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Heavy metal accumulation in four species of sea turtles from the Baja California peninsula, Mexico

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Abstract

Heavy metals were assessed in four species of sea turtles from the Baja California Peninsula, Mexico, representing the first report of heavy metal concentrations in tissues of post-yearling sea turtles from the Eastern Pacific. Concentrations of Cd measured in *C. mydas* kidney (653 μg/g dry wt) were the highest ever reported for any sea turtle species. Cd accumulated preferentially in kidney and the ratios of kidney to liver Cd in Baja California turtles were among the highest reported for sea turtles globally. Zn, Ni, and Mn concentrations were also significantly higher in kidney than other tissues, while Cu and Fe were greatest in liver, and all metals were lowest in muscle. With the exception of one value (69.9 μg/g in kidney of *C. caretta*), Pb was low in all tissues from Baja California. In comparisons across species, kidney of *C. mydas* had greater Zn and Ni concentrations as compared to other species, although there was no difference in liver metal levels among the species. Positive correlations were detected in the concentrations of Cd, Cu and Ni with the straight carapace length of *C. caretta*.

Introduction

The Baja California Peninsula, Mexico serves an important role as feeding and developmental grounds for four of the world's seven sea turtle species: Eastern Pacific green turtles, locally known as black turtles (*Chelonia mydas agassizii*), Pacific loggerhead (*Caretta caretta*), olive ridley (*Lepidochelys olivacea*), and hawksbill (*Eretmochelys imbricata*) (Clifton *et al.* 1982; Gardner & Nichols 2001). Although once abundant throughout their range, all sea turtle species are considered endangered or threatened with extinction and populations worldwide are decreasing at alarming rates (IUCN 1995). Pollution and pollution-related disease have been cited as presenting increasingly greater threats to sea turtle populations (Waldichuk 1987; Hutchinson & Simmonds 1992; Keller *et al.* 2004). However, very little information is currently available describing baseline levels of contaminants and their effects on sea turtle populations, especially in the eastern Pacific.

Although currently much of the peninsula remains relatively undeveloped, the State of Baja California Sur has mineral deposits of gold, silver, copper, zinc, and phosphorous which have been exploited since the nineteenth century (Shumilin *et al.* 2000). During the past 30 years, the human population and development of this region have increased exponentially. Well-developed commercial and artisanal fisheries encompass virtually all of the coastal areas and important plans for building large harbors are in progress. Concentrations of metals such as Zn, Cu and Pb in sediment and mollusks of some regions have been reported above those in industrialized zones in Russia and the USA (Gutiérrez-Galindo *et al.* 1999; Shumilin *et al.* 2000). Cd concentrations in Baja California mussels (2.7–70.2 μg/g ww; Gutiérrez-Galindo *et al.* 1999) are higher than in biota from highly urbanized areas of the US State of California (0.2–0.9 μg/g ww; Cohen *et al.* 2001). Cd concentrations in plankton off Baja California were approximately 3 times higher than in the plankton collected in other sampled regions of the northeast Pacific (Martin & Broenkow 1975). These authors concluded that "an extraordinary situation in regard to this toxic element may well exist off Baja California." High regional variability in heavy metal concentrations in coastal waters off Baja California has been attributed to both natural (e.g. upwelling and water column mixing) and anthropogenic (e.g. phosporite mining and urbanization) causes (Martin & Broenkow 1975, Sañuda-Wihelmy & Flegal 1996; Méndez *et al.* 1998; Gutiérrez-Galindo *et al.* 1999; Shumilin *et al.* 2001). However, the relative contribution of these various sources of heavy metals to the region is poorly understood, as are their effects on human and ecological health.

Little is known of the accumulation of heavy metals in Baja Californian fauna such as sea turtles. Studies of contaminants in sea turtles from northwestern Mexico are sparse (Presti *et al.* 1999; Gardner *et al.* 2003) and no data are available on heavy metals in organs of post-yearling turtles from the Eastern Pacific. Therefore, the objective of this study was to assess heavy metal residues in sea turtles from the Baja California peninsula.

Materials and methods

Sample collection

Liver, kidney, adipose and pectoral muscle tissues were collected from sea turtles that died as a result of incidental fisheries capture along the Baja California Peninsula in northwestern Mexico. The species was identified and the straight carapace length of each turtle was recorded using 1 m calipers, taken from the anterior nuchal notch to the longest posterior point of the carapace. Samples were obtained only from individuals for which the approximate time of death could be estimated as less than 24 h. Tissue samples were stored in plastic bags and placed on ice for transport to the laboratory where they were frozen at −80 °C until analyzed.

Laboratory analyses

Tissue samples (0.5 g) were dried in an oven at 70 °C until a dry weight was obtained and then digested in acid-washed Teflon tubes with concentrated nitric acid in a microwave oven (CEM model Mars 5X, Matthews, NC). Samples of kidney, liver, and muscle were digested in 8 ml of concentrated nitric acid and 2 ml of deionized water. The adipose samples were digested in 8 ml of nitric acid and 2 ml of H_2O_2 and taken to 25 ml with deionized water in a volumetric flask. Samples were analyzed by atomic absorption (GBC Scientific equipment, model AVANTA, Dandenong, Australia) using an air–acetylene flame. The certified standard reference material TORT-2 (National Research Council of Canada, Ottawa) was used to verify accuracy, and the analytical values were within the range of certified values. All recoveries of metals analyzed were over 95%. Detection limits were: Zn = 0.0008, Cd = 0.0009, Mn = 0.002, Cu = 0.0025, Ni = 0.004, Fe = 0.005, Pb = 0.006 μg/g.

Quantitative analyses

Reported statistics are geometric means ($n > 2$) and ranges in μg/g on a dry weight basis. Contaminants reported as less than the detection limit in individual samples were replaced with a random number between the detection limit and one-half the detection limit (Travis & Land 1990). The Kruskal–Wallis (Wilcoxon) test was used for conducting multiple sample comparisons. Analyses were conducted for each metal separately, and comparisons of metal concentrations across species were conducted individually for each tissue. When statistically significant differences were detected, a median notch Box and Whisker Plot was used to identify where those differences existed and confirmed with the multiple range test using Fishers Least Significant Difference (LSD). A method for age determination in sea turtles is not yet established, therefore straight carapace length (SCL) was used to determine size as a relative indicator of age. Correlations of metal concentrations in each tissue with turtle SCL were determined for each species separately using simple regression analyses establishing $R^2 > 50\%$ as the indicator of correlation. Preliminary analyses of the data suggested that the concentrations of Cd in kidney and liver presented a potential for toxicological impacts. Therefore, correlations of Cd concentrations with other metals were analyzed in these tissues. *E. imbricata* was not included in these comparisons because of the lack of replicate samples. The rejection limit was established at $p < 0.05$ unless otherwise noted. For the purposes of comparison, values presented as wet weight in published literature were converted to dry weight using the ratio = 6.8 and 4.9 established for sea turtle kidney and liver, respectively by Gordon *et al.* (1998).

Results and discussion

Comparison of metal concentrations across species

For reptiles in general, individual variation in metal bioaccumulation likely result from differences in exposure due to resource partitioning (Linder & Grillitsch 2000). In adult sea turtles, food habits differ greatly among species (Mckenzie *et al.* 1999; Saeki *et al.* 2000); *L. olivacea* consume crustraceans, *C. caretta* eat a wide range of bottom-dwelling invertebrates, *C. mydas* eat primarily marine algae and sea grasses, and *E. imbricata* specialize on bottom-dwelling sponges. Within each species, diet content also varies depending on the age and location of the turtle as well as the availability of food resources (Lopez Mendilaharsu *et al.* 2003, 2005). The observation that concentrations of contaminants are often higher in *C. caretta* than in *C. mydas* is consistent with interspecific differences in diet and trophic status (Meyers-Schoene & Walton 1990; Sakai *et al.* 1995; Godley *et al.* 1999). The present study represents the first report of heavy metal concentrations in tissues and organs of post-yearling sea turtles from the Eastern Pacific.

A total of 23 turtles were collected, 11 *C. mydas*, five *C. caretta*, six *L. olivacea* and one *E. imbricata* (Table 1). Metal concentrations in the liver of sea turtles from Baja California did not vary among the species compared. However in kidney, *C. mydas* had greater Zn concentrations as compared to the other species ($p = 0.008$), and greater Ni concentrations as compared to *L. olivacea* ($p = 0.04$) (Table 2). In adipose, the concentration of Zn in *C. mydas* was also greater than *L. olivacea* ($p = 0.006$). Studies conducted in Baja California have shown that Ni and Zn tend to be concentrated in marine algae, which have the capacity to accumulate trace metals several thousand times higher than the concentration in seawater (Bryan & Langston 1992; Sánchez-Rodríguez *et al.* 2001). Element abundance in marine flora appears to be controlled by both the bioavailability of metals in the surrounding water, and the uptake capacity of the particular plant species. In Baja California, studies have demonstrated that red algae (the predominant food of juvenile *C. mydas* in some regions) tend to have higher enrichment factors of heavy metals than other groups of seaweeds (Sánchez-Rodríguez *et al.* 2001), which could result in a higher exposure of these elements in *C. mydas* as compared to the other sea turtle species studied.

Table 1. Range and mean straight carapace length (SCL) of four species of sea turtles collected along the Baja California peninsula, Mexico. Standard deviation of the mean is provided in parentheses and *N* represents sample size.

Species	*N*	SCL (cm)	
		Range	Mean (SD)
C. mydas	11	48.5–76.9	62.13 (10.9)
C. caretta	5	52.0–63.0	57.0 (4.6)
L. olivacea	6	53.0–66.0	60.1 (5.1)
E. imbricata	1	48.4	48.4

Mn concentration in *C. mydas* adipose ($p = 0.0004$) and kidney ($p = 0.01$) were lower than the other species and lower than *C. caretta* in muscle ($p = 0.01$) (Table 2). The reason for the low Mn concentrations observed in *C. mydas* remains to be determined. Data on metal residues in most components of the sea turtle diet is lacking and further studies will be required in order to determine the extent to which variation in route of exposure versus metabolism contribute to difference in the bioaccumulation of heavy metals among sea turtle species.

Comparison of metal concentrations in tissues

With the data from all 4 species combined, kidney had higher concentrations of Ni ($p = 0.054$), Zn

Table 2. Metal concentrations in tissues from four sea turtle species collected along the Baja California peninsula, Mexico. Data are expressed as geometric means (μg/g dry weight) with ranges given in parentheses. nd signifies not detected.

Tissue	Species	Metal						
		Pb	Fe	Cd	Ni	Cu	Zn	Mn
Liver								
	C. mydas	nd	14.35 (nd–1765)	3.30 (nd–102)	0.01 (nd–7.40)	60.04 (6.79–133)	62.91 (1.32–166)	0.06 (nd–6.74)
	C. caretta	nd	301 (71.88–2042)	1.75 (nd–30.62)	0.35 (nd–3.26)	33.94 (16.6–58.98)	69.14 (42.45–91.87)	1.29 (0.11–8.60)
	L. olivacea	nd	731 (119–9201)	17.89 (4.98–148)	0.58 (nd–3.88)	36.73 (16.99–100)	47.14 (18.66–85.75)	0.1 (nd–9.2)
	E. imbricata	nd	71.88	0.49	2.48	2.47	25.89	0.74
Kidney								
	C. mydas	0.01 (nd–0.36)	44.09 (nd–516)	121 (6.09–653)	1.15 (nd–26.43)	5.67 (1.59–20.36)	128 (1.59–330)	0.31 (nd–8.12)
	C. caretta	0.03 (nd–69.89)	237 (94.59–660)	73.11 (13.72–140)	0.04 (nd–3.38)	4.35 (1.39–8.23)	32.47 (2.68–130)	6.0 (2.37–9.97)
	L. olivacea	0.03 (nd–2.63)	193 (40.37–667)	60.03 (0.81–274)	0.02 (nd–2.46)	4.86 (0.81–53.40)	6.68 (0.43–114)	5.31 (3.93–7.52)
	E. imbricata	nd	362	4.20	1.61	3.89	82.45	7.62
Muscle								
	C. mydas	0.01 (nd–1.23)	20.99 (nd–225)	0.01 (nd–39.24)	0.03 (nd–4.0)	0.03 (nd–13.76)	38.26 (10.44–134)	0.003 (nd–7.75)
	C. caretta	0.01 (nd–1.57)	77.44 (52.48–97.12)	0.1 (nd–1.45)	0.01 (nd −0.65)	0.41 (nd–3.44)	31.11 (0.63–100)	0.84 (nd–5.4)
	L. olivacea	nd	93.09 (57.35–319)	0.48 (nd–8.85)	0.01 (nd–0.41)	1.28 (0.7–4.37)	85.78 (49.89–107)	0.77 (nd–4.34)
	E. imbricata	0.38	258	1.02	nd	3.68	102	1.78
Adipose								
	C. mydas	0.03 (nd–1.11)	2.63 (nd–154)	0.002 (nd–1.47)	0.02 (nd–13.42)	0.01 (nd–9.48)	49.82 (19.51–163)	0.003 (nd–0.79)
	C. caretta	nd	1.33 (nd–13.61)	0.5 (0.2–1.37)	0.17 (nd–1.63)	0.69 (0.53–1.15)	12.66 (0.53–44.76)	1.82 (0.8–3.2)
	L. olivacea	nd	27.91 (6.37–236)	0.69 (0.33–2.54)	0.03 (nd–0.51)	0.83 (0.47–2.54)	3.7 (0.41–16.65)	2.1 (0.88–3.65)
	E. imbricata	nd	11.14	0.43	nd	0.72	42.39	2.53

($p = 0.009$), Cd ($p < 0.001$) and Mn ($p = 0.004$) as compared to the other tissues analyzed (Table 2). However, concentrations of Cu and Fe were greatest in liver ($p \leq 0.001$ for both) and all metals analyzed were lowest in muscle.

Correlation of metal concentrations with SCL

The SCL of the sea turtles in the present study ranged from 48.4 to 76.9 cm (Table 1) and no difference in the SCL between species was detected ($p = 0.69$). In *C. caretta*, moderately strong relationships were detected in metal concentrations with sea turtle size, similar to what has been observed in other marine vertebrates (Honda *et al.* 1986; Malcolm *et al.* 1994; Noda *et al.* 1995). Positive correlations with SCL were detected in Cd and Cu measured in *C. caretta* kidney (Cd: corr. coef. = 0.724; Cu: corr. coef. = 0.822) and Ni concentration was positively correlated with the SCL in both kidney (corr. coef. = 0.892) and liver (corr. coef. = 0.853) (Figure 1).

No correlations were detected in the concentrations of metals with the SCL of *C. mydas* or *L. olivacea* ($R^2 <$ 50%). Previous studies of *C. mydas* have reported negative correlations of metals (e.g. Cd, Cu, Mn and As) and turtle size (Gordon *et al.* 1998; McKenzie *et al.* 1999; Saeki *et al.* 2000, 2000a). This tendency has been attributed to an ontogenetic shift in *C. mydas*' feeding habit from carnivorous during their post-hatchling pelagic stage, to primarily herbivorous as juveniles and adults. Thus, maximum exposure may occur early in the life cycle when the turtles' food consumption is of higher trophic level organisms. McKenzie *et al.* (1999) predicted that as the turtles grew, the body burden of contaminants would be diluted and the intake of contaminants reduced by a change in diet with age from carnivorous to herbivorous. However, the range of turtle SCL in our study was small compared to previous studies (for example 40–80 cm, Saeki *et al.* 2000). Additionally, the lack of a relationship could be attributed to variability in feeding habit shifts among individual turtles as suggested by previous researchers (Sakai *et al.* 2000a).

Cadmium

In marine mammals, the main body stores of Cd are the kidney and liver (O'Shea 1999) and the distribution of metals among organs is influenced by both duration and concentration of exposure. Studies of fresh water turtles have demonstrated that after a single injection, the highest concentration of Cd is found initially in the liver, which is a major site of short-term storage (Thomas *et al.* 1994; Rie *et al.* 2001). However, tissue Cd concentrations found in free-ranging reptiles generally indicate a shift from the liver to the kidney. During long-term exposure, Cd is redistributed from the liver via the blood and transported as a metallothionein-complex to the kidney, where it is absorbed and concentrates (Linder & Grillitsch 2000). Accordingly, the highest concentrations of Cd found in Baja California sea turtles were in kidney ($p \leq 0.001$) and the average ratio of kidney to liver Cd concentrations in these species (22.6) was among the highest reported in studies of sea turtles globally (Table 3).

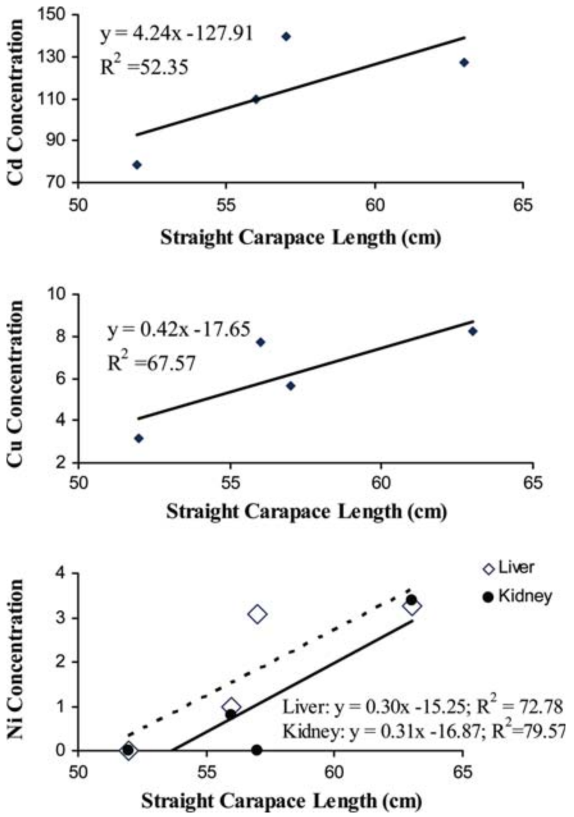

Figure 1. Concentration of heavy metals (μg/g) with size (straight carapace length) of *C. caretta* from the Baja California Peninsula, Mexico. Values represent metal concentrations in kidney unless otherwise noted.

Table 3. Concentration of cadmium (µg/g) in liver and kidney of sea turtles from different geographical regions. Values represent means (dry weight) with the ranges provided in parentheses, unless otherwise noted. In the cases where concentrations were reported as wet weight, values were converted to dry weight based on the conversion factors established by Gordon *et al.* (1998) for sea turtle liver and kidney (4.9 and 6.8, respectively). n indicates sample size for liver and kidney.

Species	Location	Cadmium Concentration	
		Liver	Kidney
C. mydas			
(*n* = 11,11)	Baja California, Mexico[a]	3.3 (nd–103)	121 (6.09–653)
(*n* = 5, 23)	Okinawa, Japan[b]	28.42 (1.47–91.14)	261.8 (49.71–549)
(*n* = 13, 2)	Cape Ashizuri, Kochi, Japan[c]	45.57 (1.91–127)	176.8 (32.10–477)
(*n* = 1, 1)	Cape Ashizuri, Kochi, Japan[d]	19.11	251.6
(*n* = 6, 1)	Cyprus, Mediterranean Sea[e]	5.89 (2.53–10.73)	3.46
(*n* = 12, 12)	Hawaii[f]	45.57 (1.91–127)	176.8 (32.44–277)
(*n* = 2, 2)	South china Sea[g]	1.1	2.48
(*n* = 38, 38)	Australia[h]	61.25 (12.25–279)	104 (11.56–516)
(*n* = 26, 25)	Yaeyama, Japan[i]	18.2 (3.58–38.3)	142 (20.3–285)
C. caretta			
(*n* = 5, 5)	Baja California, Mexico[a]	1.75 (nd–30.62)	73.11 (13.72–140)
(*n* = 7, 7)	Cape Ashizuri, Kochi, Japan[c]	45.52 (27.73–71.54)	268 (123–384)
(*n* = 6, 6)	Cape Ashizuri, Kochi, Japan[d]	47.73	260
(*n* = 12, 12)	South Adriatic Sea, Italy[j]	7.60 (3.06–20.23)	24.23 (0.39–64.0)
(*n* = 4, 2)	Cyprus, Mediterranean Sea[e]	8.64 (5.14–12.97)	30.50 (18.80–42.20)
(*n* = 8, 5)	Australia[h]	80.36 (35.77–239)	192 (77.52–268)
(*n* = 7, 5)	Pertuis charentais, France[k]	12.64 (1.47–57.82)	90.44 (11.42–243)
D. coriacea			
(*n* = 18, 5)	Pertuis charentais, France[k]	33.52 (2.94–72.03)	206 (57.60–422)
L. olivacea			
(*n* = 6, 6)	Baja California, Mexico[a]	17.89 (4.98–148)	60.03 (0.81–274)
(*n* = 1, 1)	Australia[h]	31.36	202.64
E. imbricata			
(*n* = 1, 1)	Baja California, Mexico[a]	0.49	4.20
(*n* = 22, 19)	Yaeyama, Japan[i]	7.05 (1.80–33.6)	93.7 (19.1–310)

[a]present study (geometric mean), [b]Sakai *et al.* (2000a), [c]Sakai *et al.* (1995), [d]Sakai *et al.* (2000b), based on values for female turtles, [e]Goldey *et al.* (1999) (median), [f]Aguirre *et al.* (1994) (median), [g]Lam *et al.* (2004), [h]Gorden *et al.* (1998), [i]Anan *et al.* (2001), [j]Storelli *et al.* (1998), [k]Caurant *et al.* (1999).

Maximum concentrations of Cd measured in kidney of *C. mydas* (653 µg/g) and *L. olivacea* (274 µg/g) from Baja California were the highest ever reported for these species (see Storelli & Marcotrigiano 2003 for summary) and are far above the levels generally reported for other marine vertebrates (Dietz *et al.* 1996; Beck *et al.* 1997; Cardellicchio *et al.* 2002; Méndez *et al.* 2002). The highest Cd concentration previously reported for any sea turtle species was 549 µg/g in *C. mydas* kidney from Japan (Sakai *et al.* 2000a).

Information on the toxicological effect of Cd on reptiles is lacking, so predicting the consequences of the observed Cd residues on sea turtle population health is currently not possible. However, information generated for other vertebrates suggests that detrimental effects to organs can be anticipated at Cd tissue levels below 200 µg/g (Ellis *et al.* 1984). Therefore, it is reasonable to speculate that the current Cd concentrations found in the tissues of sea turtles from Baja California should warrant concern for the health of these species. Moreover, although regulations exist that forbid the capture or consumption of sea turtles in Mexico, there are numerous natural resource-dependent communities along the Baja California Peninsula, in which sea turtles have been historically and currently consumed as a cultural tradition. The levels of Cd measured in sea turtles from this region exceed the established food safety guidelines for Cd by 25–250 times depending on the regulatory standards of the country (2.5 µg/g in Mexico, Norma 1993; 25 μg/g in USA, USFDA 1990) and could present a health threat for indigenous communities that consume these species.

Correlation of cadmium with other metals

Very few studies have assessed correlations of different metals in sea turtles. Cd concentrations were positively correlated with both Zn and Cu in the liver and kidney of *C. mydas* (Table 4). Correlations between Cd and Cu were also detected in kidney of *C. caretta* and in liver of *L. olivacea* but only at a significance level of $p < 0.1$. Positive relationships between Cd and Cu have been previously reported in sea turtles (Sakai *et al.* 2000a in *C. mydas*) and marine mammals (Noda *et al.* 1995; Honda *et al.* 1987) and are likely related to the synthesis of metallothionein or a MT-like metal-binding protein which is inducible by both elements (Yamamura & Suzuki 1984).

A strong positive correlation was also detected in the concentrations of Cd and Fe in liver of *L. olivacea* and a similar, but weaker relationship was observed in *C. caretta* liver (Table 4). Mn and Cd concentrations were also correlated in liver of *L. olivacea* and *C. caretta*. However, no corresponding correlations of these elements were detected in liver of *C. mydas* or in kidney of any of the three sea turtles species studied.

Copper

Previous studies have reported a wide variation in the placement of Cu with respect to the rank of other metals, ranging from being the second highest metal in liver of *C. mydas* (Sakai *et al.* 1995, 2000a) to being among the metals with the lowest concentrations, particularly in kidney (Sakai *et al.* 1995, 2000b; Caurant *et al.* 1999). In Baja California, the Cu values measured in turtle liver (2.47 μg/g in *E. imbricata* to 133 μg/g in *C. mydas*) were within the range of those reported for sea turtles in other parts of the world (0.74–554, μg/g).

Iron

The range of Fe concentrations observed in liver of Baja California turtles (nd −9201 μg/g) was broad compared to those reported previously in sea turtles from other regions (617–6223 μg/g in *C. mydas*) (Sakai *et al.* 1995, 2000a, 2000b) and one sample from a Baja California (9201 μg/g in *L. olivacea*) was above any measurement previously reported for sea turtles.

Lead

With the exception of one high measurement in a kidney sample from *C. caretta* (69.89 μg/g), the range of Pb concentrations in Baja California sea turtles (nd −1.57 μg/g) was low and similar to those reported elsewhere (nd −5.53 μg/g) (Storelli *et al.* 1998; Godley *et al.* 1999; Sakai *et al.* 2000a, 2000b).

Manganese

The only other reported values for Mn in sea turtles were from turtles collected in Japan (Sakai *et al.* 1995, 2000a, 2000b). In these studies, concentrations of Mn were similar in liver and kidney, ranging from 0.74 to 26.51 μg/g. Values of Mn measured in sea turtles from Baja California ranged from below detection to 9.97 μg/g. However, the significantly higher Mn concentrations in kidney as compared to other tissues and the significantly lower concentration of Mn in *C. mydas*

Table 4. Correlation coefficients between cadmium concentrations and other heavy metals in liver and kidney of sea turtles (Pb was below detection limits in all liver samples analyzed).

		Pb	Fe	Ni	Cu	Zn	Mn
Liver	*C. mydas*		−0.280	−0.216	0.678**	0.639**	0.114
	C. caretta		0.804*	0.329	0.612	0.373	0.899**
	L. olivacea		0.979***	0.346	0.798*	−0.537	0.895**
Kidney	*C. mydas*	−0.231	−0.069	0.577*	0.822***	0.638**	−0.378
	C. caretta	−0.172	−0.205	0.428	0.845*	−0.662	0.309
	L. olivacea	−0.101	0.191	−0.209	0.054	0.338	0.258

Significance (*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$)

tissues as compared to the other sea turtle species are unique findings and warrant further research in order to confirm the existence of these trends in other regions.

Nickel

The Ni concentrations in Baja California turtle tissues were high compared to previously published values. Especially noteworthy were the Ni concentrations observed in *C. mydas* kidney (0.28–26.43 μg/g), which is up to 4 times greater than values presented elsewhere in sea turtles (nd−6.52 μg/g; Sakai *et al.* 1995, 2000a, 2000b; Lam *et al.* 2004). Previous to our study, one of the highest Ni concentration reported was detected in a *D. coriacea* sample collected in the Irish Sea, UK (2.13 μg/g), which was the largest sea turtle ever captured at that time (Davenport & Wrench 1990).

Zinc

The maximum Zn concentration measured in *C. mydas* kidney from Baja California (330 μg/g) was greater than the highest value previously reported in sea turtle tissues (224 μg/g in *C. mydas* liver; Sakai *et al.* 1995). The biological relevance of this elevated concentration remains to be understood.

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