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Baseline

Trace elements distribution in hawksbill turtle (*Eretmochelys imbricata*) and green turtle (*Chelonia mydas*) tissues on the northern coast of Bahia, Brazil

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ABSTRACT

Concentrations of elements (As, Al, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sr, V, Zn) were determined in liver, kidneys and bones of *Eretmochelys imbricata* and *Chelonia mydas* specimens found stranded along the northern coast of Bahia, Brazil. Results showed that the concentrations of Cd, Cu, Ni and Zn in the liver and kidneys of juvenile *C. mydas* were the highest found in Brazil. We also observed a significant difference ($p < 0.05$) on the bioaccumulation of trace elements between the two species: Al, Co, Mo, Na and Se in the liver; Al, Cr, Cu, K, Mo, Ni, Pb, Sr and V in the kidneys; and Al, Ba, Ca, Cd, Mn, Ni, Pb, Se, Sr and V in the bones. This study represents the first report on the distribution and concentration of trace elements in *E. imbricata* in the Brazilian coast.

Environmental contaminants, such as trace elements and pesticides, may bioaccumulate in marine food chains and reach especially high concentrations in species, such as sea turtles, that are long-lived and occupy high trophic levels (Anan et al., 2001). Toxic elements exposure has been linked to serious diseases and developmental disorders, such as, reproductive impairment, immune-system diseases, neurological disorders as well as carcinogenic effects. The problem not only affects the terrestrial species, but also a variety of marine species, such as sea birds and marine mammals (De Guise et al., 2003; Franson, 1996; Law, 1996; Peakall, 1996; Reijnders, 2003).

In Brazil, sea turtles are fully protected by law and are included in the Brazilian government's official list of endangered fauna (Marcovaldi et al., 2011; Almeida et al., 2011). Hawksbills (*Eretmochelys imbricata*) are currently classified as Critically Endangered and green turtles (*Chelonia mydas*) as Endangered by the International Union for Conservation of Nature (IUCN, 2011). Sea turtles are clearly under threat of extinction due to human activities. Commercial fishing, marine pollution and loss of nesting habitat are among the human-caused threats pushing sea turtles toward extinction (Hamann et al., 2010). However, information regarding populations of sea turtles from Brazil is scarce. For example, although the recognized importance of Brazilian waters for the development and reproduction of several species of sea turtles, only three studies performed on sea turtles found in these waters were published recently (Barbieri, 2009a; Bezerra et al., 2012; Silva et al., 2014).

The Arembepe beach, located in the district of Camaçari, on the northern coast of Bahia, is one of the most important nesting grounds in Brazil (Marcovaldi and Marcovaldi, 1999). Recent studies also characterize the area as a potential foraging ground for juvenile *C. mydas* and *E. imbricata* (Macedo et al., 2011). The northern coast of Bahia, which hosts a great number of juvenile and adult turtles, also has an enormous industrial concentration, which poses a major threat to the sea turtles' survival. According to Bjorndal (2000) studies on foraging grounds are of great importance to determine priority conservation areas for sea turtle populations and to ensure ecological integrity.

Trace elements distribution and concentration have already been described in sea turtles at different stages of development. However, these data rarely exist for *E. imbricate*, especially along the Brazilian coast. This study aims to investigate the distribution and concentration of trace elements in tissues (liver, kidneys and bones) of two sea turtle species (*E. imbricata* and *C. mydas*) and to establish a comparison between the two species.

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Twenty-six necropsies were conducted on juvenile individuals of *E. imbricata* ($n = 16$) and *C. mydas* ($n = 10$), between January 2010 and July 2011. The animals were found stranded on Arembepe beach (-12,97786; -38,4216 at -12,70848; -38,12327), in Municipal District of Camaçari, Bahia, Brazil (Fig. 1). Most of the turtles apparently were alive when they beached, or had died very recently. Some of them died while being rehabilitated at Tamar Project rehabilitation facility, located in Praia do Forte, Mata de São João Municipal District, in the State of Bahia.

After determining the turtles' species, the animals were measured – curved carapace length (CCL) and curved carapace width (CCW) as suggested by Bolten (2000), had their sex determined by observation of the gonads and were assigned to one of four condition categories: good, fair, bad or emaciated. Tissue samples (liver, kidneys and bones) were collected during necropsy, placed in Ziploc bags and frozen at −20 °C for subsequent analysis. Additionally, we examined the occurrence of marine debris in the turtles' gastrointestinal tract.

Tissue samples were dried for 24 h in lyophilizer. Tissue fragments were then ground and weighed. Occasionally, insufficient tissue was obtained, specifically from *E. imbricata*, after the samples were weighed. For this reason, these samples were randomly paired and homogenized, generating a total of eight samples for *E. imbricata* and ten samples for *C. mydas* turtles.

The acid digestion of the samples was performed using a commercial high-pressure laboratory microwave oven (Milestone Ethos 1600 Microwave Labstation, Sorisole, Italy) operating at a frequency of 2450 Hz with an energy output of 900 W. Approximately 0.25 g of the tissue samples were placed in Teflon® vessels with a mixture of HNO_3 (3.5 mL), ultrapure water (3.5 mL) and H_2O_2 (1.0 mL). The heating programme was performed in four successive steps. In the first step the temperature was linearly increased up to 90 °C in 6 min. In the second step, the temperature was kept at 90 °C for 4 min. In the third step, the temperature was linearly increased up to 180 °C in 8 min and, in the fourth step the temperature was kept at 180 °C for 15 min. After cooling, the digest was diluted to 20 mL with ultrapure water. Three replicates of each sample were analyzed. Blank assays were carried out.

Twenty-two trace element concentrations (As, Al, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sr, V, Zn) were determined using inductively coupled plasma optical emission spectrometry (ICP OES) (Vista Pro, Varian, Australia) and

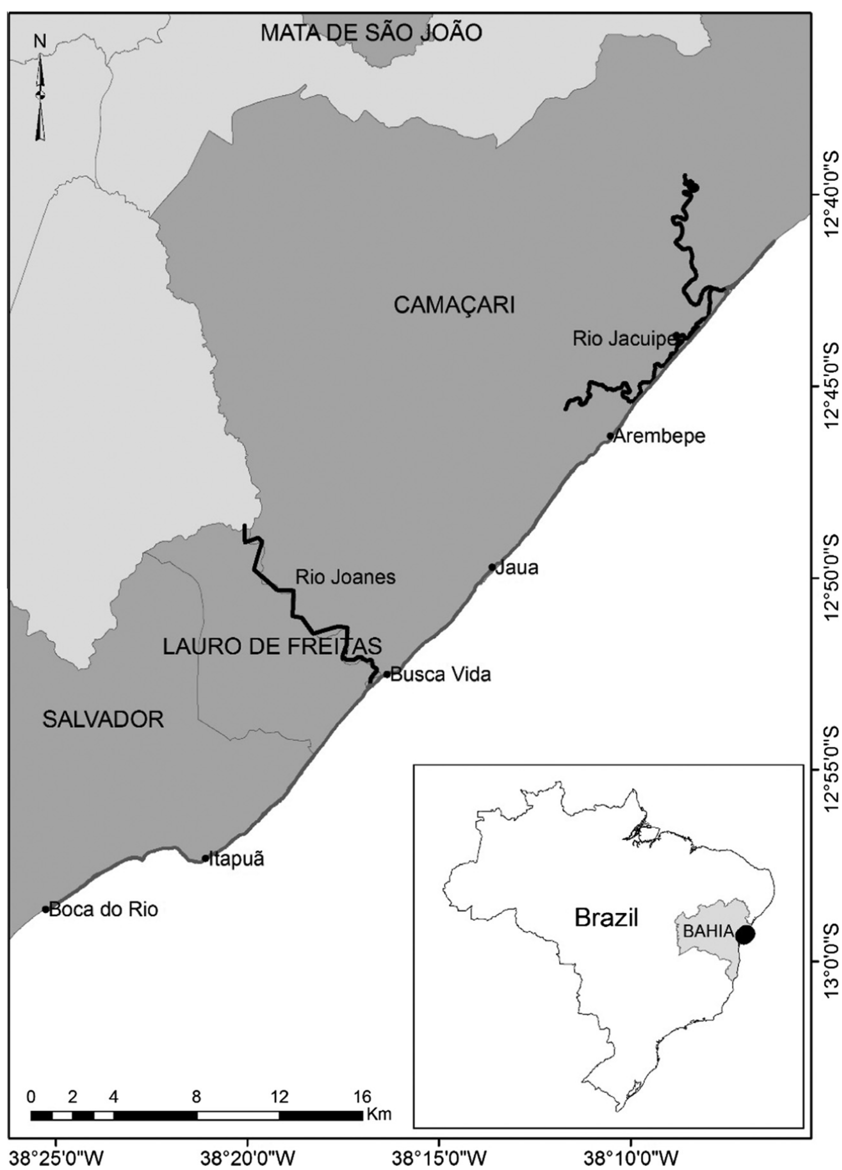

Fig. 1. Collection station in the Arembepe beach, Bahia State, Brazil.

Table 1
Analysis of reference material TORT-2 (lobster hepatopancreas): certified values, measured values (mean ± S.D.) and recovery (%).

Element	Observed values	Certified values	Recovery (%)
As	18.4 ± 0.9	21.6 ± 1.8	85
Cd	24.1 ± 0.4	26.7 ± 0.6	90
Co	0.60 ± 0.02	0.51 ± 0.09	118
Cr	0.92 ± 0.09	0.77 ± 0.15	119
Cu	95.0 ± 4.9	106 ± 10	90
Fe	97.2 ± 3.9	106 ± 13	92
Mn	13.2 ± 0.2	13.6 ± 1.2	97
Hg	0.30 ± 0.07	0.27 ± 0.06	111
Ni	2.52 ± 0.18	2.5 ± 0.19	101
Pb	0.29 ± 0.02	0.35 ± 0.13	83
Se	5.18 ± 1.88	5.63 ± 0.67	92
Sr	37.4 ± 3.3	45.2 ± 1.19	83
V	1.85 ± 0.18	1.64 ± 0.19	113
Zn	183 ± 3	180 ± 6	101

inductively coupled plasma mass spectrometry (ICP-MS) (XseriesII, Thermo Electron Corporation, Germany).

The concentrations were expressed in micrograms of metal per dry weight of tissue samples ($\mu g\ g^{-1}$). The limits of detection (LOD) and quantification (LOQ) of each analyte were calculated as the analyte concentration that corresponded to three and ten times, respectively, the standard deviation of ten independent measurements of the blank, divided by the slope of the calibration curve. Accuracy was evaluated using the certified reference material, TORT-2, Lobster Hepatopancreas (National Research Council Canada). The recoveries for As, Cd, Cu, Pb, Se and Zn varied from 83% to 119% (Table 1).

Concentrations of the elements analyzed in the livers, kidneys and bones of juvenile *C. mydas* and *E. imbricata* are presented in Table 2. A summary of biometric data, body condition and occurrence of marine debris in the gastrointestinal tract of juvenile *C.*

Table 2
Trace element concentrations (mean ± S.D. and variation in mg g^{-1} of dry weight) in liver, kidneys and bone of juvenile *C. mydas* and *E. imbricata* from Arembepe, Brazil.

	As	Al	Ba	Ca	Cd	Co	Cr	Cu	Fe
Liver									
C. mydas	29.8 ± 26.5	20.2 ± 21.7	ND	971 ± 913	18.8 ± 10.6	1.04 ± 0.50	0.60 ± 0.58	36.7 ± 9.3	4542 ± 2783
	(2.86–87.9)	(6.9–58.4)		(103–2899)	(8.48–40.0)	(0.52–2.00)	(0.24–2.15)	(21.6–51.6)	(573–10,013)
E. imbricata	30.3 ± 11.8	85.5 ± 57.7	ND	396 ± 229	20.1 ± 5.43	1.92 ± 0.92	0.68 ± 0.37	21.8 ± 9.2	5566 ± 1441
	(16.4–46.9)	(24.9–206)		(158–574)	(12.8–29.7)	(0.84–3.55)	(0.36–1.18)	(10.2–35.4)	(4207–7892)
Kidneys									
C. mydas	1205 ± 1054	69.6 ± 57.7	ND	2349 ± 1874	54.5 ± 21.2	4.44 ± 2.34	1.55 ± 0.59	13.6 ± 6.53	435 ± 232
	(578–4127)	(13.8–179)		(988–6470)	(24.9–93.6)	(1.61–8.54)	(0.75–2.74)	(6.72–27.4)	(74.1–630)
E. imbricata	1271 ± 480	318 ± 100	ND	804 ± 321	76.2 ± 38.1	2.01 ± 1.12	0.90 ± 0.21	7.03 ± 2.95	309 ± 145
	(811–2358)	(148–459)		(488–1420)	(15.5–124)	(0.53–3.79)	(0.64–1.21)	(3.02–11.3)	(126–481)
Bone									
C. mydas	7244 ± 667	<0.053	148 ± 69	4768 ± 89	<0.060	0.53 ± 0.27	1.01 ± 0.81	1.26 ± 1.37	44.7 ± 33.6
	(6395–8326)		(31–256)	(4656–4916)		(0.21–0.97)	(0.15–2.34)	(0.19–3.91)	(6.73–108)
E. imbricata	7006 ± 421	73.2 ± 22.6	71.0 ± 21.5	32,942 ± 348	0.56 ± 0.63	0.38 ± 0.09	0.65 ± 0.45	0.73 ± 0.73	41.5 ± 17.8
	(6511–7572)	(43.8–107)	(39.2–112)	(32,440–33,458)	(0.17–2.03)	(0.25–0.50)	(0.18–1.43)	(0.14–2.00)	(12.3–67.1)

	Hg	K	Mg	Mn	Mo	Na	Ni	Pb	Sb
Liver									
C. mydas	1.34 ± 0.61	7130 ± 1314	1043 ± 920	8.73 ± 2.45	1.09 ± 0.31	7929 ± 1246	0.79 ± 0.34	0.53 ± 0.45	0.08 ± 0.10
	(0.63–2.59)	(5404–9402)	375–3358	(6.00–14.1)	(0.59–1.71)	(6074–10,592)	(0.19–1.28)	(0.18–1.58)	(0.01–0.32)
E. imbricata	1.36 ± 0.61	8302 ± 658	1010 ± 251	7.97 ± 1.69	0.62 ± 0.26	9552 ± 1449	0.75 ± 0.39	0.27 ± 0.19	0.08 ± 0.15
	0.72–2.25	(7530–9339)	(606–1343)	(5.35–9.94)	(0.29–1.04)	(7704–11,715)	(0.41–1.66)	(0.08–0.62)	(0.01–0.44)
Kidneys									
C. mydas	0.36 ± 0.14	7653 ± 1021	1205 ± 1054	6.05 ± 2.81	0.70 ± 0.32	9418 ± 926	1.92 ± 1.41	0.15 ± 0.14	0.05 ± 0.02
	(0.12–0.60)	(5483–9107)	(578–4127)	(2.68–12.1)	(0.44–1.22)	(7865–11,066)	(0.63–5.21)	(0.03–0.48)	(0.02–0.07)
E. imbricata	0.57 ± 0.42	11,517 ± 1549	1271 ± 480	5.28 ± 1.88	0.31 ± 0.11	9699 ± 2164	0.72 ± 0.39	0.07 ± 0.09	0.11 ± 0.10
	(0.18–1.52)	(9737–14,923)	(811–2358)	(3.24–8.61)	(0.16–0.47)	(6393–12,760)	(0.22–1.15)	(0.02–0.24)	(0.01–0.23)
Bone									
C. mydas	<0.128	3566 ± 1464	7244 ± 667	4.68 ± 1.63	0.49 ± 0.77	5032 ± 615	3.52 ± 1.43	0.98 ± 0.61	<0.025
		(1974–6840)	(6395–8326)	(2.64–7.50)	(0.03–2.04)	(3892–5902)	(1.94–6.76)	(0.48–2.09)	
E. imbricata	<0.128	2748 ± 761	7006 ± 421	7.10 ± 2.12	0.09 ± 0.07	5387 ± 462	1.71 ± 0.3	0.64 ± 0.48	
		(1456–3800)	(6511–7572)	(5.25–11.2)	(0.005–0.21)	(4675–6097)	(1.48–2.42)	(0.27–1.52)	<0.025

	Se	Sr	V	Zn
Liver				
C. mydas	16.8 ± 7.8	11.9 ± 4.7	3.22 ± 5.57	132 ± 22
	(7.96–30.0)	(5.32–16.9)	(0.43–17.8)	(116–168)
E. imbricata	29.5 ± 4.80	11.3 ± 4.83	3.02 ± 5.41	144 ± 21.0
	(19.1–33.5)	(4.72–20.6)	(0.48–15.9)	(108–184)
Kidneys				
C. mydas	13.4 ± 6.3	11.5 ± 5.4	4.00 ± 2.44	151 ± 21
	(6.75–27.5)	(7.73–23.9)	(1.58–8.79)	(126–205)
E. imbricata	11.0 ± 1.9	5.14 ± 2.34	1.13 ± 1.18	121 ± 30
	(8.61–13.4)	(3.10–10.1)	(0.46–3.98)	(79.1–164)
Bone				
C. mydas	2.97 ± 0.45	1152 ± 318	<0.064	196 ± 34
	(2.35–3.73)	(637–1495)		(156–254)
E. imbricata	1.65 ± 0.41	772 ± 60	0.85 ± 0.39	215 ± 18
	(1.07–2.19)	(683–855)	(0.35–1.64)	(194–238)

Table 3
Summary of biometric data, body condition and occurrence of marine debris in the gastrointestinal tract of juvenile *C. mydas* and *E. imbricata* from Arembepe.

Species	Sex	CCL[a] (cm)	Weight (kg)	Body condition	Occurrence of marine debris
E. imbricata (n = 16)					
1	Female	33.4	2.77	Emaciated	–
2	Male	34.4	2.51	Emaciated	–
3	Female	30	1.55	Emaciated	–
4	Female	34.6	2.78	Emaciated	+
5	Female	32.7	3.02	Bad	–
6	Male	35.7	3.34	Bad	+
7	Female	37	3.40	Bad	+
8	Male	31.2	2.09	Emaciated	+
9	Female	30.9	2.17	Bad	+
10	Male	36.3	2.92	Emaciated	+
11	Male	29	1.75	Emaciated	+
12	Female	33.3	2.68	Emaciated	+
13	Female	34.6	2.39	Emaciated	–
14	Female	34.5	3.24	Emaciated	+
15	Female	33.8	2.52	Emaciated	+
16	Male	36.6	2.81	Emaciated	+
Mean		33.6 ± 2.36	2.62 ± 0.54		Positive = 11
C. mydas (n = 10)					
1	Female	33.3	3.25	Fair	+
2	Female	32.8	2.45	Emaciated	+
3	Female	36.8	4.66	Emaciated	+
4	Female	35.5	2.96	Emaciated	+
5	Female	36.5	3.91	Bad	+
6	Male	32.6	2.52	Emaciated	+
7	Female	39.3	3.41	Emaciated	+
8	Male	39.6	5.29	Bad	+
9	Female	30.8	2.02	Emaciated	+
10	Female	38.7	4.02	Emaciated	+
Mean		35.6 ± 3.1	3.45 ± 1.03		Positive = 10

[a] CCL = curved carapace length.

Table 4
Results of a non parametric test (Kruskal–Wallis) for trace element concentrations in different tissues of *C. mydas* and *E. imbricata*.

	Chelonia mydas	*Eretmochelys imbricata*	*p* value < 0.05
Liver			
Al	5.700	14.250	0.0006
Co	6.950	12.68750	0.0233
Mo	12.70	5.50	0.0045
Na	6.8000	12.8750	0.0164
Se	7.05000	12.56250	0.0293
Kidneys			
Al	6.6000	13.1250	0.0100
Cr	12.500	5.750	0.0077
Cu	12.30	6.00	0.0129
K	5.50	14.50	0.0004
Mo	13.300	4.750	0.0007
Ni	12.6000	5.6250	0.0058
Pb	11.85000	6.56250	0.0354
Sr	12.8000	5.3750	0.0034
V	12.900	5.250	0.0025
Bone			
Al	5.50	14.50	0.0001
Ba	12.4000	5.8750	0.0100
Ca	5.50	14.50	0.0004
Cd	5.50	14.50	0.0001
Mn	6.900	12.750	0.0208
Ni	13.2000	4.8750	0.0010
Pb	11.95000	6.43750	0.0293
Se	11.90	6.50	0.0329
Sr	11.90	6.50	0.0330
V	6.0000	13.8750	0.0004

mydas and *E. imbricata* are shown in Table 3. The analysis of variance showed differences in hepatic, renal and osseous trace element concentrations between the two species of sea turtles analyzed in this study.

Significant differences ($p < 0.05$) in the hepatic concentrations of Al, Co, Mo, Na and Se were observed between the two species. Moreover, significant differences in the renal concentrations of Al, Cr, Cu, K, Mo, Ni, Pb, Sr, V and in the osseous concentrations of Al, Ba, Ca, Cd, Mn, Ni, Pb, Se, Sr, V were also observed.

The turtles were all determined to be juveniles (curved carapace length range: 34–38 cm). Due to the similarity of their biometric characteristics, curved carapace length was not used as a variable that influenced the concentrations of trace elements. On clinical examination, 73% (19/26) of the turtles were classified as emaciated based on a body weight that was less than expected for known carapace length, a concave plastron and a sunken neck. Additionally, necropsies were performed and marine debris abundance in gastrointestinal tract was recorded. Debris was found in 21 of 26 turtles, which corresponds to 80.7% of the animals. Data for each species (*C. mydas* and *E. imbricata*) were also analyzed separately: anthropogenic debris was ingested by 100% (10/10) of the green turtles and by 68.75% (11/16) of the hawksbill turtles.

Trace element concentrations reported in this study were found in at least one of the three tissues examined from each turtle. The distribution pattern of trace elements between the both species was similar in the liver, kidneys and bone. This finding corroborates the ideas of Anan et al. (2001) that despite a few variations in the studied metal concentrations between green turtles and hawksbill turtles, trace elements tend to show a proportionally similar organotropism. The concentrations of Al, Cd, and V in the bones were determined only for the species *E. imbricata*, while in the species *C. mydas*, these elements were below the limits of detection. Data on the accumulation of trace elements in the bones of *E. imbricata* are scarce. Therefore, the results in this topic were generally difficult to interpret.

We found significant differences in certain trace element concentrations in tissues analyzed from both species, as shown in Table 4. These differences may be partially explained by differences in feeding habits and habitat use of *C. mydas* and *E. imbricata*. According to Bjorndal (1997), in sea turtles, different dietary patterns may cause different patterns of accumulation. However, it is relevant to cite that pollution exposure of sea turtles may vary according to the level of contamination in the foraging grounds and time spent in these areas. Hawksbill turtles are known to feed mainly on marine sponges (Meylan, 1988), while green turtles feed primarily on sea grasses and algae (Bjorndal, 1997).

According to Araújo et al. (2003), trace elements tend to accumulate in marine sponges. However, further comparative studies on trace element accumulation in marine sponges between polluted and non-polluted sites are required. Additionally, a method to analyze if high pollutant concentrations are a result of environmental pollution or a bioaccumulation process resulting from marine sponges metabolism, would also be of great importance. The authors also evaluated the concentrations of trace elements in areas with little human activity in order to determine toxicity and bioaccumulation associated with rates of growth and metabolism of sponges. They found that these animals have low levels of Al, Si, Ti, Mn, Fe and Zr, but at the same time, high levels of Sr and Ca were observed. So far, there is no data available on the concentration of trace elements in marine sponges in our study area. Recently, Brito et al. (2012) determined trace elements in ten species of macroalgae collected from six sites in the Todos os Santos Bay, Bahia, Brazil, and reported high levels of As, Cd, Co, Mn, Ni, Pb and Zn.

The distribution and concentrations of trace elements in sea turtles are reported in different parts of the world (Anan et al., 2001; Lam et al., 2004; Storelli et al., 2008; Barbieri, 2009a). The abundances of elements can be significantly influenced by species

Table 5
Mean concentrations of trace elements (1 μg g^{-1} dry weight) in tissues of *E. imbricata* and *C. mydas* from different studies.

	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	References
Liver									
C. mydas	18.8 ± 10.6	0.60 ± 0.58	36.7 ± 9.3	1.34 ± 0.61	0.79 ± 0.34	0.53 ± 0.45	16.8 ± 7.8	132 ± 22	Present study
	18.2 ± 9.7	2.2 ± 0.6	139 ± 86	0.42 ± 0.19	NA[b]	0.51 ± 0.41	5.1 ± 2.3	87.2 ± 30.6	Anan et al. (2001)
	1.09 ± 0.99	<LOQ[a]	133 ± 148.6	0.78 ± 0.19	0.27 ± 0.25	0.15 ± 0.04	25.65 ± 28.6	128.9 ± 63.9	Lam et al. (2004)
	4.26 ± 3.02	NA[b]	32.75 ± 16.42	NA[b]	NA[b]	NA[b]	NA[b]	34.53 ± 13.36	Storelli et al. (2008)
	0.279 ± 0.14	NA[b]	20.7 ± 2.46	NA[b]	0.13 ± 0.04	0.06	NA[b]	NA[b]	Barbieri (2009a)
	5.9 ± 0.9	NA[b]	100.9 ± 15.9	NA[b]	NA[b]	4.5 ± 0.5	NA[b]	45.0 ± 2.9	Silva et al. (2014)
E. imbricata	20.1 ± 5.4	0.68 ± 0.37	21.8 ± 9.2	1.36 ± 0.61	0.75 ± 0.39	0.27 ± 0.19	29.5 ± 4.8	144 ± 21	Present study
	7.05 ± 6.37	0.85 ± 0.68	54.9 ± 116	0.87 ± 1.87	NA[b]	0.17 ± 0.13	49 ± 37	109 ± 54	Anan et al. (2001)
Kidneys									
C. mydas	54.5 ± 21.2	1.55 ± 0.59	13.6 ± 6.5	0.36 ± 0.14	1.92 ± 1.41	0.15 ± 0.14	13.4 ± 6.3	151 ± 21	Present study
	142 ± 64	2.2 ± 0.7	8.27 ± 4.06	0.30 ± 0.14	NA[b]	0.81 ± 0.56	5.3 ± 2.4	169 ± 61	Anan et al. (2001)
	2.49 ± 1.74	1.06 ± 0.4	15.2 ± 7.22	0.34 ± 0.04	0.20 ± 0.12	0.31 ± 0.19	5.89 ± 1.25	143 ± 12	Lam et al. (2004)
	5.06 ± 2.23	NA[b]	8.20 ± 4.20	NA[b]	NA[b]	NA[b]	NA[b]	26.39 ± 10.51	Storelli et al. (2008)
	1.00 ± 0.32	NA[b]	12.55 ± 1.04	NA[b]	0.09 ± 0.01	0.17	NA[b]	NA[b]	Barbieri (2009a)
	28.3 ± 2.3	NA[b]	12.2 ± 1.1	NA[b]	NA[b]	5.4 ± 0.4	NA[b]	54.3 ± 4.1	Silva et al. (2014)
E. imbricata	76.2 ± 38.1	0.90 ± 0.21	7.03 ± 2.95	0.57 ± 0.42	0.72 ± 0.39	0.07 ± 0.09	11.04 ± 1.88	121 ± 30	Present study
	93.7 ± 76.3	1.6 ± 0.8	7.04 ± 2.79	1.3 ± 1.2	NA[b]	0.27 ± 0.24	28 ± 19	120 ± 32	Anan et al. (2001)
Bone									
C. mydas	<LOQ[a]	1.01 ± 0.81	1.26 ± 1.37	<LOQ[a]	3.52 ± 1.43	0.98 ± 0.61	2.97 ± 0.45	196 ± 34	Present study
	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	NA[b]	Anan et al. (2001)
E. imbricata	0.56 ± 0.63	0.65 ± 0.45	0.73 ± 0.73	<LOQ[a]	1.71 ± 0.3	0.64 ± 0.48	1.65 ± 0.41	215 ± 18	Present study

[a] LOQ = limit of quantification.
[b] NA = not analyzed.

variations, life stage of the animals, dietary differences between populations from different feeding grounds, natural trace element concentrations as well as anthropogenic trace element concentrations in the environment (Barbieri, 2009a).

High concentrations of Al were found in both examined turtle species. Indeed, significantly higher levels of the element were observed in all the tissues from *E. imbricata* turtles. These results may be explained by their intrinsic characteristics, based on their feeding habits or even on their metabolic properties. Acquiring more specific data on the concentration of Al and other trace elements in algae and sponges found along the study area, could contribute to the correct interpretation of these results.

According to Anan et al. (2001), trace element concentrations difference cannot be solely attributed to the diet and feeding habits of each sea turtle species. The authors suggest that further studies be performed regarding dynamic interactions of sea turtles at different life stages in order to measure the trophic transfer of elements and evaluate the influence of body size and food habits on the accumulation of contaminants in these animals.

The overall mean values for cadmium in the liver and kidney samples of *C. mydas* were 18.8 μg g^{-1} and 54.5 μg g^{-1}, respectively. Cadmium concentrations in the osseous tissue were below the limits of detection. The cadmium concentrations for the liver are similar to those found by Anan et al. (2001). However, the author found higher values for this element in the kidneys of *C. mydas*. These are the highest values recorded in the literature, as shown in Table 5. As for *E. imbricata*, the Cd values in liver samples from this study were significantly higher than those found by Anan et al. (2001), while the concentrations for the kidneys were similar. Cadmium can be highly toxic to marine life, such as fish and shrimp (Barbieri, 2007, 2009b). However, according to Tan et al. (2010) *C. mydas* line cells were found to be more tolerant to cadmium than human or fish cells, suggesting green turtles might be more resistant.

The Zn concentrations for all tissues were similar to those found in other studies, except for the results reported by Storelli et al. (2008), which were slightly lower when compared to other research values (Table 5). Copper values in liver samples were significantly lower than those found in turtles from Asia (Anan et al., 2001; Lam et al., 2004). According to Maffucci et al. (2005), both zinc and copper are regulated by homeostatic processes and are considered essential trace metal in small concentrations for several metabolic functions. Additionally, the values reported here are not likely to be high enough to pose any direct toxic effect on sea turtles.

Mercury concentrations were relatively high when compared to other published studies, with exception of *E. imbricata* kidneys (Table 5), which contained lower concentrations of the element. Mercury values in the osseous tissue from both species were below the limit of quantification. Bezerra et al. (2012) reported finding mercury concentrations in carapace fragments of green turtles along the coast of Ceará State, Brazil. According to the authors, their average results were in the lower range of reported Hg concentrations for *C. mydas* (average of 154.8 ng g^{-1} d.w.), which possibly suggests a smaller Hg exposure. Overall, the Hg levels we found in this study are actually in line with what has been reported in other studies. Storelli et al. (1998) also found lower than expected values for loggerheads. Considering that this species feeds mainly on mollusks and crustaceans, the concentrations are expected to be magnified as they move up the food web. According to Lam et al. (2004) mercury is potentially toxic to the nervous and immune systems, therefore, monitoring this element is important for the environment, and animal and human health.

The highest concentrations of lead were found in the bones of both species, which corroborates the findings of Sakai et al. (2000). According to this author, sea turtle bone and carapace are known to be important tissues for the accumulation of lead. However, in this study, lead was also found in other tissues. Liver samples reached concentrations of more than six times the ones found by Barbieri (2009a) on the coast of São Paulo. These findings indicate that sea turtles from Arembepe were exposed to high levels of lead. The toxicity of lead and its compounds may cause various symptoms, such as chronic anemia, immune system suppression and the development of neoplasias (Beyersmann and Hartwig, 2008). According to Barbieri (2009a) marine animals are especially prone to the health effects of lead, because of the large amount of the element which is deposited yearly in the oceans. Additionally, lead can easily enter the food chain and accumulate in animal tissues.

To the best of our knowledge, this is the first detailed report of selected trace elements in the tissues of sea turtle species in this region. Our results show significant differences in terms of contamination levels between the turtles from Arembepe and turtles that occur in other places. This highlights the importance of the time spent in foraging grounds and the level of contamination of these sites. It can be concluded that sea turtles may serve as sensitive biomarkers for the toxicity of certain trace elements. However, further studies are required for a better understanding of its deleterious effects.

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