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Trace Metals in Tissues of Resident and Migratory Birds from a Lagoon Associated with an Agricultural Drainage Basin (SE Gulf of California)

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Abstract. With the aim of knowing Cd, Cu, Fe, Mn, Pb, and Zn concentrations in selected tissues of birds from two places at Altata-Ensenada del Pabellón lagoon in the SE Gulf of California, 39 specimens of 14 species were analyzed. Migratory birds in this study showed the highest values of Cd, Cu, and Pb in liver; Fe and Mn, in viscera; and Zn, in feathers. Concerning the resident avifauna, the highest levels of Cd, Cu, and Fe were detected in the liver, Mn in viscera; and Pb and Zn, in feathers. Regarding Cu and Fe, higher concentrations were detected in migratory avifauna, while Mn and Zn were more accumulated in resident waterfowl. In the case of Cd and Pb, both elements showed a tendency to be more accumulated in resident seabirds. Statistical comparisons showed that in carnivorous and omnivorous birds the resident component was the group with higher levels in more comparisons where mainly Cu and Fe were involved. In the rest of the metals the differences in the concentrations in the distinct tissues of migratory versus resident species were not clearly evident in one group in particular. In a few cases, carnivorous birds had higher levels of Cd than herbivorous and omnivorous birds; for the rest of the metals there was not a clear trend of metal accumulation.

Studies concerning the presence of trace metals in invertebrates from the continental margin of the Gulf of California have been extensively documented (*e.g.*, Páez-Osuna *et al.* 1991, 1993, 2002; Páez-Osuna and Ruiz-Fernández 1995; Méndez and Páez-Osuna 1998; Ruelas-Inzunza and Páez-Osuna 1998; Szefer *et al.* 1998; Méndez *et al.* 2002), while reports on trace metals in vertebrates are scarce.

Among vertebrates, seabirds are considered potential monitors of environmental contamination because of the vulnerability associated with their long life and high trophic position. Furthermore, the mobility of seabirds, perhaps at first appearing to be a drawback for a biomonitor, can be an advantage if the aim is to monitor over a broad scale and the ranging behavior of the birds is known (Furness and Camphuysen 1997). The region where birds were collected for this work is known as Altata-Ensenada del Pabellón, in Sinaloa state. In this study, four essential (Cu, Fe, Mn, and Zn) and two nonessential (Cd and Pb) metals were measured and compared in different tissues of nine resident species and five migratory species collected during the winter of 2000. Implications of high levels of metals in the context of sublethal effects are discussed.

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Materials and Methods

Study Area

Altata-Ensenada del Pabellón lagoon is located between 24°20′ and 24°40′N and 107°30′ and 108°00′W (Figure 1). The weather of the region is from semiarid to arid, with temperatures ranging from 19 to 33.3°C and an annual average precipitation of 673 mm (INEGI 1999). The study area receives waste effluents from intensive agricultural activity (140,000 ha) consisting mostly of vegetable and sugar cane crops (Green-Ruiz and Páez-Osuna 2001). It is known that large amounts of pesticides and fertilizers are used in this region, mainly organophosphorous, carbamates, and metallic fungicides (IAEA 1990).

Field and Laboratory Work

Sampling was conducted under an official permit from SEMARNAP (DOO.O2-3324). Thirty-nine specimens of 14 bird species were obtained from hunters between February and March 2000; biometric data, common names, and feeding habits of analyzed species are provided in Table 1. Glassware and materials used for handling and transportation of samples were thoroughly acid washed to prevent contamination of samples (Moody and Lindstrom 1977). After identification and determination of length and weight of specimens, dissection with a stainless-steel knife was performed in order to obtain heart, liver, muscle, gut (and its contents), and feathers. With the exception of feathers, samples were freeze-dried for 72 h at −49°C and 75 × 10^{-3} mBar in a Labconco freeze-drying system, then powdered in an automatic agate grinder (Retsch) for 10 min. Powdered samples and feather samples (finely cut) were digested with quartz-distilled concentrated nitric acid in a microwave apparatus (CEM; MDS 2000) under the following conditions: first step, 20 psi for 10 min; second step, 40 psi for 10 min; and third step, 90 psi for 30 min.

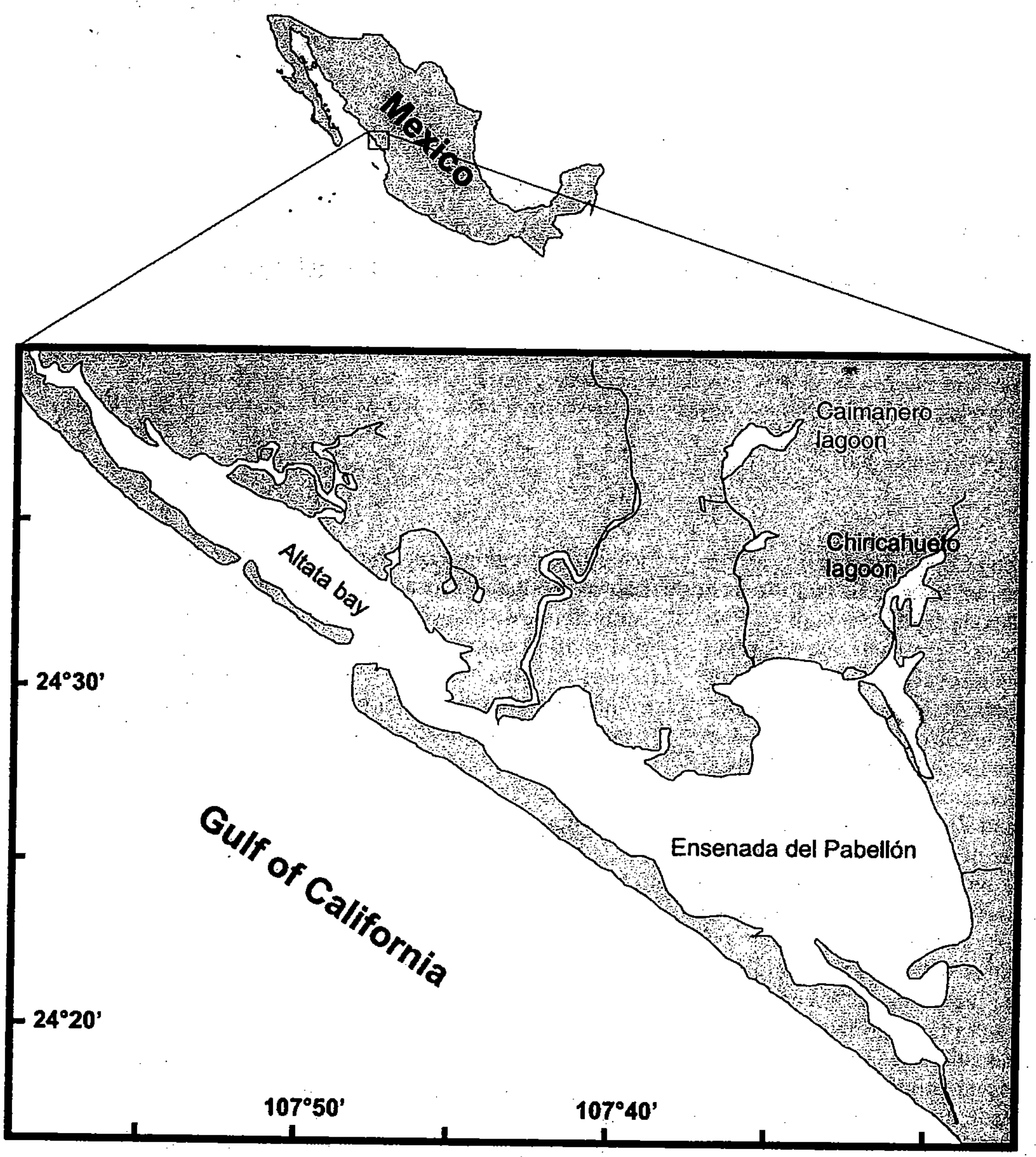

Fig. 1. Location of Altata-Ensenada del Pabellón lagoon and surrounding areas where birds were collected

These conditions were sufficient to assure the digestion and total dissolution of the tissue aliquots (Ruelas-Inzunza *et al.* 2000).

Analyses were made by flame atomic absorption spectrophotometry for Cu, Fe, Mn, and Zn; in the case of Cd and Pb, graphite furnace atomic absorption spectrophotometry was used. All determinations were carried out in a Varian SpectrAA 220 spectrophotometer. Levels of the different elements are expressed as micrograms per gram on a dry weight basis. In order to assess the precision of the employed method, reference materials (MA-B-3/TM and SRM 2976) were analyzed (IAEA 1987). Concentrations of analyzed elements were within certified values of reference materials. Percentages of recovery for Cd, Cu, Fe, Mn, Pb, and Zn were 90, 92, 95, 125, 102, and 65%, respectively.

Data Analysis

Data sets were analyzed for normality using the Kolmogorov–Smirnov test and proved to follow a Gaussian distribution. Average metal concentrations in the different tissues of resident and migratory birds of similar feeding habits were compared by Student *t* test. One-way ANOVA was used to define significant differences among tissues of every species. Statistical analyses were conducted using GraphPad Prism 2.01 (Graph Pad Software Inc., San Diego CA).

Results and Discussion

Considering the distinct tissues, migratory birds in this study showed the highest values of Cd, Cu, and Pb in liver, Fe and Mn in viscera, and Zn in feathers (Table 2). Concerning the resident avifauna, the highest levels of Cd, Cu, and Fe were detected in the liver, Mn in viscera, and Pb and Zn in feathers (Table 3). The sequence of average metal concentrations for migratory and resident birds was Fe > Zn > Cu > Mn > Pb > Cd, with essential metals being at higher levels than nonessential metals.

The main route of entrance of pollutants in wild animals is through food (Szefer and Falandysz 1987) and, depending on the nature of the pollutant, will be the degree of concentration through successive levels in a given trophic chain. Such a

Table 1. Biometric data and feeding habits of sampled species from Altata-Ensenada del Pabellón Iagoon, Sinaloa

Species	Common name	*n*	Feeding habit	Weight (g)	Length (cm)	Residence
Recurvirostra americana	American avocet	2	C	370 ± 16	45 ± 1	M
Dendrocygna autumnalis	Black-bellied tree duck	2	H	793 ± 17	39 ± 1	M
Fulica americana	American coot	3	O	657 ± 126	36 ± 3	M
Anas cyanoptera	Cinnamon teal	2	O	763 ± 347	45 ± 8	M
Himantopus mexicanus	Black-necked stilt	2	C	154	28	R
Dendrocygna bicolor	Fulvous tree duck	2	H	792	42	R
Pelecanus occidentalis	Brown pelican	2	C	3700 ± 200	88 ± 3	R
Phalacrocorax olivaceus	Olivaceous cormorant	6	C	973 ± 84	51 ± 4	R
Plegadis chihi	White-faced ibis	7	C	574 ± 58	43 ± 5	R
Aythya affinis	Lesser scaup	2	O	535	33	R
Oxyura jamaicensis	American ruddy duck	2	O	662	38	R
Casmerodius albus	Great egret	3	C	1125 ± 15	78 ± 2	R
Bubulcus ibis	Cattle egret	2	C	336	38	R
Charadrius vociferus	Killdeer	2	C	90	25	R

Note. C, carnivorous; H, herbivorous; O, omnivorous; M, migratory; R, resident.

Table 2. Concentration ($\mu g\ g^{-1}$ dry weight) and distribution of selected trace metals in migratory birds from Altata-Ensenada del Pabellón lagoon, Sinaloa (México)

Species	Tissue	Cd	Cu	Fe	Mn	Pb	Zn
R. americana	Heart	0.7 ± 0.5	9.0 ± 2.9	826 ± 410	3.2 ± 0.1	3.3 ± 1.7	43.5 ± 24
	Muscle	1.2 ± 0.4	15.7 ± 0.7	296 ± 34	2.3 ± 1.5	4.8 ± 1.7	7.3 ± 1.8
	Liver	2.4 ± 0.3	9.7 ± 4.0	2165 ± 999	15 ± 3.1	1.3 ± 0.8	76 ± 12
	Viscera	0.6 ± 0.1	4.9 ± 1.8	788 ± 682	87 ± 79	1.2 ± 0.1	82 ± 8
	Feather	0.8 ± 0.4	6.9 ± 1.9	62 ± 10	N.A.[a]	2.2 ± 0.4	168 ± 13
D. autumnalis	Heart	0.5 ± 0.2	20.1 ± 1.2	687 ± 83	0.4 ± 0.1	2.8 ± 2.0	102 ± 7
	Muscle	1.3 ± 0.2	31.2 ± 1.2	247 ± 1.5	N.A.[a]	1.8 ± 0.4	40 ± 5
	Liver	0.8 ± 0.2	164 ± 32	1712 ± 171	12.5 ± 1.7	5.6 ± 1.2	167 ± 62
	Viscera	0.8 ± 0.4	7.2 ± 5.7	234 ± 79	26.5 ± 20	2.7 ± 2.2	93 ± 26
	Feather	0.5 ± 0.1	3.1 ± 0.2	257 ± 80	36.2 ± 15	5.1 ± 3.8	214 ± 8
F. americana	Heart	1.2 ± 1.2	41 ± 24	515 ± 108	4.3 ± 3.7	1.6 ± 0.5	62 ± 8*
	Muscle	1.4 ± 0.6	74 ± 25	415 ± 59*	1.9 ± 0.7	4.1 ± 2.0	40 ± 5.2*
	Liver	3.3 ± 2.8	38 ± 13*	3779 ± 922*	17.5 ± 7.6	4.3 ± 2.1	155 ± 47*
	Viscera	1.1 ± 0.8	12.4 ± 1.2*	4367 ± 1298	19.4 ± 5.4	2.9 ± 0.5	52 ± 13
	Feather	0.2 ± 0.1	2.5 ± 1.2*	131 ± 51*	9.7 ± 5.0	1.0 ± 0.4	187 ± 26
A. cyanoptera	Heart	0.3 ± 0.1	8.6 ± 2.6	1060 ± 516	1.9 ± 0.1	2.4 ± 1.1	30.7 ± 1.3
	Muscle	1.3 ± 0.2	27 ± 0.8	322 ± 73	4.4 ± 0.5	1.4 ± 0.2	24.3 ± 1.9
	Liver	1.2 ± 0.1	84 ± 51	4200 ± 521	10.7 ± 0.1	1.4 ± 0.8	163 ± 16
	Viscera	1.1 ± 0.4	8.4 ± 0.8	1584 ± 769	75 ± 45	4.1 ± 2.2	119 ± 13
	Feather	0.5 ± 0.1	6.5 ± 1.5	889 ± 397	28.3 ± 24	2.4 ± 0.3	179 ± 10

[a] Not available.
* For a given element, significant differences ($p < 0.05$) in concentrations among tissues of a single species.

trophic level-dependent accumulation has been found in aquatic birds (Lee *et al.* 1989).

Cd levels varied one order of magnitude among migratory birds. The highest value (3.3 $\mu g\ g^{-1}$) was found in the liver of the American coot *F. americana,* however, this value was below the interval 100–200 $\mu g\ g^{-1}$ dry weight considered harmful for the renal tissue of birds (Blomqvist *et al.* 1987); the lowest value was detected in feathers of the same species. Cd appears to originate from direct atmospheric deposition, and when it is ingested it becomes firmly bound in kidney and bone and only enters feathers in trace amounts (Stewart *et al.* 1994). Regarding feeding habits, the herbivorous species (*D. autumnalis*) had lower average Cd levels in all tissues than omnivorous or carnivorous species (Table 2). In similar studies (Muirhead and Furness 1988; Thompson 1990) it has been considered that Cd levels seem to be higher among squid-eating seabirds than among fish-eating species.

In the case of resident birds, Cd variation was also of one order of magnitude. The highest levels were detected in the liver of the pelican *P. occidentalis* (4.7 $\mu g\ g^{-1}$), while the lowest values (0.1 $\mu g\ g^{-1}$) corresponded to feathers of *P. occidentalis* and the great egret *C. albus* (Table 3). Cu concentrations in migratory birds varied two orders of magnitude; the highest levels of this element were found in the liver of *D. autumnalis* and the lowest values in feathers of *F. americana* (Table 2). Concerning resident birds, Cu was mostly accumulated in the liver of *D. bicolor,* while the lowest value was detected in the feathers of the cormorant *P. olivaceus;* this pattern has been found in *S. mollisima* (Eisler 1981) and *F. americana* (Hui 1998). Fe and Mn levels varied two orders of magnitude, with the highest levels of Fe in the liver of a

Table 3. Concentration (μg g^{-1} dry weight) and distribution of selected trace metals in resident birds from Altata-Ensenada del Pabellón lagoon, Sinaloa (México)

Species	Tissue	Cd	Cu	Fe	Mn	Pb	Zn
H. mexicanus	Heart	0.6 ± 0.1	10.9 ± 1.3	573 ± 2	4.7 ± 0.6	3.5 ± 1.9	53 ± 5
	Muscle	0.4 ± 0.2	17.5 ± 0.2	262 ± 2	3.6 ± 0.3	1.7 ± 1.4	12.8 ± 0.3
	Liver	2.5 ± 0.8	25.6 ± 0.4	875 ± 20	16.7 ± 0.1	0.7 ± 0.3	103 ± 2
	Viscera	0.5 ± 0.1	11 ± 0.3	1171 ± 124	79.4 ± 10	0.9 ± 0.5	118 ± 2
	Feather	0.2 ± 0.1	13.8 ± 0.2	252 ± 15	5 ± 1.6	1.3 ± 0.1	203 ± 4
D. bicolor	Heart	1.6 ± 0.1	14.1 ± 0.2	1053 ± 17	2.1 ± 0.1	2.2 ± 1.7	33.4 ± 0.1
	Muscle	0.2 ± 0.1	28.3 ± 0.2	254 ± 3	2.4 ± 0.6	2.8 ± 1.8	18.8 ± 0.5
	Liver	0.4 ± 0.2	153 ± 2	2621 ± 31	5.4 ± 0.4	2.3 ± 0.1	114 ± 3.8
	Viscera	0.9 ± 0.3	4.6 ± 0.2	721 ± 262	27.1 ± 3.5	2.4 ± 0.4	82 ± 0.1
	Feather	0.1 ± 0.1	2.9 ± 0.2	566 ± 19	36.6 ± 9.2	0.7 ± 0.1	177 ± 2.7
P. occidentalis	Heart	2.6 ± 0.4	10.4 ± 1.6	343 ± 69	0.7 ± 0.3	3.4 ± 0.1	57.1 ± 3.9
	Muscle	0.7 ± 0.1	14.8 ± 1.6	259 ± 19	1.1 ± 0.3	4.2 ± 1.5	23.3 ± 5.0
	Liver	4.7 ± 0.4	13.7 ± 4.6	2364 ± 971	10.4 ± 1.2	1.3 ± 0.6	130 ± 65
	Feather	0.6 ± 0.2	N.A.[a]	125 ± 17	2.6 ± 0.5	1.9 ± 1.0	82 ± 24
P. olivaceus	Heart	1.2 ± 0.7	11.6 ± 2.1	626 ± 224	1.8 ± 0.8*	2.4 ± 1.1	94 ± 27*
	Muscle	1.2 ± 0.8	19.1 ± 2.4	322 ± 51	2.3 ± 1.1	1.7 ± 0.9	35 ± 18*
	Liver	2.1 ± 1.8	20.3 ± 3.0*	1098 ± 311*	11 ± 1.8*	2.6 ± 1.4	98 ± 18
	Viscera	1.1 ± 0.8	3.0 ± 1.3*	174 ± 121*	10.7 ± 14	1.3 ± 0.8	107 ± 2
	Feather	0.6 ± 0.3	2.2 ± 0.6	339 ± 156	33.5 ± 11*	1.4 ± 0.4	192 ± 14*
P. chihi	Heart	1.2 ± 0.5	11.0 ± 1.4	770 ± 408*	3.1 ± 0.2*	2.8 ± 0.7	47 ± 17
	Muscle	1.3 ± 0.6	12.3 ± 0.6*	277 ± 13*	2.29 ± 0.9	2.5 ± 1.2	14 ± 13*
	Liver	1.8 ± 0.9	6.1 ± 0.5*	2959 ± 191*	8.48 ± 2.3*	2.4 ± 1.2	45 ± 6*
	Viscera	1.7 ± 1.5	7.2 ± 3.7	927 ± 590	88.8 ± 50	2.1 ± 1.4	90 ± 38
	Feather	1.1 ± 1.1	2.5 ± 1.0*	231 ± 139	53.9 ± 13*	1.9 ± 1.1	241 ± 18*
A. affinis	Heart	2.1 ± 1.5	18.2 ± 3.4	1245 ± 168	2.15 ± 0.2	1.0 ± 0.2	125 ± 9
	Muscle	1.2 ± 0.3	46 ± 1	484 ± 15	1.45 ± 0.2	N.A.	35 ± 3
	Liver	1.8 ± 0.3	84.6 ± 0.3	3695 ± 12	17 ± 0.1	1.9 ± 1.5	157 ± 6
	Viscera	0.8 ± 0.1	15.4 ± 6.1	290 ± 7	16.3 ± 1.6	0.1 ± 0.1	170 ± 29
	Feather	1.1 ± 0.7	8.1 ± 0.2	144 ± 13	N.A.[a]	1.3 ± 0.1	154 ± 8
O. jamaicensis	Heart	1.2 ± 0.2	7.9 ± 0.1	855 ± 0.2	1.7 ± 0.2	N.A.[a]	54 ± 6
	Muscle	1.5 ± 1.1	27.8 ± 0.2	415 ± 9	2.55 ± 0.1	N.A.[a]	8.1 ± 0.1
	Liver	2.3 ± 0.7	73.8 ± 0.5	3788 ± 42	18.5 ± 0.1	3.7 ± 1.9	108 ± 4
	Viscera	1.5 ± 1.2	4.6 ± 0.1	490 ± 248	31 ± 9.2	0.9 ± 0.2	97 ± 2.0
	Feather	0.1 ± 0.01	8.1 ± 0.4	158 ± 14	N.A.[a]	3.0 ± 0.3	144 ± 4.0
C. albus	Heart	1.3 ± 0.4	12.3 ± 1.4	610 ± 89*	1.5 ± 0.4*	3.7 ± 2.4	55 ± 2.1*
	Muscle	1.4 ± 0.5	14.5 ± 2.3	247 ± 29*	2.3 ± 0.3	0.9 ± 0.1	26 ± 2.3*
	Liver	2.3 ± 0.1	16 ± 3.8*	3123 ± 598*	10.6 ± 0.8*	2.8 ± 1.0	96 ± 15*
	Viscera	1.4 ± 0.4	4.1 ± 1.6*	80.3 ± 30*	7.2 ± 1.8*	2.5 ± 1.3	67 ± 26
	Feather	1.4 ± 0.8	9.6 ± 2.5	131 ± 42	7.9 ± 1.9	0.9 ± 0.1	97 ± 19
B. ibis	Heart	1.0 ± 0.6	16.2 ± 1.1	336 ± 30	N.A.[a]	1.4 ± 1.0	32.3 ± 1.9
	Muscle	0.7 ± 0.2	11.9 ± 0.2	290 ± 2.7	1.1 ± 0.2	1.0 ± 0.5	21.8 ± 0.1
	Liver	2.3 ± 1.4	15.7 ± 1.1	1233 ± 4.1	10.9 ± 0.4	2.1 ± 0.8	132 ± 10
	Viscera	0.6 ± 0.1	13.7 ± 1.0	202 ± 8.4	21.5 ± 0.9	0.4 ± 0.1	159 ± 3
	Feather	0.3 ± 0.0	15.1 ± 0.3	647 ± 102	8.3 ± 2.0	5.7 ± 2.0	129 ± 9
C. vociferus	Heart	0.9 ± 0.7	16.9 ± 1.1	634 ± 34	3.9 ± 0.1	1.6 ± 0.1	79.7 ± 0.9
	Muscle	1.6 ± 1.3	13.5 ± 0.3	201 ± 3.4	2.8 ± 0.1	5.7 ± 2.3	2.7 ± 0.0
	Liver	1.4 ± 0.1	23.2 ± 0.1	448 ± 8.4	11.4 ± 0.4	3.5 ± 3.1	86.1 ± 3.1
	Viscera	2.5 ± 1.6	42.9 ± 0.7	297 ± 15	9.4 ± 0.8	5.9 ± 0.8	131 ± 1.1
	Feather	0.5 ± 0.1	13.7 ± 1.9	401 ± 45	7.1 ± 0.9	3.8 ± 1.0	170 ± 1.9

[a] Not available.

* For a given element, significant differences ($p < 0.05$) in concentrations among tissues of a single species.

resident species, *O. jamaicensis,* and viscera of a migratory species, *F. americana;* the highest levels of Mn were detected in viscera of migratory and resident species (Tables 2 and 3). Similarly, Eisler (1981) reported high levels of Fe in liver of birds of the genera *Somateria* and *Larus.* Though scarce information on Mn levels in seabirds is available, its concentration is relevant to consider because it is being used as an additive in gasoline to replace Pb in the United States and also in Canada (Cooper 1984) and as a fungicide in intensive agriculture lands from Culiacán valley (Páez-Osuna *et al.* 1993), so it is important to obtain baseline levels before its use extends to other countries.

Pb is one of the most studied elements among seabirds (*e.g.*, Furness and Camphuysen 1997; Kim *et al.* 1998; Burger and Gochfeld 2000), perhaps as a consequence of the increasing supply of this metal into the atmosphere through industrial and automobile activity. Pb concentrations in migratory birds var-

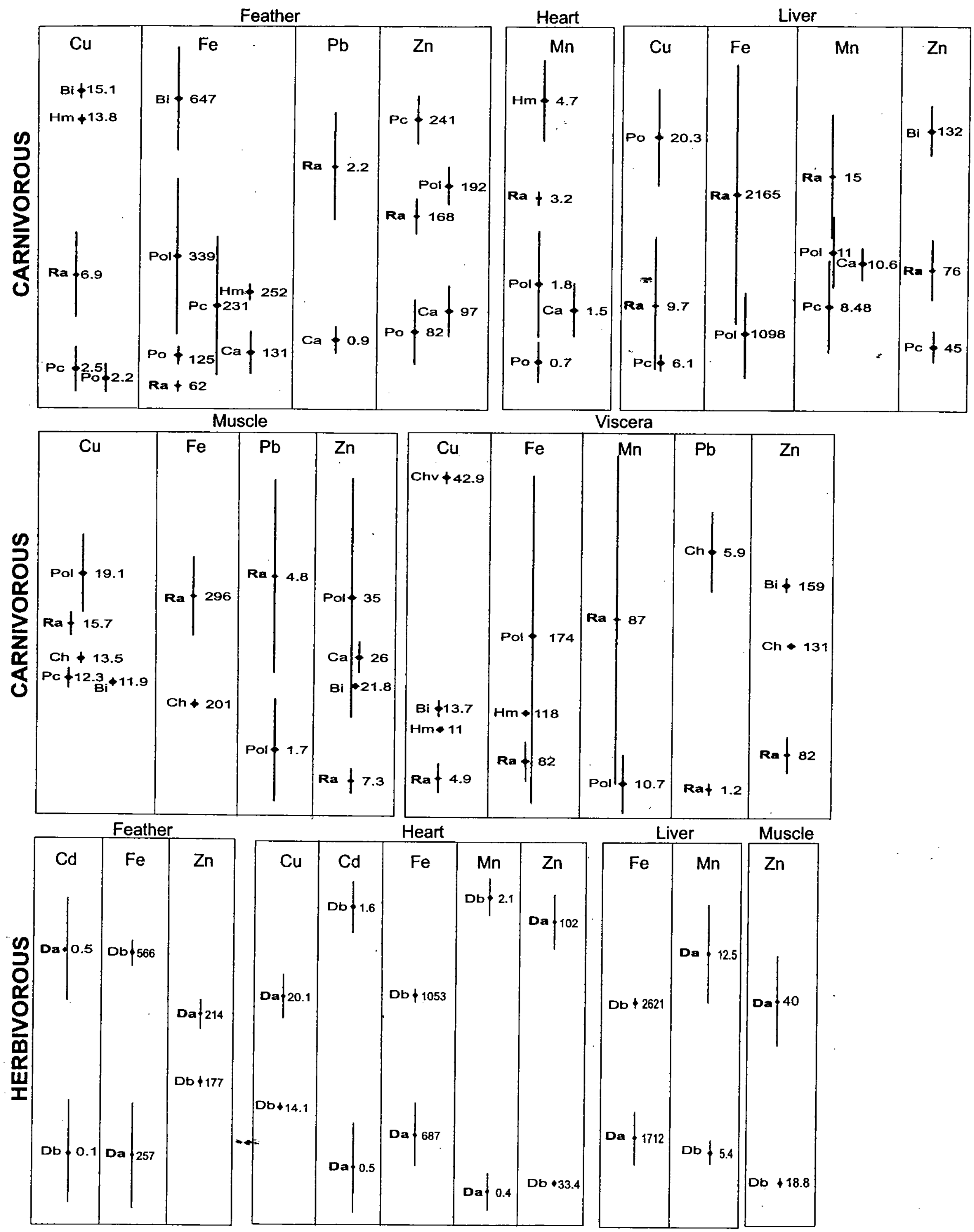

Fig. 2. Metal average (±SD) in different migratory and resident birds considering feeding habit. *R. americana*, Ra; *B. ibis*, Bi; *Ch. vociferus*, Ch; *H. mexicanus*, Hm; *P. chihi*, Pc; *P. olivaceus*, Pol; *P. occidentalis*, Po; *D. autumnalis*, Da; *D. bicolor*, Db; *A. cyanoptera*, Ac; *F. americana*, Fa; *A. affinis*, Aa; *C. albus*, Ca; *O. jamaicensis*, Oj

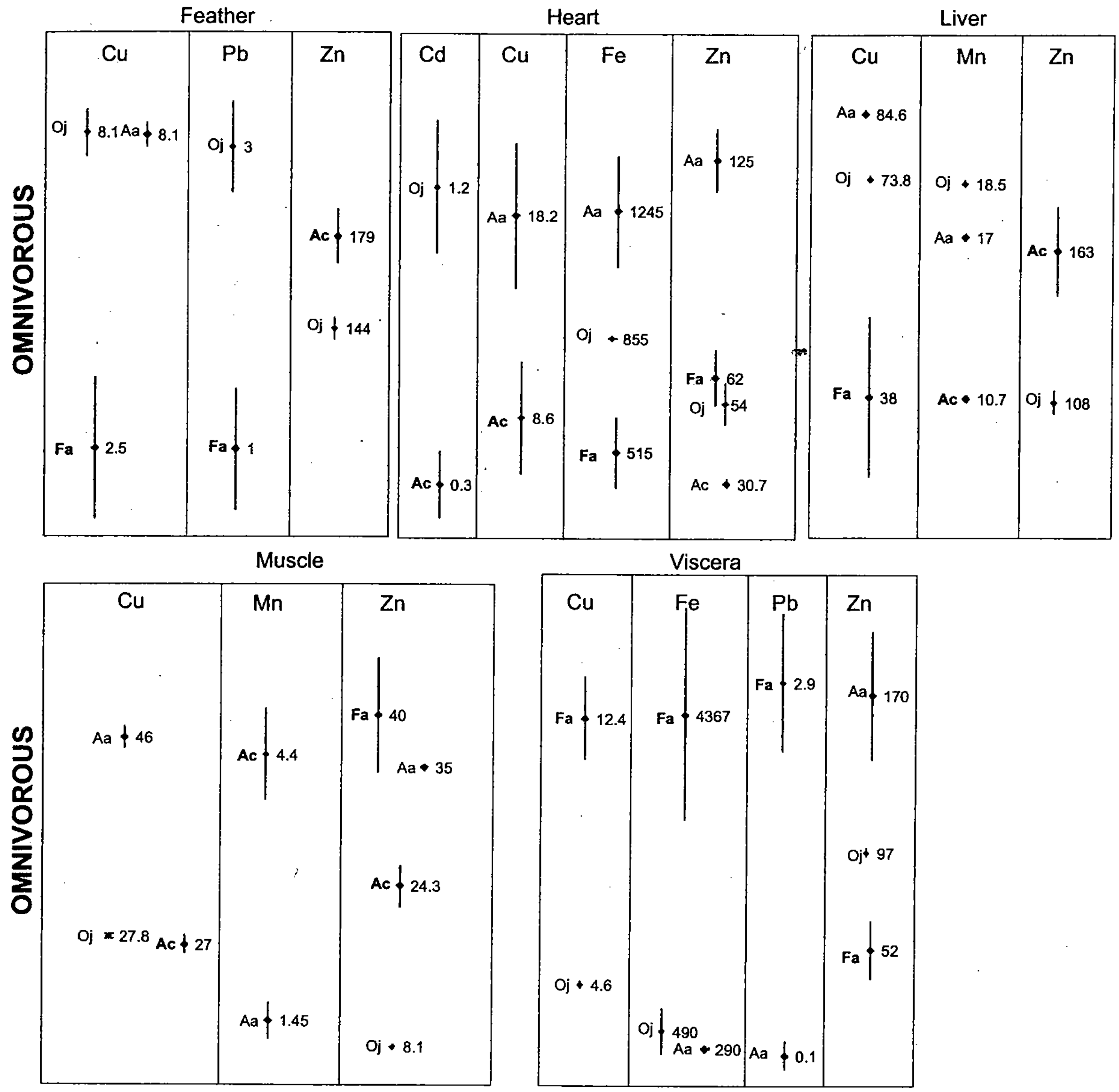

Fig. 2. Continued

ied one order of magnitude, with the highest level in the liver of *D. autumnalis* (11.3 μg g^{-1}). In the case of resident birds Pb varied two orders of magnitude, with the highest concentration in viscera of *C. vociferous* (Table 3); these concentrations are above values (4 μg g^{-1}) that are known to cause sublethal and reproductive effects (Burger 1995). In a study with five species of Anatidae from an area near our study site, Rendón-Von Osten *et al.* (2001) reported an average concentration of Pb of 37.1 μg g^{-1} in feather, suggesting that there may be a relationship between ingestion of seeds (and lead pellets) and susceptibility to Pb accumulation. Regarding Zn levels, values ranged two orders of magnitude in all avifauna; the highest concentrations occurred in feathers of *D. autumnalis* (Table 2) and *P. chihi* (Table 3). In a study with common eiders *Somateria mollissima* from a contaminated site in Norway (Lande 1977). Zn concentrations in liver were 111 μg g^{-1} on a wet weight basis; correcting for wet content and considering only liver concentrations, birds in this study had lower concentrations (Tables 2 and 3).

In order to put into context the metal concentrations in the studied species, a comparison of trace metal levels in livers with avian species from other sites of the world was made. Cd levels in most of the birds in our study were of the same order of magnitude as the pintail *Anas acuta* (1.22 μg g^{-1} dry weight) from northern Siberia (Kim *et al.* 1996) and the American coot *Fulica americana* (1.63 μg g^{-1} dry weight) from San Francisco Bay (Hui 1998). Cu concentrations in most of our studied species were one order of magnitude lower than in the canvasback *Aythya valisineria* (187 μg g^{-1} dry weight) from Louisiana, USA (Custer and Hohman 1994). Concerning Fe and Mn, levels were comparable to values reported in the scaup duck *Aythia marila* (1400 and 12.8 μg g^{-1} dry weight, respectively) from the Baltic Sea (Szefer and Falandysz 1987). In the case of Pb, liver concentrations in *Fulica americana* (4.3 μg

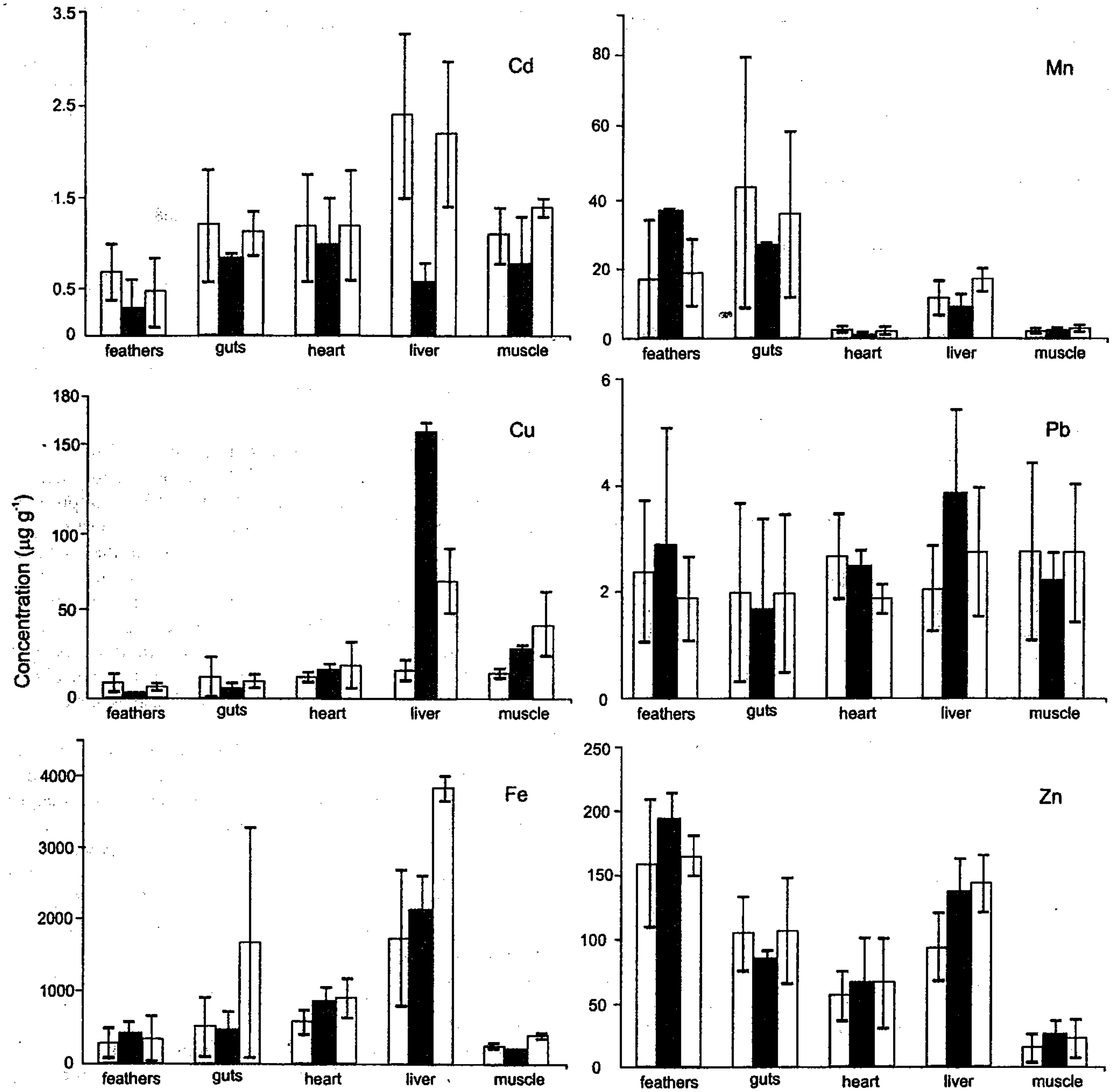

Fig. 3. Trace metal levels in analyzed tissues of carnivorous (shaded bars), hervivorous (filled bars), and omnivorous (open bars) avifauna from Altata-Ensenada del Pabellón lagoon

g^{-1} dry weight [this study]) were higher than in the coot *Fulica atra* (1.2 µg g^{-1} dry weight) from the Ebro delta in Spain (Mateo and Guitart 2003). Zn concentrations in waterfoul from our study varied by an order of magnitude. The highest values were recorded in the liver of *Dendrocygna autumnalis* (167 µg g^{-1} dry weight); this figure is comparable to data reported in the little shag *Phalacrocorax melanoleucos brevirostris* (164 µg g^{-1} dry weight) from New Zealand (Lock *et al.* 1992).

Regarding statistical comparisons of average metal concentrations between resident and migratory birds, a summary of the Student *t*-test ($p < 0.05$) results is given in Figure 2; it can be seen that in carnivorous and omnivorous birds the resident component was the group with higher levels in more comparisons where mainly Cu and Fe are involved. In the rest of the metals the differences in the concentrations in the distinct tissues of migratory versus resident species were not clearly due to one group in particular. In the case of the herbivorous species, both resident and migratory components had a comparable number of cases (five and six, respectively) with higher metal concentrations in the different tissues (Figure 2).

In relation to feeding habits, carnivorous birds had higher levels of Cd than herbivorous and omnivorous; in the case of

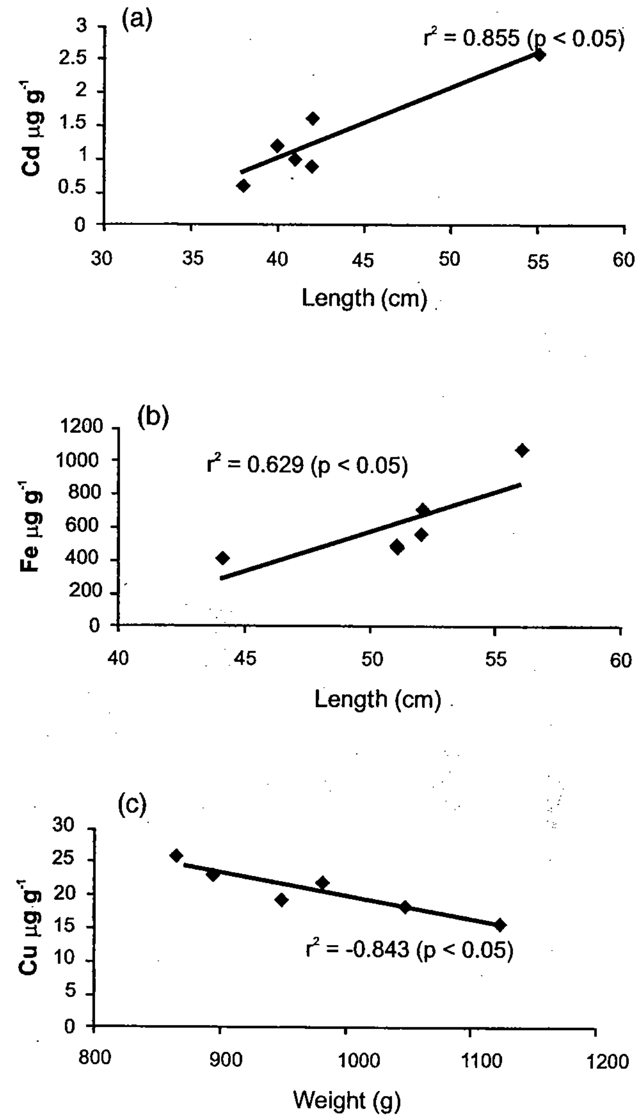

Fig. 4. Variation in trace metal concentration with body size—(a) Cd associated with muscle in *P. chihi* and (b) Fe associated with heart in *P. olivaceus*—and with weight—(c) Cu associated with liver in *P. olivaceus* ($p < 0.05$)

Fe, with the exception of feathers, omnivorous had higher levels. For the rest of the metals there was not a clear trend of metal accumulation (Figure 3).

Relationships between metal concentrations and body size are plotted in Figure 4; only significant relationships are included, *i.e.*, Fe *versus* length in heart of *P. olivaceus* (positively), Cu versus weight in liver of *P. olivaceus* (negatively), and Cd versus length in muscle of *P. chihi* (positively). Cd accumulation with length has been reported in liver and kidney of the common cormorant *Phalacrocorax carbo* (Saeki *et al.* 2000). Pedersen and Myklebust (1993) and Debacker *et al.* (2001) found a positive correlation between age and Cd content of the liver and kidney of the willow ptarmigan (*Lagopus lagopus*) and the guillemot (*Uria aalgae*). In relation to Cu, several studies in bivalves have shown inverse relationships between whole soft parts and Cu concentrations (Boyden 1977). Variation of metal concentrations in different age categories has been reported in different organisms such as insect larvae Chironomous (Krantzberg 1989), amphipods (Rainbow and Moore 1986), and shrimp (Páez-Osuna and Ruiz-Fernández 1995), where it is observed that smaller individuals have higher concentrations than larger individuals. In the resident *P. chihi* the adult specimens are representative of the advanced life stages where Cu concentrations tend to decrease with age. A similar situation has been found in fish and mollusks (Cross *et al.* 1973; Boyden 1977); unfortunately, in birds the available information is limited and corresponds to other elements.

Table 4. Correlation coefficient matrix of trace metals in different tissues of the white faced ibis *Plegadis chihi*[a]

	Cu	Fe	Cd
Liver			
Zn	0.78		
Pb		−7.9	
Feathers			
Cu		0.94	
Mn		0.68	
Viscera			
Cu		0.80	
Mn		0.84	
Zn	0.71		
Heart			
Pb			0.83

[a] Only significant values are given ($p < 0.05$).

The influence of size may be a function of one or several age-dependent parameters, such as differences in the surface area/volume ratio and metabolic and feeding rates of larger versus smaller individuals. Age dependence may be a function of the period over which an organism has been exposed to a pollutant (Phillips 1980). In the particular case of *P. chihi*, as a resident organism, it is possible that when this bird was in juvenile stages, Cu levels available were more elevated than when the bird reached an adult stage. *P. chihi* showed significant correlations for several metals (Table 4), which indicate similar physical/chemical properties of metals (Szefer and Falandysz 1987).

Regarding Cu and Fe, higher concentrations were detected in migratory avifauna, while Mn and Zn were more accumulated in resident waterfowl. In the case of Cd and Pb, both elements were more accumulated in resident seabirds. Cd concentrations were below values considered harmful for birds, but several Pb concentrations were above values that are known to cause reproductive effects. Though no morphological effects were evident in studied avifauna, more studies concerned with the sublethal effects of toxic elements in seabirds from the lower Gulf of California are necessary.

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