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Baseline

Heavy metal levels in bottlenose and striped dolphins off the Mediterranean coast of Israel

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Very little is known about heavy metal concentrations in tissues of cetaceans inhabiting the Eastern Mediterranean. This report presents such data for two Delphinid species: the bottlenose dolphin (*Tursiops truncatus*) and the striped dolphin (*Stenella coeruleoalba*). The former is by far the most common species in Israeli Mediterranean (IM) coastal waters (Goffman et al., 2000). From June of 1993 to December 2001, the bodies of 61 bottlenose dolphins were collected and documented by IMMRAC (Israeli Marine Mammal Research & Assistance Center) along the IM coast. By comparison, only eight bodies of striped dolphins, the second most common species, were collected during the same period. The bodies of seventeen bottlenose dolphins (including 11 entanglement victims and six beached animals) and six stripeds dolphins (all beached) were sufficiently fresh (known or estimated time of death ranging from 4–48 h) to avoid significant dehydration and putrefaction effects on heavy metal analysis.

The heavy metal data reported for the bottlenose dolphin are the first large series from the entire Mediterranean. To our knowledge, it is also the first large series ever reported with the scope of metals and tissues tested. Knowing the age of eleven animals allowed evaluation of the age-dependency of heavy metal concentrations in this coastal population. Existing reports on Mediterranean striped dolphins (André et al., 1991; Augier et al., 1993a,b; Cardellicchio et al., 2000; Leonzio et al., 1992; Monaci et al., 1998), only extend to the Ionian and Adriatic coasts of Apulia, Southern Italy (Cardellicchio et al., 2000). In view of the regional differences in tissue concentrations of trace elements demonstrated in striped dolphin populations from the western Mediterranean (Monaci et al., 1998), information on IM striped dolphins hold particular interest as representing individuals in the easternmost reach of the Mediterranean range of this species.

Animals were measured, weighed and sex was determined according to Norris (1961). Teeth, extracted from the mid upper and lower jaws, were sent for age determination to Dr. V. Cockroft's laboratory in South Africa (01/1995–03/1998) and to Dr. C. Lockyer's laboratory in Denmark (from then on). Aging methods are described in Cockcroft and Ross (1990) and Hohn et al. (1989), respectively. Aging of teeth from three animals sent to both laboratories, tallied to within two growth layer groups (GLGs). In a few animals for which an estimated range rather than an exact age was given, we used mid-range for ranges $\leqslant 3$ GLGs and omitted larger uncertainties.

Skin, blubber, epaxial muscle (*m. longissimus dorsi*), liver, kidney and brain samples were taken for heavy metal analysis. Samples were kept at −20 °C prior to analysis. Defrosted, weighed aliquots were placed in Uniseal, Teflon-lined, high-pressure decomposition vessels and digested with concentrated nitric acid for 3–4 h at 140 °C. The cooled digests were diluted in volumetric flasks with DDW to the appropriate volume. Each sample was duplicated. Accuracy was checked by analyzing certified standard reference materials from the National Institute of Standards and Technology

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(NIST—Bovine liver) and from the National Research Council of Canada (NRCC—DORM 2 and DOLT 1) in the same analytical run with the samples (Hornung et al., 1989). Analytical runs were accepted when standard reference materials gave results within 5% of the certified values.

Cold vapor atomic absorption spectrometry was used for total mercury analysis (Coleman Mercury Analyzer MAS-50), while cadmium, copper, zinc, iron and manganese were analyzed with flame atomic absorption spectrometry (Perkin–Elmer 1100B spectrophotometer equipped with a deuterium-arc background corrector). Detection limits for Cd, Hg, Cu, Zn, Fe and Mn were 0.01, 0.005, 0.03, 0.07, 0.04 and 0.01 μg/g wet weight (WW), respectively. Chemical blanks that were run during the analysis presented no evidence of contamination.

Non-parametric rank order correlation between concentrations of different trace elements in different tissues was assessed by Spearman's r coefficient. In order to compare our values to those reported by other laboratories that measured concentrations in dried samples (DW), we used a global conversion factor of 0.22 WW/DW (Becker et al., 1995; Wood and Van Vleet, 1996; Marsili and Forcadi, 1996). The significance of differences between group medians (in our own groups as well as in comparable groups of other studies) was assessed by the Mann–Whitney U-test and the Kruskal–Wallis ANOVA (Statistica for Windows).

Heavy metal concentrations in key tissues (muscle, liver and kidney) of each of the individual bottlenose dolphins are listed in Table 1. Summarized descriptive statistics of heavy metal concentrations in all tissues are reported in Table 2.

Mercury concentrations in liver, muscle and skin showed a positive correlation with age (r coefficients: 0.88, 0.87, 0.82; p-values: 0.0002, 0.0009, 0.004, respectively). All combinations of across-tissues mercury concentrations were highly correlated, some r coefficients (i.e. liver–kidney), approaching 1.0. Liver versus kidney concentrations of cadmium, copper and zinc were also positively correlated (r coefficients: 0.88, 0.66, 0.59; p-values 0.00008, 0.01, 0.03, respectively). In addition, copper in kidney and in blubber as well as manganese in kidney and in brain, showed a positive correlation ($p < 0.01$). Noteworthy within and across-tissues positive correlations between paired metal concentrations were found between mercury and cadmium, as well as between copper and zinc. Kidney cadmium concentration correlated with the mercury concentrations of all the other tissues (p-values ranging between 0.02 and 0.002). In several tissues, mercury and cadmium correlated with either or both copper and zinc, but always negatively (r range: −0.52 to −0.95 and p range: 0.04–0.001). As an example, the inverse relationship between Cd and Zn in liver is presented in Fig. 1. In muscle, mercury was correlated with iron ($r = 0.76$, $p < 0.0004$) and cadmium with manganese ($r = 0.74$, $p < 0.001$).

Summarized descriptive statistics of heavy metal concentrations in all sampled tissues of stripped dolphins are reported in Table 3. There are not enough data to test for age effects. Mercury in liver is positively correlated with mercury in kidney ($r = 0.9$, $p < 0.037$), mercury in muscle ($r = 0.83$, $p < 0.041$), cadmium in liver ($r = 0.83$, $p < 0.041$), cadmium in kidney ($r = 0.9$, $p < 0.037$) and iron in kidney ($r = 0.9$, $p < 0.037$). Liver zinc is positively correlated with liver and kidney manganese ($r = 0.94$, 0.9; $p < 0.005$, 0.037, respectively).

In both species, liver concentrations were highest for all metals except cadmium, which was more concentrated in kidneys, and zinc which accumulated in skin. Significant differences in tissue metal concentrations between the two species were seen only for cadmium in the liver and cadmium and zinc in the kidney. In these cases, concentrations were higher in the striped dolphins (Table 4).

Most of the general trends seen in our results are in accordance with previously described results in these or in other cetacean species. Higher cadmium levels in striped dolphins compared to bottlenose dolphins were also noted before (Honda and Tatsukawa, 1983; Leonzio et al., 1992; Law et al., 1992) and ascribed to a higher dietary fraction of cephalopods, known to be cadmium accumulators (Martin and Flegal, 1975).

Positive mercury versus cadmium and copper versus zinc correlations have been described in striped dolphins (Honda et al., 1983; Monaci et al., 1998). The first group also reported a negative correlation between Hg and Cu in kidney and Hg and Zn in liver ($p < 0.001$). Our finding of a negative Cd–Zn relationship ($r = -0.78$; $p < 0.001$) in the liver of bottlenose dolphins (Fig. 1) is opposite to that of Honda and Tatsukawa (1983) in stripped dolphin's liver. Also, a positive Cd–Zn correlation in the kidney of striped dolphins (Honda et al., 1983; Honda and Tatsukawa, 1983) is not confirmed in bottlenose dolphin's kidney ($r = -0.51$; $p < 0.06$).

Tissue concentrations of copper and zinc, essential elements homeostatically regulated over widely variable habitats and dietary regimes (Thompson, 1990), present an opportunity to compare results of laboratories differing in technique, mainly in dry versus wet sample analysis. The almost perfect agreement in tissue copper concentrations seen in bottlenose dolphins (Wood and Van Vleet, 1996; Holsbeek et al., 1998; Leonzio et al., 1992; Frodello and Marchand, 2001, our study) and striped dolphins (Honda et al., 1983; Honda and Tatsukawa, 1983; Monaci et al., 1998; Augier et al., 1993b; Leonzio et al., 1992; Cardellicchio et al., 2000, our study) is truly remarkable and gives credence to the use of wet weight (WW) to dry weight (DW) conversion factors for comparing results of fresh samples. Law et al.

Table 1
Heavy metal concentrations (μg/g WW) in key tissues of bottlenose (Tt) and striped (Sc) dolphins from the Mediterranean coast of Israel

Sp	Date	S	Length (cm)	Age (years)	Hg			Cd			Cu			Zn			Fe			Mn		
					M	L	K	M	L	K	M	L	K	M	L	K	M	L	K	M	L	K
Tt	7.94	f	231	–	14	–	–	0.12	–	–	1.1	–	–	14	–	–	180	–	–	0.29	–	–
Tt	8.94	f	275	–	38	491	–	0.18	1.1	–	0.7	4.3	–	13	15	–	246	457	–	0.54	1.3	–
Tt	8.94	m	255	–	13	185	32	0.14	0.26	4.2	0.8	6.6	1.9	47	25	15	339	251	231	0.67	2.5	0.59
Tt	9.94	f	239	–	3.5	48	20	0.07	0.44	0.35	1.2	11	2.9	15	21	20	164	221	183	0.32	2.9	1.2
Tt	4.95	f	237	11.5	8.3	137	5.3	0.18	1.02	0.32	1.3	8.5	2.7	11	28	14	194	285	193	0.54	2.4	0.80
Tt	7.95	m	219	–	1.3	8.5	9.7	0.08	0.42	3.4	1.1	4.5	3.8	25	37	20	95	308	207	0.11	5.1	0.89
Tt	11.95	m	164	< 1	0.47	1.3	4.4	0.04	0.12	0.27	0.98	24	3.6	19	58	24	76	163	125	0.14	4.9	1.2
Tt	3.96	f	161	< 1	0.37	0.97	0.50	0.11	0.14	0.06	1.8	7.9	5.4	13	47	30	85	251	127	0.55	1.9	2.9
Tt	8.96	f	173	3.5	1.9	7.7	0.32	0.07	0.53	0.11	1.0	4.5	3.1	21	28	18	93	167	186	0.37	2.7	0.68
Tt	8.96	m	175	2.0	1.2	5.3	3.1	0.11	0.38	0.87	1.2	8.9	2.9	23	49	19	125	189	124	0.56	4.8	0.69
Tt	10.96	f	231	20.0	11	–	1.4	0.20	–	0.24	1.3	–	3.8	23	–	21	240	–	104	0.79	–	0.48
Tt	4.97	m	235	5.0	3.4	–	12	0.05	–	0.79	1.0	–	2.8	16	–	13	219	–	183	0.32	–	0.69
Tt	4.97	f	236	10.0	3.8	44	–	0.04	1.0	–	1.3	4.8	–	11	23	–	165	458	–	0.22	2.6	–
Tt	9.97	m	206	5.0	2.8	19	4.3	0.04	0.62	0.89	1.1	5.3	2.1	13	30	13	157	248	246	0.18	4.0	0.63
Tt	1.98	f	248	21.5	39	345	4.5	0.05	0.39	0.34	1.2	5.3	3.0	11	41	17	221	391	97	0.23	2.1	0.68
Tt	10.98	m	195[a]	13	3.4	22	21	0.09	0.22	0.40	1.7	15	2.7	29	105	16	321	699	105	0.22	6.5	0.61
Tt	8.99	m	171	3.5	5.1	42	5.1	0.06	0.21	0.20	1.7	15	4.7	57	115	20	121	842	181	0.41	5.4	0.36
Sc	6.94	m	195	–	9.1	126	–	0.14	3.8	–	1.1	7.4	–	10	50	–	169	317	–	0.12	2.3	–
Sc	9.94	m	194	–	11	143	9.9	0.09	4.6	15	1.6	8.3	2.7	7.8	23	17	197	593	232	0.24	4.1	0.6
Sc	8.95	m	102	< 1	0.54	1.4	1.9	0.02	0.07	0.18	1.8	1.1	4.0	21	53	32	109	129	63	0.18	0.4	1.2
Sc	12.96	m	187	8	2.3	26	1.9	0.07	1.6	3.6	1.5	12	0.61	32	46	27	249	251	207	0.86	3.6	1.3
Sc	10.00	f	194	16	8.8	244	15	–	3.3	11	1.5	22	4.3	7.5	95	51	177	448	224	BDL	0.03	BDL
Sc	4.01	f	197	16	21	550	27	0.12	9.0	30	0.94	7.3	2.4	32	34	33	144	352	266	0.33	3.0	0.7

[a] Individual with extreme scoliosis.

Table 2
Descriptive statistics of heavy metal concentrations (µg/g WW) in tissues of bottlenose dolphins from the Mediterranean coast of Israel

Metal	Tissue	*N*	Median	Mean	SD	Min	Max
Hg	Skin	13	3.2	4.2	3.0	0.27	10
	Blubber	14	0.58	1.5	3.2	0.03	12
	Muscle	17	3.5	8.9	12	0.37	39
	Liver	14	32	97	149	0.97	491
	Kidney	14	4.8	8.8	9.3	0.32	32
	Brain	9	1.6	3.2	4.1	0.28	11
Cd	Skin	13	0.20	0.18	0.1	0.04	0.35
	Blubber	12	0.07	0.07	0.06	0.01	0.19
	Muscle	17	0.08	0.1	0.05	0.04	0.20
	Liver	14	0.41	0.49	0.33	0.12	1.1
	Kidney	14	0.34	0.88	1.7	0.06	4.2
	Brain	9	0.10	0.09	0.05	0.01	0.17
Cu	Skin	13	0.98	1.1	0.51	0.30	2.2
	Blubber	14	0.28	0.36	0.22	0.14	0.95
	Muscle	17	1.2	1.2	0.30	0.74	1.8
	Liver	14	7.3	8.9	5.6	4.3	24
	Kidney	14	3.0	3.2	0.93	1.9	5.4
	Brain	9	2.5	2.6	1.1	0.74	4.8
Zn	Skin	13	266	432	662	3.8	2611
	Blubber	14	8.9	10	6.1	3.4	28
	Muscle	17	16	21	13	11	57
	Liver	14	33	44	30	15	115
	Kidney	14	18	18	4.6	13	30
	Brain	9	14	14	4.8	7.5	23
Fe	Skin	13	26	50	42	9.5	137
	Blubber	14	30	40	24	18	106
	Muscle	17	165	179	78	76	339
	Liver	14	268	352	203	163	842
	Kidney	14	182	164	49	97	246
	Brain	9	46	49	20	18	78
Mn	Skin	13	0.53	0.51	0.20	0.17	0.84
	Blubber	13	0.29	0.42	0.41	0.11	1.6
	Muscle	16	0.32	0.38	0.20	0.11	0.79
	Liver	14	2.8	3.5	1.6	1.3	6.5
	Kidney	14	0.68	0.89	0.62	0.36	2.9
	Brain	9	0.53	0.73	0.47	0.29	1.6

N—number of specimens, SD—standard deviation, Min—minimum, Max—maximum.

(1991), hypothesized a homeostatic range of liver zinc concentrations in the common porpoise (*Phocoena phocoena*) as 20–100 µg/g WW. The similar range in our bottlenose dolphins (15–115 µg/g WW), in our striped dolphins (23–94 µg/g WW) and in other large series of bottlenose and striped dolphins, would extend the hypothesis to include the two Delphinid species.

The negative relationship between Zn–Cu and Hg–Cd levels may indicate competition for and displacement from a common binding site. Metallothioneins (MT) and metallothionein-like proteins are thought to be the major "buffer-storage" elements of essential bivalent metals as well as (inducible) detoxifying agents of chemically homologous "pollutant" metals in marine mammal liver and kidney (Caurant et al., 1996; Das et al., 2000). Since the decreasing order of metal binding affinity of MT is: Hg > Cu > Cd > Zn (George, 1990), tissue MT-bound zinc and copper displacement by age-related accumulated cadmium and mercury, respectively, seems a feasible hypothesis.

Iron and manganese are also considered essential and their concentrations are likely to be regulated, other than in exceptional and local cases (Thompson, 1990). Our results match those of Honda et al. (1983) in striped dolphins for both metals in liver, kidney and muscle.

Mercury demonstrates both bioaccumulation up the food web and age accumulation within the tissues of individual marine mammals (Bernhard, 1985; André et al., 1991; Wood and Van Vleet, 1996). The latter causes a very large tissue concentration variance within individuals from the same population, especially in the liver. As with mercury in the liver, cadmium concentrations in the marine mammalian kidney, its main detoxifying organ (Fujise et al., 1988), may reach levels many times higher than those known to be nephrotoxic in terrestrial mammals (Das et al., 2000). It would stand to reason that kidney concentrations of cadmium would also increase with age. This is, however, not supported by our results in bottlenose dolphins, nor in reported data on striped dolphin populations from the Pacific (Honda and Tatsukawa, 1983) and the western Mediterranean (Monaci et al., 1998).

Unlike the essential elements, mercury and cadmium levels in tissues of marine mammals may show regional variations, on account of varying natural and anthropogenic local inputs and/or varying diets (André et al., 1990, 1991; Monaci et al., 1998). The comparative data for bottlenose and striped dolphins in the most widely reported tissues (i.e. liver, kidney and muscle) are detailed in Tables 5 and 6, respectively.

Any conclusive comparison based on reports from different laboratories has obvious drawbacks, but in practice may be the only alternative until the adoption of international methodological standards (André, 1997). Even accepting the validity of WW to DW conversion factors, age accumulation would confine any

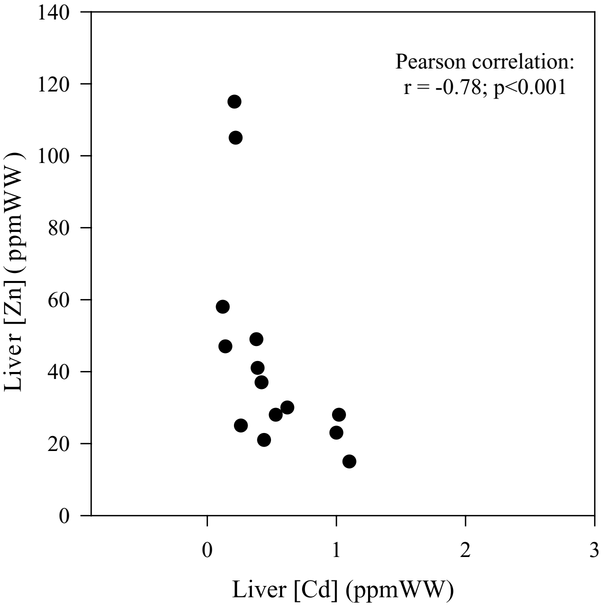

Fig. 1. Inverse relationship between Cd and Zn in livers of 14 bottlenose dolphins from the Israeli Mediterranean Coastline.

Table 3
Descriptive statistics of heavy metal concentrations (μg/g WW) in tissues of striped dolphins from the Mediterranean coast of Israel

Metal	Tissue	*N*	Median	Mean	SD	Min	Max
Hg	Skin	5	5.8	5.1	2.7	1.4	7.6
	Blubber	5	1.7	1.6	1.4	0.14	2.9
	Muscle	6	8.9	8.8	7.2	0.45	21
	Liver	6	134	181	200	1.4	550
	Kidney	5	9.9	11	11	1.9	27
Cd	Skin	5	0.13	0.11	0.08	0.001	0.17
	Blubber	5	0.01	0.05	0.08	0.01	0.17
	Muscle	5	0.09	0.09	0.05	0.02	0.14
	Liver	6	3.5	3.7	3.1	0.07	9.0
	Kidney	5	11	11	12	0.18	30
Cu	Skin	5	2.1	2.1	1.1	1.1	3.2
	Blubber	5	0.8	0.8	0.11	0.64	0.90
	Muscle	6	1.5	1.4	0.33	0.94	1.8
	Liver	6	7.8	9.7	6.9	1.1	21
	Kidney	5	2.7	2.8	1.5	0.58	4.3
Zn	Skin	5	232	394	157	957	376
	Blubber	5	17	17	13	21.4	3.9
	Muscle	6	18	16	12	7.5	32
	Liver	6	50	48	25	23	95
	Kidney	5	32	32	12	17	51
Fe	Skin	5	19	36	13	94	39
	Blubber	5	77	67	28	85	26
	Muscle	6	177	173	48	104	245
	Liver	6	317	349	160	129	594
	Kidney	5	215	198	79	63	232
Mn	Skin	5	0.41	0.43	0.22	0.67	0.19
	Blubber	5	0.10	0.21	0.03	0.61	0.27
	Muscle	6	0.21	0.29	0.001	0.86	0.86
	Liver	6	2.6	2.2	0.03	4.1	4.1
	Kidney	5	0.70	0.77	0.001	1.3	1.3

N—number of specimens, SD—standard deviation, Min—minimum, Max—maximum.

Table 4
Differences in tissue metal concentrations in striped and bottlenose dolphins (values expressed in μg/g WW)

Metal	Tissue	Striped dolphins			Bottlenose dolphins			P
		N	Mean	SD	N	Mean	SD	
Cd	Liver	5	2.7	1.8	14	0.49	0.3	0.021
	Kidney	4	7.5	6.9	14	0.88	1.3	0.042
Zn	Kidney	4	31	14	14	18	4.6	0.016

N—number of specimens, SD—standard deviation.

Table 5
Tissue mercury and cadmium concentrations (μg/g DW) in bottlenose dolphins from various locations

Location (N)	Liver		Kidney		Muscle	
	Mean	SD (range)	Mean	SD (range)	Mean	SD (range)
Mercury						
Florida[a] (12)	134	149 (BDL–443)	–	–	–	–
French Atlantic[b] (4-5)	461	325 (24–783)	40	35 (6.9–71)	45	37 (5.3–85)
N. Tyrrhenian[c] (4–6)	270[d]	(12–13,155)	80[d]	(7.1–882)	38[d]	(4.9–292)
Israeli Med.[e] (14–17)	436	671 (4.4–2210)	40	42 (1.4–144)	40	54 (1.7–176)
Cadmium						
Florida[a] (21–29)	0.20	0.8 (BDL–1.7)	1.3	1.8 (BDL–6.4)	BDL	–
French Atlantic[b] (4–5)	0.38	0.4 (BDL–1.1)	4.9	5.0 (0.74–11)	0.06	0.12 (BDL–0.31)
N. Tyrrhenian[c] (4–6)	0.75[d]	(0.30–1.1)	9.1[d]	(0.20–11)	0.06[d]	(0.04–0.57)
Corsica[f] (7)	0.84	(0.07–2.1)	4.9	(0.16–10)	0.23	(0.03–0.50)
Israeli Med.[e] (14–17)	2.2	1.5 (0.54–5.0)	4.0	5.7 (0.27–19)	0.45	0.24 (0.18–0.90)

When given as a range, N—number of sampled animals varied for each tissue. Med.—Mediterranean.

[a] Rawson et al. (1993).

[b] Holsbeek et al. (1998).

[c] Leonzio et al. (1992).

[d] Median.

[e] Present study.

[f] Frodello and Marchand (2001).

attempt to establish the significance of observed differences in group medians to data sets listing individual values as well as exact age or some reliable age estimation. Taking all limitations into consideration, whenever possible, we nevertheless attempted a statistical comparison of the results. To this end, we followed the suggestion of Monaci et al. (1998) and, when possible, used muscle as the preferable tissue for comparison.

Bottlenose dolphins. Of the series listed in Table 5, the one of Rawson et al. (1993) allowed a direct comparison (only liver tissue was studied). Matching values from nine dolphins aged between 5 and 21 years from Florida with values of seven dolphins from our series aged between 5 and 21.5 years, we could not find a significant difference between the group medians (Mann–Whitney U-test: $p < 0.31$). Another series amenable to age matching is that of Holsbeek et al. (1998). Muscle (and other tissue) mercury levels were not statistically different, yet for cadmium, the Mann–Whitney U-test showed our series to have significantly higher ($p < 0.04$) muscle levels.

Other available data only permit qualitative observations. Wood and Van Vleet (1996) show very low cadmium levels in bottlenose dolphins beached on both coasts of Florida. Out of 32 immature and mature animals in the series, cadmium was detected in only 11 kidney samples, six liver samples and in none of the muscle samples. This cannot be explained entirely by a less sensitive analytical method, as the few animals in which the metal was detected (mainly stranded on the west coast), had liver and kidney levels near the mean of our sample. The only relevant reports from the Mediterranean (Leonzio et al., 1992; Frodello and Marchand, 2001) give no information on age or length (all animals less than 3 years in the latter report). It would still seem that mercury levels tend to be similar while cadmium levels (at least in muscle and liver) are lower in the Western Mediterranean locations.

Striped dolphins. Several detailed studies of mercury levels have been performed in the Mediterranean region and are published with individual data specified (Table 6). We compared muscle mercury concentration medians in five series, including our own, using values from individuals older than 10 years or longer than 188 cm. These are roughly the points of attaining physical maturity in the Mediterranean populations (Viale, 1985; André et al., 1991; Monaci et al., 1998). The comparison, depicted in Fig. 2, shows that while muscle mercury

Table 6
Tissue mercury and cadmium concentrations (μg/g DW) in striped dolphins from various locations

Location (*N*)	Liver		Kidney		Muscle	
	Mean	SD (range)	Mean	SD (range)	Mean	SD (range)
Mercury						
E. Coast Japan[a] (20–51)	923[b]	(7.7–2183)	39[b]	(4.1–79)	32[b]	(2.3–71)
French Atlantic[c] (7–8)	230	131 (5.4–392)	29	22 (12–68)	9.9	17 (6.8–54)
Spanish Med.[d] (20–30)	1043	835	63	100	28	73
French Med.[c] (6–17)	1472[f]	1602 (5.4–6948)	104[f]	153 (6.3–806)	63[f]	131 (4.5–365)
French Med.[f] (13)	481	587 (68–2271)	62	88 (14–341)	37	40 (7.4–155)
W. Italian Med.[d] (39–51)	593	1120	44	72	53[g]	65
N. Tyrrhenian[h] (18–22)	324	(13–4400)	65	(5.8–204)	37	(6.5–168)
Corsica[i,j] (5)	176	620 (27–1548)	36	64 (18–176)	21	40 (8.6–104)
Apulian Coasts[k] (5)	851[b]	128 (703-975)	46[b]	9.7 (34–59)	49[b]	11 (37–65)
Israeli Med.[l] (5–6)	603	900 (6.3–2475)	45	50 (8.6–122)	40	32 (2.0–95)
Cadmium						
E. coast Japan[a] (54–59)	28[b]	10 (BDL–50)	119[b]	(BDL–313)	0.45[b]	0.27 (BDL–1.35)
Spanish Med.[d] (20–33)	4.0	5.1	8.4	6.6	0.05	0.08
W. Italian Med.[d] (39–51)	4.4	6.2	28[g]	31	0.1[g]	0.72
N. Tyrrhenian[h] (18–22)	7.3	(0.20–13)	45	(11–99)	0.18	(0.07–1.8)
Corsica[i,j] (4–5)	2.6	3.5 (0.8–8.6)	22	8.1 (6.8–27)	–	–
Apulian Coasts[k] (5)	7.9[b]	5.7 (0.5–15)	32[b]	18 (8.2–58)	0.18[b]	0.09 (0.09–0.23)
Israeli Med.[l] (5–6)	16	14 (0.32–41)	50	54 (0.81–135)	0.41	0.23 (0.09–0.63)

When given as a range, number of sampled animals varied for each tissue. Med.—Mediterranean.
[a] Honda et al. (1983).
[b] Mean.
[c] André et al. (1991).
[d] Monaci et al. (1998).
[f] Significantly higher than the French Atlantic.
[f] Augier et al. (1993a).
[g] Significantly higher than the Spanish Mediterranean.
[h] Leonzio et al. (1992).
[i] Frodello and Marchand (2001).
[j] Viale (1994).
[k] Cardellicchio et al. (2000).
[l] Present study.

levels at all Mediterranean locations so far reported are significantly higher than in the French Atlantic coast, levels in dolphins from our series seem intermediate, being not significantly different from any other group. From Table 6, it can be seen that the two series medians from the Balearic and Ligurian basins (Monaci et al., 1998) are in line with those of other Mediterranean series. That is also true for the series from the East Coast of Japan (Honda et al., 1983).

There are no individual data in any of the series listed in Table 5 that would allow strict comparisons of reported cadmium levels to our findings. Judging from muscle concentration medians, we may only note that for striped dolphins, animals off the Israeli coastline tend to be more burdened with cadmium than at other Mediterranean sites and as burdened as animals off the East Coast of Japan.

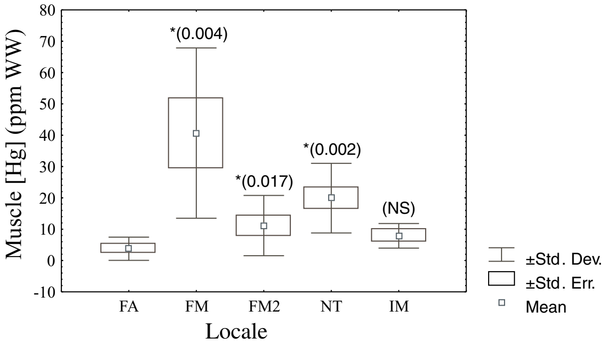

Fig. 2. Box and whiskers plot of muscle mercury concentrations of striped dolphins from: FA—Atlantic coast of France (André et al., 1991), FM—Mediterranean coast of France (ibid.), FM2—Mediterranean coast of France (Augier et al., 1993a), NT—North Tyrrhenian (Leonzio et al., 1992), IM—Mediterranean coast of Israel (this study). *N*—number of specimens. *—Significantly higher than FA. *P* values in parentheses.

The ability of marine mammals to cope with concentrations and total body loads of mercury and cadmium that are orders of magnitude higher than those considered lethal for terrestrial mammals relies on metabolic pathways that must have developed in response to environmental inputs well preceding anthropogenic pollution. Without underrating the potential of the latter to locally overwhelm these pathways in inhabitants of water bodies with high waste inputs and slow mixing, it should be realized that some of the highest reported values were found in animals residing in pristine surroundings. As an example, kidneys of the Antarctic Ross seal (*Ommatophoca rossi*) have been shown to contain up to 422 μg/g DW cadmium, the highest value in a marine vertebrate (McClurg, 1984).

High mercury concentrations in tissues of top predators in the Mediterranean were claimed to originate from a natural anomaly (Bernhard, 1978; André et al., 1991). Local coastal fauna may indeed be affected by natural inputs such as weathering of cinnabar deposits in central-western Italy (Bacci, 1989) and hence the astoundingly high liver mercury levels in some coastal dolphins from the Northern Tyrrhenian Sea (Leonzio et al., 1992). Yet, the evidence for a higher than average Hg level in the water body of the entire Mediterranean basin, which is then magnified up the food web to produce higher than average tissue levels in all Mediterranean top predators, has been questioned (Aston and Fowler, 1985).

Our results and comparison show that Mediterranean bottlenose dolphins do not have abnormally high tissue mercury levels. Indeed, Tables 4 and 5 show the French Atlantic striped dolphins to be exceptional in having appreciably lower levels than do all other tested series, of both species. In this they are joined by short-beaked common dolphins (*Delphinus delphis*) in both the French Atlantic (Holsbeek et al., 1998) and the Irish Sea (Law et al., 1992), showing liver and muscle median Hg concentration of 70–100 and 3.6 μg/g DW, respectively. From the available data to date, it would then seem more probable that species-specific dietary habits in different regions rather than local anomalies are the major determinants of tissue mercury levels in Delphinids of the same age.

Regional cadmium differences show a wider range, with individuals of both species from the Eastern Mediterranean basin and stripped dolphins from the East Coast of Japan occupying the high end of the range. The interspecies diet-related difference is preserved regardless of region. Similarly higher levels of cadmium in tissues (skin, liver, kidneys and gonads) of Eastern Mediterranean versus North Atlantic deep sea sharks were demonstrated by Hornung et al. (1993). Cadmium entry into the food chain seems to be mainly through ingestion of wind-swept particles of both natural and industrial origin, sinking (as such or adsorbed on biogenic particulate matter) through the water column (Fowler, 1986; Fowler and Knauer, 1986; Noriki and Tsunogai, 1992). Since Mediterranean industrialization and eutrophication levels are not conspicuously higher near the Israeli coast (Anon., 1999), remote sources should be considered. Atmospheric deposition is the most important part of the geochemical cycle of Cd in the Mediterranean, originating mainly in European anthropogenic aerosols but also naturally from North African and Arabian dust (Guerzoni et al., 1999; Herut et al., 2001). The particles are transported with the air masses, deposited on the sea surface and carried eastward by prevailing currents.

Our striped dolphin database is still too small to ascertain a unique heavy metal accumulation pattern within the Mediterranean context. Of the two populations described by Monaci et al. (1998), our animals more resemble the Tyrrhenian–Ligurian population in their mercury levels but could be distinct in having higher cadmium and zinc concentrations in muscle and skin.

Uncited reference 385

Lenfant et al. (1970) 386

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