baleen whales examined had very low hepatic mercury levels (< 1μg/g), although only one adult (a pygmy right whale) was examined.

The data for lead concentrations are so few and so dispersed among species and ages (Fig. 5) that it is difficult to draw any meaningful conclusions. Values are generally low, less than 5μg/g across all species and tissues, with the highest concentration being 17.6μg/g in the kidney of a sub-adult pygmy sperm whale.

DISCUSSION

For the metals examined here, the site specificity recorded agrees largely with previous findings for cetaceans. In a review of the literature, Bowles (1999) lists the liver as the tissue most commonly containing the highest concentrations of mercury (12/12 species) and the liver (or kidney) as containing the highest concentrations of copper (10/10 species). The kidney (or kidney and liver) was the tissue most commonly containing the highest concentration of cadmium (12/12 species). Excluding skin and bone (which were not sampled in this study), highest concentrations of zinc were found in the liver (6/10 species) or kidney (2/10 species) or both (1/10 species); the tenth species had its highest concentration in the muscle. Site specificity for lead was not often determined (in general, lead concentrations are highest in bone which was not examined in this study). The present results extend Bowles' listing by several species, including the dwarf sperm whale, Blainville's beaked whale, strap-toothed whale, Risso's dolphin, dusky dolphin, Heaviside's dolphin and common dolphin.

Relationships between maturity status and the concentrations of zinc, copper, cadmium and mercury in the liver/kidney recorded in this paper for pygmy sperm whales, Risso's dolphins, bottlenose dolphins, dusky dolphins, Heaviside's dolphins and common dolphins generally agreed with trends found with age in other or the same species. For most essential metals there is no clear age relationship (Bowles, 1999), and the only trend found here was for hepatic zinc concentrations to decline after maturity in common dolphins. High concentrations of zinc relative to those in adults have been found in the livers of neonatal harbour porpoises (Law *et al.*, 1992; Paludan-Muller *et al.*, 1993), and in striped dolphins hepatic zinc concentrations increased during gestation and lactation but declined after weaning (Honda and Tatsukawa, 1983). These trends are not inconsistent with the pre-/post-maturity contrast seen here in common dolphins. Elevated hepatic copper levels in neonates, as evident here for right whales and Bryde's whales, have been previously recorded in several cetacean species (Bowles, 1999). Of the non-essential metals, a strong correlation with age has been demonstrated for mercury in at least eight different cetacean species; harbour porpoises, *Globicephala* spp., striped dolphins, white-beaked dolphins, narwhals, white whales, fin whales and minke whales (Bowles, 1999). To these can now be added pygmy sperm whales, Risso's dolphins, dusky dolphins and Heaviside's dolphins. Hepatic levels of cadmium showed increases with age in at least some post-natal stages of striped dolphins, *Globicephala* spp., narwhals, white whales and harbour porpoises (Bowles, 1999). The significant increases in renal cadmium levels with maturity in Risso's dolphins, dusky dolphins and Common dolphins demonstrated here are consistent with this trend.

Comparisons of the levels of metals found in cetaceans off southern Africa with those elsewhere is complicated by possible inter-specific differences in bioaccumulation rates, differing ages (and sexes) of animals in the samples, and inconsistent analytical techniques (Aguilar *et al.*, 1999). Furthermore, the high individual variability in concentration levels of non-essential metals means that adequate sample sizes must be available for a valid statistical comparison. Bowles (1999) considers that mercury is the only metal which can be readily compared between regions as it accumulates throughout life and has been widely researched. Of the seven species for which he tables values for hepatic mercury from a number of geographical regions (striped dolphins, spotted dolphins, *Globicephala* spp., narwhals, white whales, harbour porpoises, bottlenose dolphins and white-beaked dolphins), only the bottlenose dolphin is common to the list of species for which an adequate number of adult specimens was analysed in this paper (Table 4). Unfortunately the data for this species tabled by Bowles come from a single specimen, so that a comparison is hardly meaningful. Kemper *et al.* (1994) give a range of values of 0.14-10.18 μg/g for hepatic mercury in nine bottlenose dolphins from Australian waters; four out of twelve values for hepatic mercury from southern African bottlenose dolphins exceeded this range. However, no associated ages are available for the Australian animals, so the significance of this apparent difference cannot be determined.

Although the physiological effects of the metal concentrations found were not part of the investigation, it is interesting to compare the levels recorded with proposed tolerance limits for the metals. Before doing so however, it should be noted that tolerance limits are usually based on information from a range of species and extrapolation from one species to another requires considerable caution. Wagemann and Muir (1984) suggested a range of 100-400μg/g for hepatic mercury[1], whilst Law (in Bowles, 1999), in the context of humans, proposed a range of 200-400μg/g for renal cadmium and 40-200μg/g for hepatic cadmium, as tolerance limits above which toxic effects could occur. Levels of hepatic mercury within (but not exceeding) Wagemann and Muir's tolerance limits only occurred in two out of 151 individuals analysed here, a sub-adult bottlenose dolphins (251.2μg/g) and an adult strap-toothed whales (171.0μg/g). There were no individuals (amongst 142 analysed) with renal cadmium levels that equalled or exceeded Law's proposed tolerance limits. There were six out of 134 cetaceans analysed, however, with hepatic cadmium levels that fell within (but did not exceed) Law's tolerance limits: two adults strap-toothed whales (49.5 and 78.4μg/g), a juvenile hourglass dolphin (41.2μg/g) and three sub-adult Risso's dolphins (46.7, 59.9 and 72.3μg/g). Considering the nature of the sample (dominated by stranded individuals, in which debilitated animals might be expected to feature strongly), the absence of individuals with mercury or cadmium levels exceeding the proposed tolerance ranges suggests that contamination of cetaceans with these metals is not as yet a serious problem in the region noting however, the problems associated from extrapolating from one species to another.

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[1] The toxic form of mercury is methylmercury. This was not analysed in this study and this should be borne in mind in any consideration of tolerance limits.

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[*Appendix Table 1 and Figs 1 - 5 begin overleaf*]

Appendix

Appendix Table 1

Details of cetaceans from southern Africa sampled for heavy metal analysis. Key: C = calf, J = juvenile, SA = subadult, A = adult; S = stranding, I = incidental catch, P = special permit catch.

Field no.	Length(cm)	Sex	Weight(kg)	Age	Origin	Date	Location	
Southern right whale								
86/29	460	F	-	C	S	20 Aug. 1986	34°33'S	19°21'E
86/32	485	M	-	C	S	2 Sep. 1986	34°33'S	20°25'E
89/23	463	M	-	C	S	31 Jul. 1989	33°38'S	18°23'E
90/29	480	F	1,146	C	S	14 Aug. 1990	34°24'S	19°16'E
Pygmy right whale								
82/11	596	M	2,716	A	S	25 May 1982	34°19'S	18°28'E
89/03	332	F	408	J	S	17 Feb. 1989	22°50'S	14°31'E
Minke whale								
83/17	666	M	4,310	SA	S	30 Mar. 1983	32°43'S	17°59'E
84/34	333	F	-	C	S	20 Nov. 1984	33°54'S	18°26'E
89/01	429	F	-	J	S	3 Jan. 1989	33°58'S	18°22'E
Bryde's whale								
84/20	409	F	514	C	S	10 Jul. 1984	34°46'S	19°52'E
84/28	616	M	-	J	S	9 Nov. 1984	32°44'S	18°01'E
88/04	804	M	-	J	S	15 Feb. 1988	34°46'S	19°42'E
Humpback whale								
90/40	615	F	-	C	S	14 Dec. 1990	33°09'S	17°59'E
Sperm whale								
86/19	1605	M	-	A	S	13 May 1986	34°08'S	18°20'E
Pygmy sperm whale								
82/04	288	F	344	A	S	6 Feb. 1982	32°52'S	17°53'E
82/20	299	F	329	A	S	26 Sep. 1982	34°23'S	20°51'E
82/21	215	M	161	J	S	26 Sep. 1982	34°23'S	20°51'E
83/20	301	F	350	A	S	6 May 1983	34°23'S	20°51'E
83/21	191	M	127	C	S	6 May 1983	34°23'S	20°51'E
83/27	147	M	68	C	S	11 Jun. 1983	34°22'S	18°52'E
83/33	256	F	272	J	S	23 Sep. 1983	34°25'S	19°15'E
84/24	301	F	-	A	S	10 Aug. 1984	34°21'S	19°03'E
84/26	238	F	-	SA	S	4 Sep. 1984	22°50S	14°31'E
86/17	321	F	480	A	S	11 Apr. 1986	34°30'S	20°28'E
86/22	218	M	186	SA	S	23 May 1986	33°27'S	18°16'E
Dwarf sperm whale								
84/36	178	M	110	J	S	26 Nov. 1984	34°06'S	18°28'E
84/35	230	M	200	SA	S	26 Nov. 1984	34°06'S	18°28'S
85/02	251	F	-	A	S	8 Mar. 1985	34°30'S	20°28'E
88/02	226	F	178	SA	S	27 Jan. 1988	34°31'S	20°27'E
88/20	231	F	173	J	S	14 Jul. 1988	34°37'S	19°24'E
90/34	238	M	191	SA	S	16 Oct. 1990	32°47'S	18°04'E
Southern bottlenose whale								
90/02	655	F	-	SA	S	10 Jan. 1990	32°46'S	18°08'E
Cuvier's beaked whale								
89/21	557	F	-	J	S	17 Jul. 1989	33°38'S	18°23'E

continued

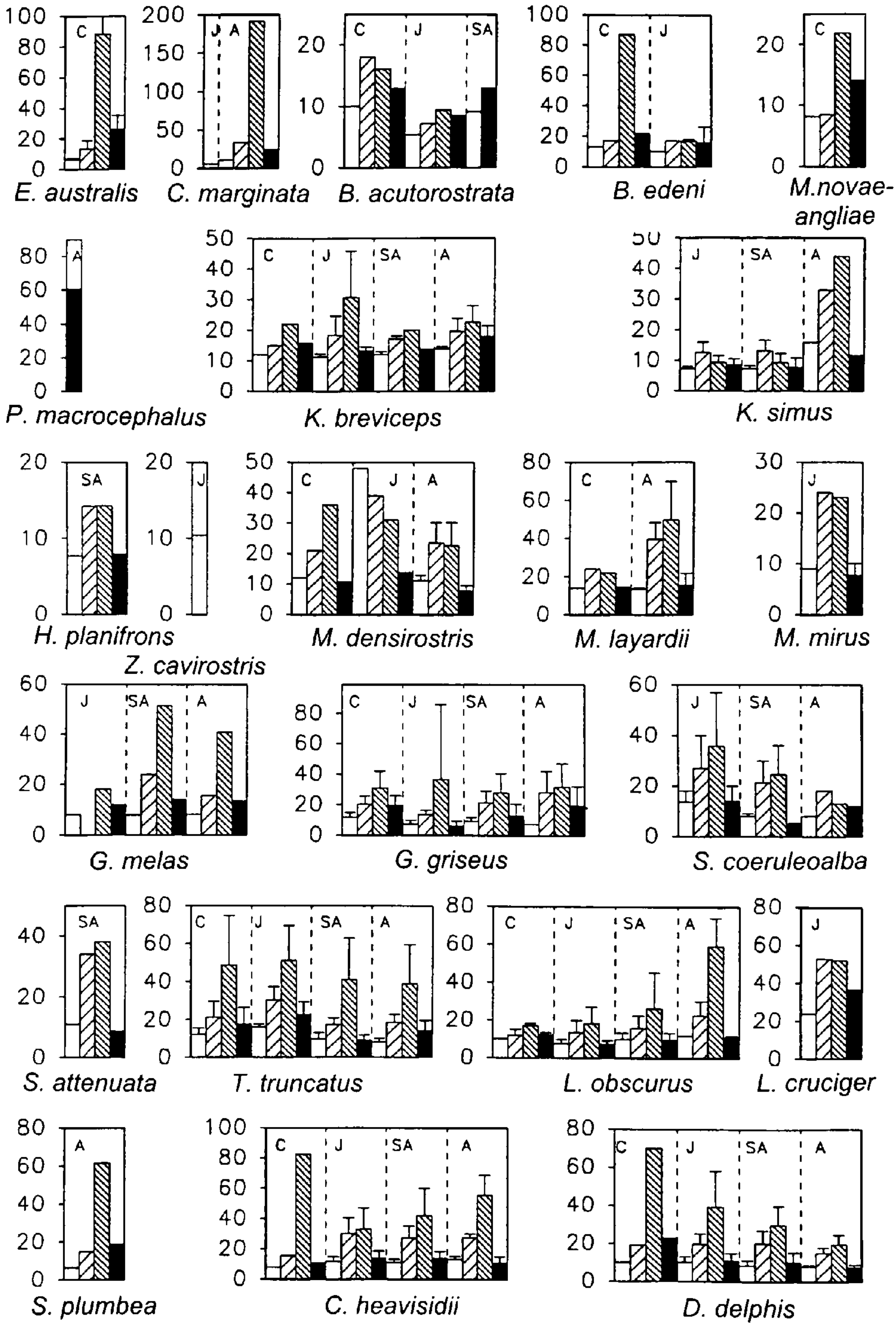
Field no.	Length(cm)	Sex	Weight(kg)	Age	Origin	Date	Location	
Blainville's beaked whale								
84/11	346	F	460	J	S	12 Mar. 1984	34°06S	18°28'E
84/12	454	F	986	A	S	15 Mar. 1984	34°50'S	20°00'E
84/15	225	M	159	C	S	30 Apr. 1984	34°49'S	19°57'E
84/16	454	F	-	A	S	30 Apr. 1984	34°49'S	19°57'E
84/23	425	F	-	A	S	31 Jul. 1984	34°28'S	20°32'E
86/23	376	M	624	A	S	7 Jun. 1986	34°46'S	19°52'E
88/09	436	M	-	A	S	5 Apr. 1988	34°46'S	19°42'E
88/25	413	M	-	A	S	18 Oct. 1988	34°46'S	18°03'E
88/27	401	F	-	A	S	25 Nov. 1988	34°46'S	18°03'E
Strap-toothed whale								
82/09	562	F	690	A	S	6 Apr. 1982	32°43'S	17°59'E
82/10	318	F	415	C	S	6 Apr. 1982	32°43'S	17°59'E
83/14	553	F	1,568	A	S	20 Mar. 1983	32°42'S	18°14'E
83/16	526	F	1,618	A	S	30 Mar. 1983	32°45'S	18°01'E
85/10	500	M	-	A	S	15 Apr. 1985	32°43'S	17°58'E
True's beaked whale								
86/30	318	F	351	J	S	22 Aug. 1986	32°33'S	18°19'E
86/38	417	-	-	J	S	2 Nov. 1986	33°47'S	18°22'E
Long-finned pilot whale								
83/44	381	M	520	J	S	19 Dec. 1983	33°24'S	20°52'E
90/25	371	F	-	SA	S	2 Jun. 1990	33°21'S	18°09'E
90/26	410	F	-	A	S	6 Jun. 1990	34°28'S	19°21'E
Risso's dolphin								
82/18	302	F	325	A	S	24 Aug. 1982	32°43'S	17°56'E
83/15	303	F	350	SA	S	23 Mar. 1983	33°48'S	18°28'E
83/18	152	F	32	C	S	30 Mar. 1983	34°07'S	22°08'E
83/25/1	297	F	327	SA	S	27 May 1983	34°19'S	18°28'E
83/25/2	341	M	486	SA	S	27 May 1983	34°19'S	18°28'E
83/25/3	315	M	404	SA	S	27 May 1983	34°19'S	18°28'E
83/25/4	331	M	450	SA	S	27 May 1983	34°19'S	18°28'E
83/25/5	327	M	468	SA	S	27 May 1983	34°19'S	18°28'E
83/25/6	292	F	292	SA	S	27 May 1983	34°19'S	18°28'E
83/25/7	301	F	345	SA	S	27 May 1983	34°19'S	18°28'E
83/25/8	284	F	304	SA	S	27 May 1983	34°19'S	18°28'E
83/30	188	M	67	C	S	18 Jun. 1983	34°01'S	18°20'E
83/34	225	M	125	J	S	4 Oct. 1983	34°12'S	18°27'E
84/25	314	M	350	SA	S	31 Aug. 1984	34°12'S	18°27'E
88/11	317	M	375	SA	S	17 Jun. 1988	34°22'S	19°51'E
88/12	290	F	313	SA	S	17 Jun. 1988	34°22'S	19°51'E
88/13	315	M	422	SA	S	17 Jun. 1988	34°22'S	19°51'E
89/05	165	F	46	C	S	21 Feb. 1989	34°16'S	18°23'E
89/11/1	304	F	-	SA	S	5 Apr. 1989	32°46'S	17°59'E
89/11/2	266	M	-	J	S	5 Apr. 1989	32°46'S	17°59'E
89/11/3	336	M	-	A	S	5 Apr. 1989	32°46'S	17°59'E
89/11/4	276	M	-	J	S	5 Apr. 1989	32°46'S	17°59'E
89/11/5	270	F	-	J	S	5 Apr. 1989	32°46'S	17°59'E
89/11/6	286	M	-	J	S	5 Apr. 1989	32°46'S	17°59'E
89/11/8	306	M	-	SA	S	5 Apr. 1989	32°46'S	17°59'E
89/11/9	282	F	-	SA	S	5 Apr. 1989	32°46'S	17°59'E
89/20	294	F	-	SA	S	17 Jun. 1989	34°18'S	18°28'E
89/22	281	F	324	SA	S	17 Jul. 1989	34°12'S	18°27'E
89/35	226	M	96	J	S	23 Feb. 1989	34°22'S	20°52'E
90/27	305	M	318	SA	S	3 Apr. 1990	34°50'S	20°01'E

continued

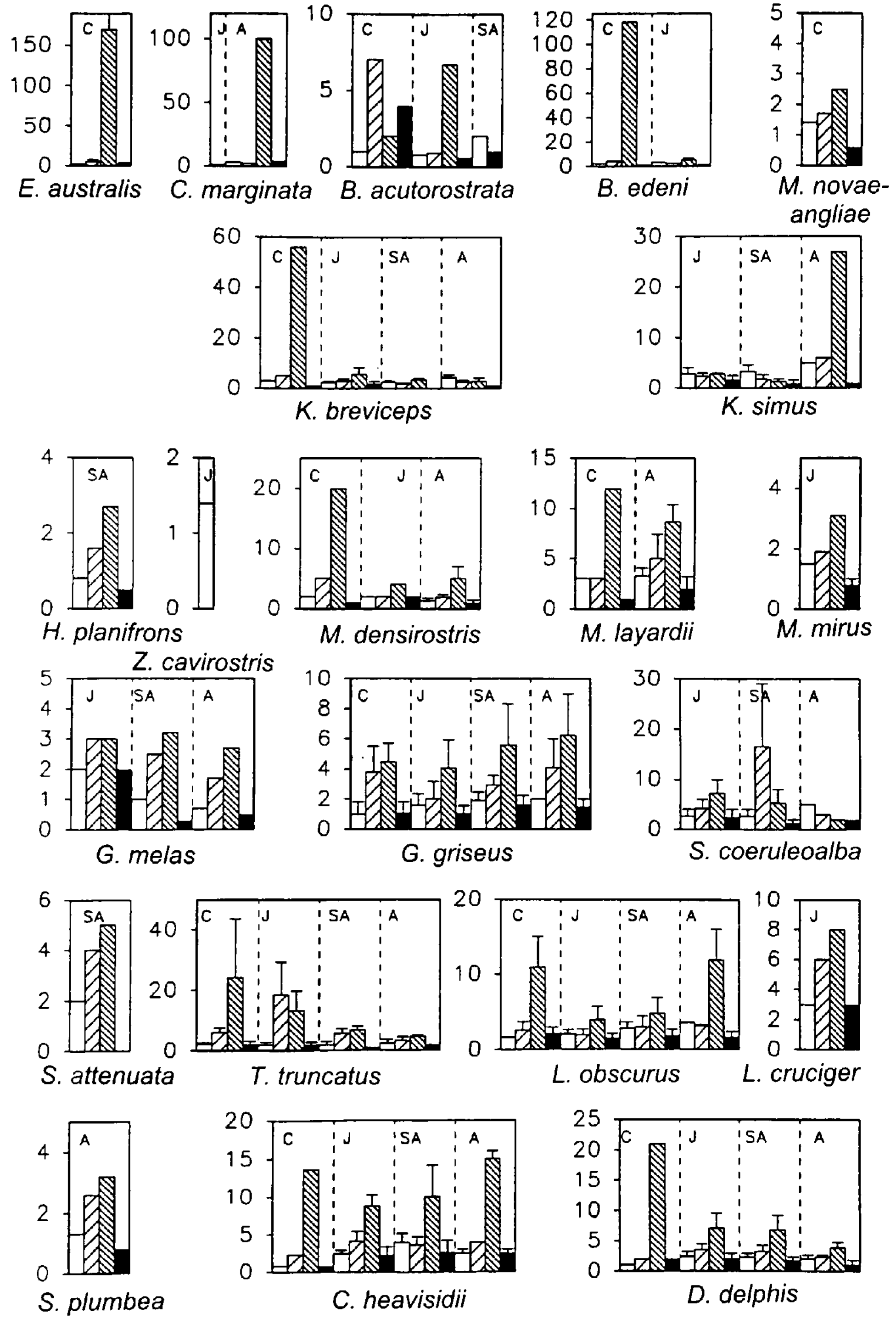
Field no.	Length(cm)	Sex	Weight(kg)	Age	Origin	Date	Location	
Bottlenose dolphin								
80/25	266	M	260	J	S	17 Oct. 1980	22°50'S	14°31'E
82/12	275	M	169	A	S	15 Jun. 1982	33°25'S	19°08'E
83/45	293	M	265	SA	S	21 Dec. 1983	34°29'S	19°21'E
89/08	259	M	166	SA	S	28 Dec. 1988	34°22'S	20°52'E
89/17	293	F	204	A	S	3 Jun. 1989	34°22'S	18°50'E
89/18	218	F	-	C	S	3 Jun. 1989	34°22'S	18°50'E
83/28/1	281	F	304	A	S	14 Jun. 1983	32°43'S	17°56'E
83/28/2	220	F	125	C	S	14 Jun. 1983	32°43'S	17°56'E
83/29	227	M	130	J	S	15 Jun. 1983	34°11'S	22°09'E
84/13	135	M	26	C	S	14 Mar. 1984	22°13'S	14°19'E
85/14	172	M	60	J	S	24 May 1985	34°08'S	18°20'E
85/19	-	M	-	C	S	12 Dec. 1985	34°13'S	22°02'E
Striped dolphin								
82/14	195	M	62	J	S	7 Jul. 1982	34°22'S	21°26'E
83/42	215	F	96	SA	S	6 Dec. 1983	34°09'S	18°51'E
84/31	230	F	116	A	S	18 Oct. 1984	34°08'S	18°20'E
87/37	199	M	77	J	S	19 Dec. 1987	34°23'S	21°12'E
89/28	216	M	104	SA	S	28 Nov. 1989	34°33'S	20°25'E
Pantropical spotted dolphin								
84/19	210	F	88	SA	S	25 Jun. 1984	34°40'S	19°29'E
Humpback dolphin								
90/35	259	F	171	A	S	24 Nov. 1990	34°22'S	21°26'E
Dusky dolphin								
82/01	165	M	52	SA	S	6 Jan. 1982	22°50'S	14°31'E
83/32	-	F	-	A	S	16 Jul. 1983	33°54'S	18°24'E
83/38	187	M	86	SA	P	22 Nov. 1983	33°22'S	18°00'E
84/10	166	M	68	SA	P	26 Feb. 1984	32°16'S	18°13'E
84/33	169	F	62	J	S	6 Jan. 1982	22°57'S	14°30'E
86/03	89	M	8	C	S	22 Jan. 1986	34°08'S	18°27'E
86/24	187	F	93	A	I	16 May 1986	32°43'S	17°58'E
87/01	178	F	55	SA	S	7 Feb. 1987	34°12'S	18°22'E
87/03	92	M	9	C	S	25 Feb. 1987	33°43'S	18°27'E
88/15	160	M	59	J	I	13 Jul. 1988	19°20'S	12°32'E
88/16	182	F	78	SA	I	13 Jul. 1988	19°20'S	12°32'E
88/17	173	F	65	J	I	13 Jul. 1988	19°20'S	12°32'E
88/18	176	F	78	SA	I	13 Jul. 1988	19°20'S	12°32'E
89/09	167	F	57	J	I	19 Mar. 1989	34°08'S	18°27'E
89/26	173	F	67	SA	I	26 Oct. 1989	30°00'S	16°01'E
89/27	176	F	66	J	I	26 Oct. 1989	30°00'S	16°01'E
89/31	170	F	69	J	I	23 Jun. 1989	24°44'S	14°28'E
89/32	176	F	62	J	I	27 Jun. 1989	18°15'S	12°04'E
89/33	169	F	64	J	I	23 Jun. 1989	24°44'S	14°28'E
89/34	156	M	56	J	I	23 Jun. 1989	24°44'S	14°28'E
90/23	170	F	68	J	I	11 May 1990	30°49'S	17°29'E
Hourglass dolphin								
82/07	164	F	74	J	P	25 Dec. 1981	55°39'S	60°41'W
Heaviside's dolphin								
77/07	168	F	64	A	P	18 Jan. 1977	23°00'S	14°22'E
80/17	166	F	68	SA	P	24 Aug. 1980	29°08'S	16°46'E
82/19	158	F	52	J	P	28 Aug. 1982	30°52'S	17°33'E
84/08	147	M	51	J	P	26 Feb. 1984	32°50'S	17°45'E
84/09	156	M	56	SA	P	28 Aug. 1982	32°45'S	17°46'E
84/30	156	M	59	A	P	29 Sep. 1984	30°25'S	17°18'E
85/07	118	F	27	J	S	9 Apr. 1985	32°20'S	18°19'E

continued

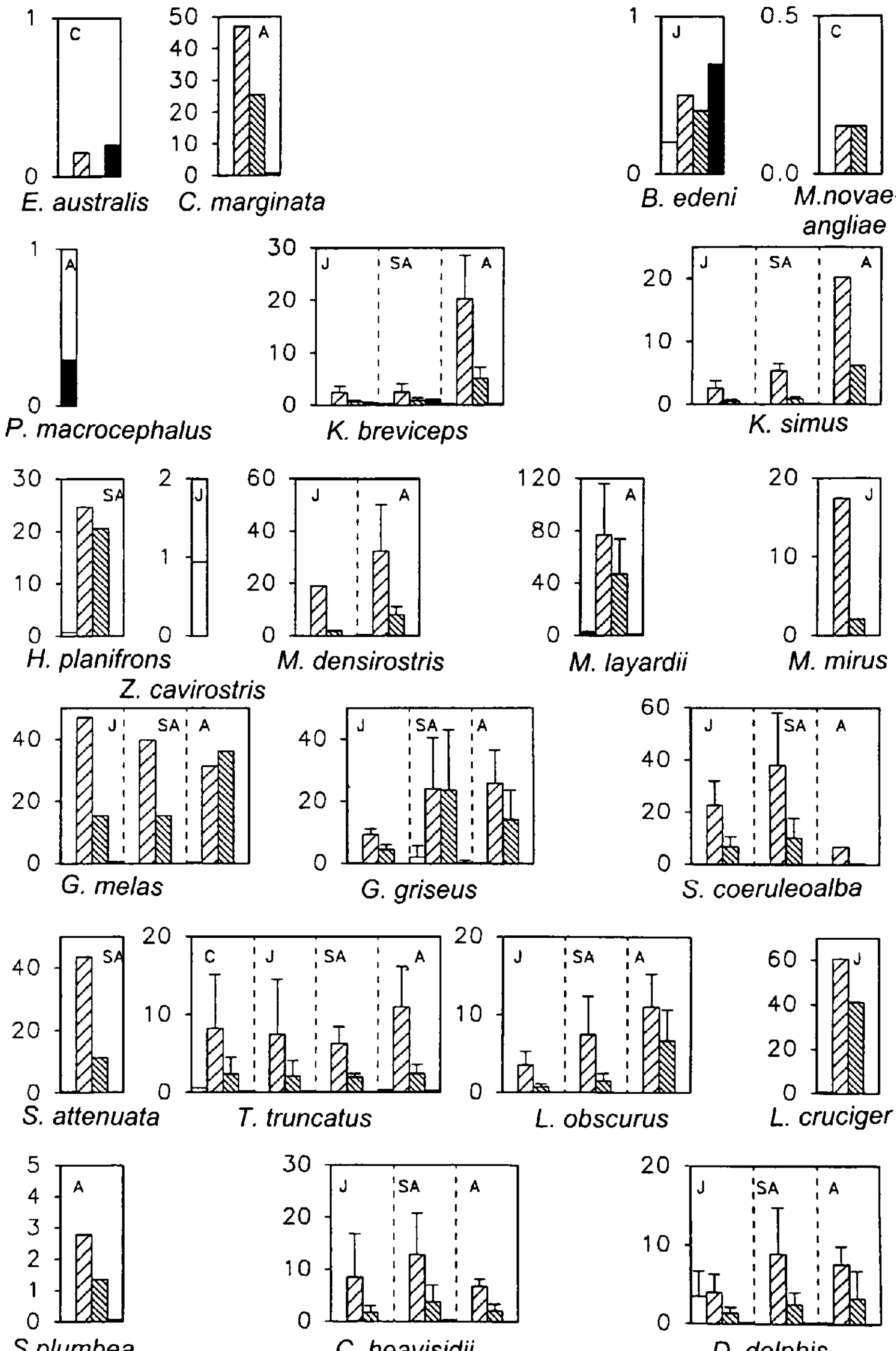
Field no.	Length(cm)	Sex	Weight(kg)	Age	Origin	Date	Location	
Heaviside's dolphin (cont.)								
85/09	-	-	-	SA	I	11 Mar. 1985	32°44'S	17°52'E
85/15	151	M	44	SA	S	19 Jul. 1985	34°03'S	18°22'E
87/15	155	M	46	J	P	17 Aug. 1987	18°48'S	12°19'E
89/29	79	M	6	C	S	18 Jan. 1989	22°07'S	14°16'E
90/21	164	M	68	SA	I	19 Apr. 1990	30°18'S	17°10'E
Common dolphin								
82/06	102	M	10	C	S	15 Feb. 1982	34°10'S	18°26'E
83/01	224	M	136	SA	P	23 Jan. 1983	34°38'S	24°38'E
83/02	208	F	87	J	P	26 Jan. 1983	33°50'S	25°50'E
83/03	221	F	136	SA	P	27 Jan. 1983	34°15'S	24°53'E
83/04	196	M	85	J	P	9 Feb. 1983	34°18'S	18°18'E
83/05	203	F	88	J	P	12 Feb. 1983	34°44'S	19°04'E
83/06	220	F	103	J	P	13 Feb. 1983	34°49'S	20°29'E
83/10	248	M	158	A	S	5 Mar. 1983	34°28'S	20°32'E
83/11	190	M	76	J	I	23 Feb. 1983	17°42'S	11°28'E
83/12	177	F	65	J	I	22 Feb. 1983	17°45'S	11°26'E
83/19	215	M	81	J	S	1 Apr. 1983	34°19'S	18°28'E
83/36	208	F	96	J	I	8 Nov. 1983	34°28'S	20°58'E
83/37	215	F	90	J	I	8 Nov. 1983	34°28'S	20°58'E
83/39	223	M	109	SA	P	29 Nov. 1983	34°14'S	18°19'E
83/40	210	F	90	J	P	29 Nov. 1983	34°27'S	18°29'E
84/01	208	M	82	J	S	26 Jan. 1984	34°08'S	18°20'E
84/03	222	M	106	J	P	22 Feb. 1984	34°48'S	19°11'E
84/04	232	M	121	SA	P	22 Feb. 1984	34°54'S	19°31'E
84/05	230	M	115	SA	P	22 Feb. 1984	35°00'S	19°58'E
84/06	210	M	102	J	P	24 Feb. 1984	34°44'S	19°04'E
84/07	215	F	98	J	P	24 Feb. 1984	34°39'S	18°59'E
84/17	149	M	27	J	S	30 Apr. 1984	34°22'S	18°52'E
84/32	155	M	38	J	S	30 Nov. 1984	34°26'S	19°14'E
85/11	216	F	92	J	P	18 Apr. 1985	34°07'S	22°31'E
85/12	210	M	93	J	P	21 Apr. 1985	34°00'S	25°08'E
85/13	254	M	158	SA	P	24 Apr. 1985	34°27'S	21°34'E
86/01	195	F	80	SA	S	3 Jan. 1986	34°39'S	20°15'E
86/07	115	M	15	J	S	10 Feb. 1986	34°05'S	18°34'E
86/09	220	F	100	SA	I	18 Feb. 1986	34°35'S	19°05'E
86/10	207	M	84	J	I	18 Feb. 1986	34°35'S	19°05'E
86/11	197	M	69	J	I	18 Feb. 1986	34°35'S	19°05'E
86/12	211	F	84	J	I	18 Feb. 1986	34°35'S	19°05'E
86/13	226	F	98	J	I	18 Feb. 1986	34°35'S	19°05'E
86/33	207	M	65	J	S	6 Sep. 1986	34°09'S	18°27'E
86/37	224	M	124	SA	S	24 Oct. 1986	34°06'S	18°31'E
86/39	243	M	129	A	S	10 Oct. 1986	34°45'S	19°36'E
87/07	184	F	63	J	S	10 Mar. 1987	34°24'S	19°16'E
87/36	217	F	96	SA	S	17 Dec. 1987	34°23'S	21°12'E
89/25	165	F	34	J	S	15 Sep. 1989	33°54'S	18°28'E
90/01	224	F	96	A	S	6 Jan. 1990	34°06'S	18°48'E
90/22	224	F	94	SA	S	25 Apr. 1990	34°43'S	20°07'E
90/24	151	F	31	J	-	-	-	-
90/31	231	F	94	A	S	4 Sep. 1990	34°47'S	19°38'E



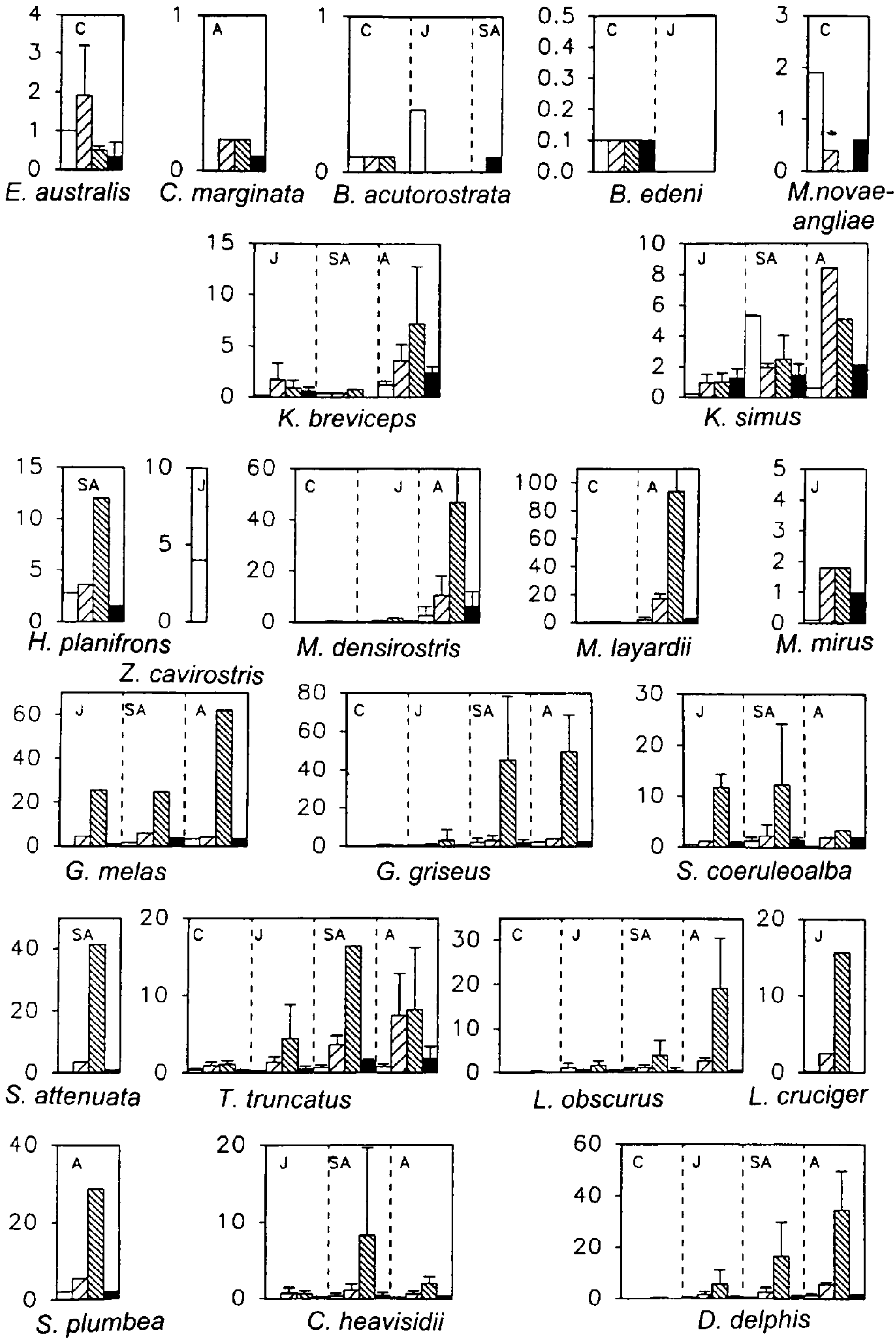
Appendix Fig. 1. Mean concentrations (in μg/g wet weight) of zinc in brain (open), kidney (rising right), liver (rising left) and muscle (solid) of different age classes of cetaceans from southern Africa (C = calf, J = juvenile, SA = sub-adult, A = adult).



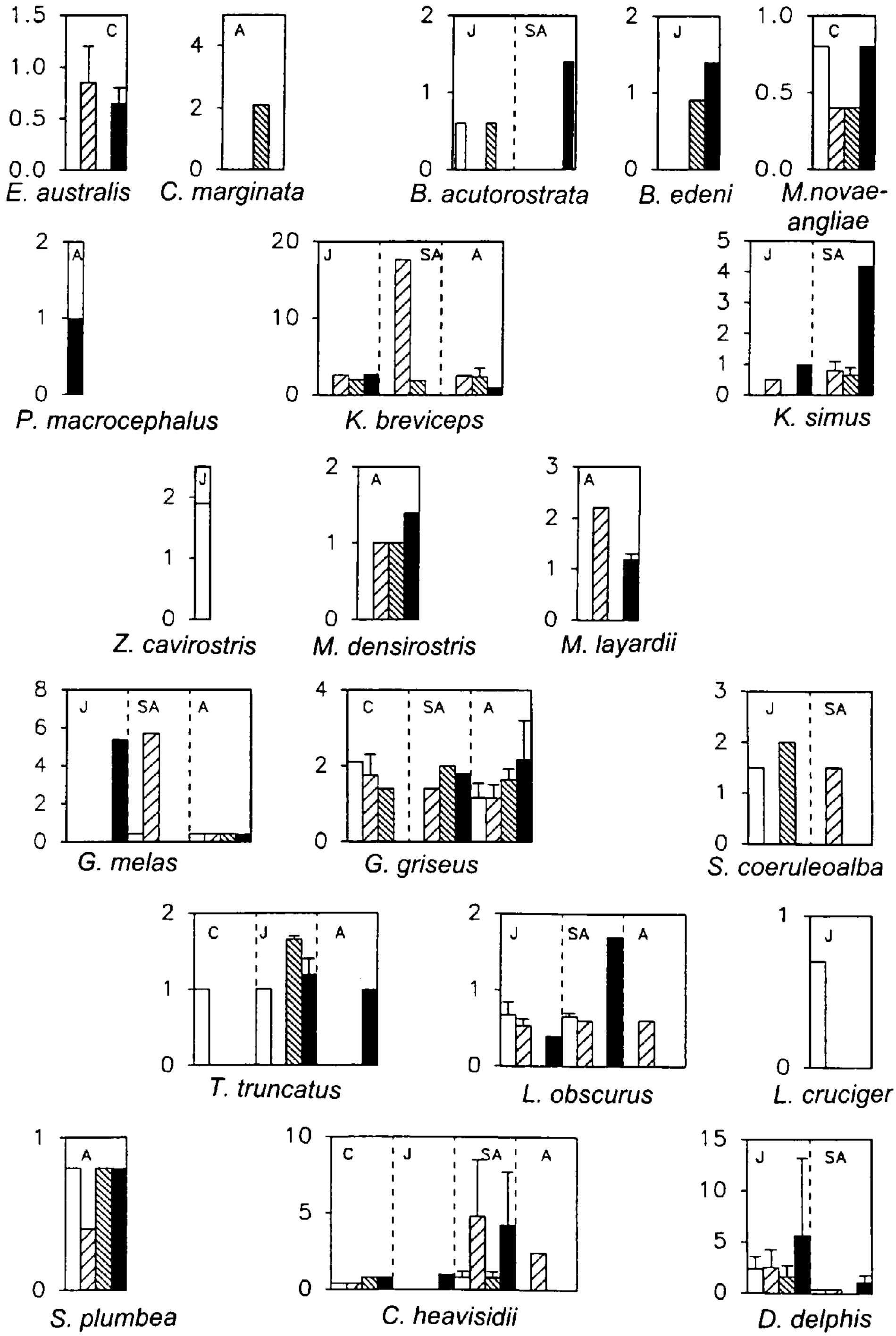
Appendix Fig. 2. Mean concentrations (in µg/g wet weight) of copper in brain (open), kidney (rising right), liver (rising left) and muscle (solid) of different age classes of cetaceans from southern Africa (C = calf, J = juvenile, SA = sub-adult, A = adult).



Appendix Fig. 3. Mean concentrations (in μg/g wet weight) of cadmium in brain (open), kidney (rising right), liver (rising left) and muscle (solid) of different age classes of cetaceans from southern Africa (C = calf, J = juvenile, SA = sub-adult, A = adult).



Appendix Fig. 4. Mean concentrations (in µg/g wet weight) of mercury in brain (open), kidney (rising right), liver (rising left) and muscle (solid) of different age classes of cetaceans from southern Africa (C = calf, J = juvenile, SA = sub-adult, A = adult).



Appendix Fig. 5. Mean concentrations (in µg/g wet weight) of lead in brain (open), kidney (rising right), liver (rising left) and muscle (solid) of different age classes of cetaceans from southern Africa (C = calf, J = juvenile, SA = sub-adult, A = adult).