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# Mercury Distribution in Selected Tissues of Migratory and Resident Avifauna from Altata-Ensenada del Pabellón Lagoon, Southeast Gulf of California

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Aquatic birds are ideal monitors of pollutants over wide geographical areas because of their long life span and trophic status (Furness and Camphuysen, 1997). Studies concerning the occurrence of trace metals in vertebrates from Altata-Ensenada del Pabellón lagoon (an impacted system with agricultural, urban, and shrimp-farming effluents) are scarce (Rendón-Von Osten et al., 2001; Ruelas-Inzunza and Páez-Osuna, 2004, 2005); in the particular case of mercury concentrations in marine birds, the studies are nonexistent. In the present study, mercury distribution in muscle, heart, liver, viscera, and feathers of resident and migratory avifauna from Altata-Ensenada del Pabellón lagoon was investigated.

## Materials and Methods

Birds were collected in inner lagoons surrounding Altata-Ensenada del Pabellón lagoon; the system is located in the central part of Sinaloa state (24° 20' and 24° 40' N; 107° 30' and 107 58' W) (Fig. 1). The major source of pollution is waste effluents from the intensive agriculture (140,000 ha) around the lagoon system; the main crops are vegetables, grains, and sugar cane. Agricultural effluents drain directly via small channels (esteros) and inner lagoons into the principal lagoon system. Another source of pollution is the urban sewage from the towns (pop. 100,000) and the cities of Culiacán (pop. 750,000) and Navolato (pop. 50,000). Both of these cities are located on the margin of the Culiacán River, 40 and 20 km away from the main lagoon, respectively (Páez-Osuna et al. 1998). In addition, from December to June, effluents from a sugar-cane industry called Ingenio La Primavera are discharged directly into the Ensenada del Pabellón lagoon portion. Glassware and other utensils, used for the manipulation and preparation of the samples, were previously washed with nitric (2 M) and hydrochlorc acid (2 M) (Moody and Lindstrom, 1977). Birds were collected between February and March 2000; twenty resident specimens (five species) and nine migratory specimens (four species) were gun shot by hunters using lead-free ammunitions. Though birds were collected within the hunting season, a special permit from SEMARNAT was given (DOO.02.-3324).

Identification of specimens was made according to field guides (Peterson and Chalif, 1989). After identification, specimens were measured and weighed; relevant biological data are provided in Table 1. Dissection of organisms was made in order to separate heart, liver, muscle, viscera, and primary feathers. Pectoral muscle and primary fathers were used for the analysis. With the exception of feathers, samples were freeze-dried for 72 hours (–49°C and 133 x $10^{-3}$ mBar) and then were ground in an automatic agate mortar (Retsch) for 10 min. Powdered samples (and finely cut feathers) were acid digested (5 mL of quartz- distilled concentrated nitric acid) using a microwave digestion unit (CEM 2000) under the following conditions (MESL, 1997): step 1, 20 psi for 10 min; step 2, 40 psi for 10 min; step 3, 90 psi for 30 min. Digested samples were stored in polyethylene containers for further analysis. Analyses were per-

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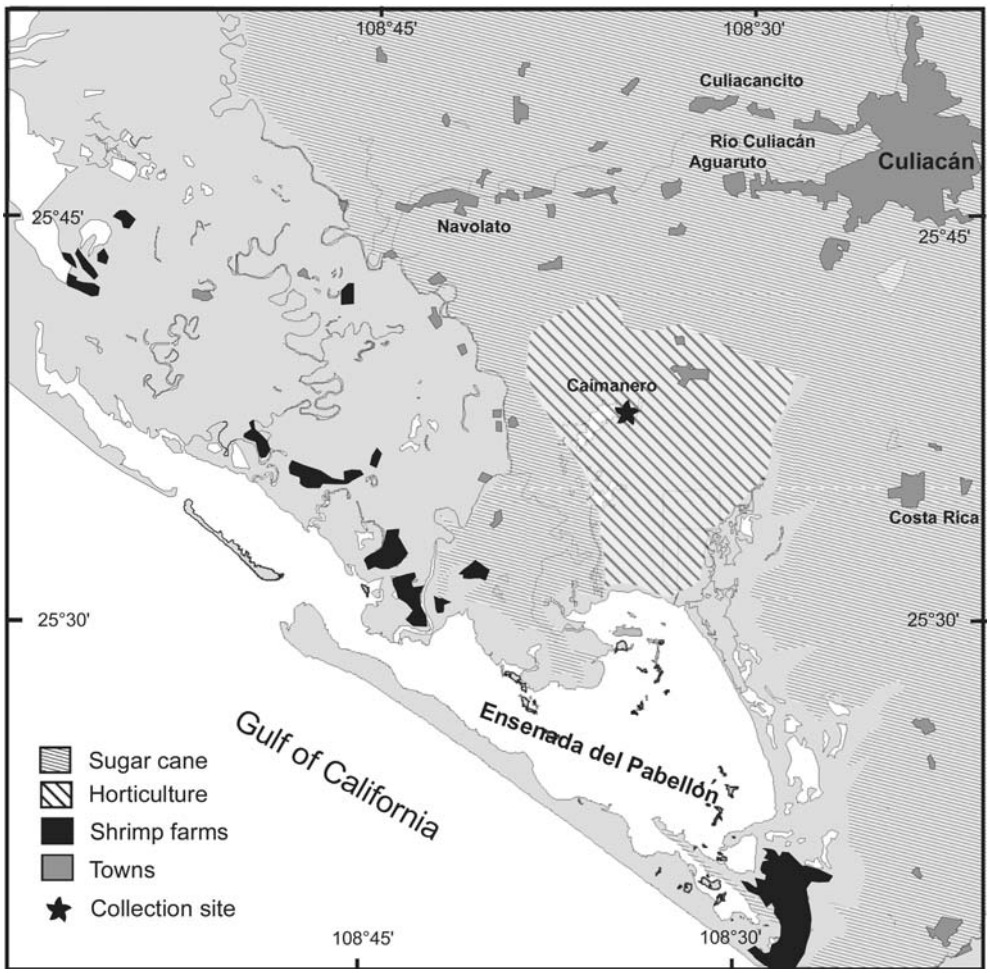


**Fig. 1** Study area showing the collection site and main sources of pollution

**Table 1** Biological features of resident (R) and migratory (M) birds collected in Altata-Ensenada del Pabellón lagoon, Southeast Gulf of California between February and March 2000

| Species | Common name | Residence | Average weight (g) | Average length (cm) | Feed items |
|---|---|---|---|---|---|
| *Pelecanus occidentalis* | Brown pelican | R (n = 2) | 3700 ± 200 | 88 ± 3 | Fish, crustaceans |
| *Phalacrocorax olivaceus* | Olivaceous cormorant | R (n = 6) | 973 ± 84 | 51 ± 4 | Fish, crustacean, molluscs |
| *Casmerodius albus* | Great egret | R (n = 3) | 1125 ± 15 | 78 ± 2 | Fish, amphibians, reptiles, insects |
| *Bubulcus ibis* | Cattle egret | R (n = 2) | 336 | 38 | Insects, amphibians, reptiles |
| *Plegadis chihi* | white-faced ibis | R (n = 7) | 574 ± 58 | 43 ± 5 | Invertebrates, seeds, fruits, mammals |
| *Recurvirostra americana* | American avocet | M (n = 2) | 370 ± 16 | 45 ± 1 | Grasshoppers, snails, crustaceans |
| *Dendrocygna autumnalis* | Black-bellied duck | M (n = 2) | 793 ± 17 | 39 ± 1 | Corn and insects |
| *Anas cyanoptera* | Cinnamon teal | M (n = 2) | 763 ± 347 | 45 ± 8 | Aquatic plants, seeds, insects |
| *Fulica americana* | American coot | M (n = 3) | 657 ± 126 | 36 ± 3 | Leaves, seeds, fish, insects |

n, number of specimens

formed by reducing mercury compounds in solution samples using $SnCl_2$ (Loring and Rantala, 1995); measurements were made with a mercury analyzer (Buck Scientific400A, East Noewalk, CT, USA). Mercury concentrations are expressed as μg $g^{-1}$ on a dry weight basis; precision and accuracy of the analytical method were assessed by using certified reference material MA-B-3/TM (IAEA, 1987). A satisfactory agreement between the analytical results (0.60 ± 0.05 μg $g^{-1}$ dry weight) and the certified values (0.54 ± 0.07 μg $g^{-1}$ dry weight) was obtained. To check for contamination, blanks were run with every batch of 8 samples. Normality of data was assessed by a Kolmogorov-Smirnoff test; average concentrations of mercury for the different tissues were compared by a one-way ANOVA ($p < 0.05$);

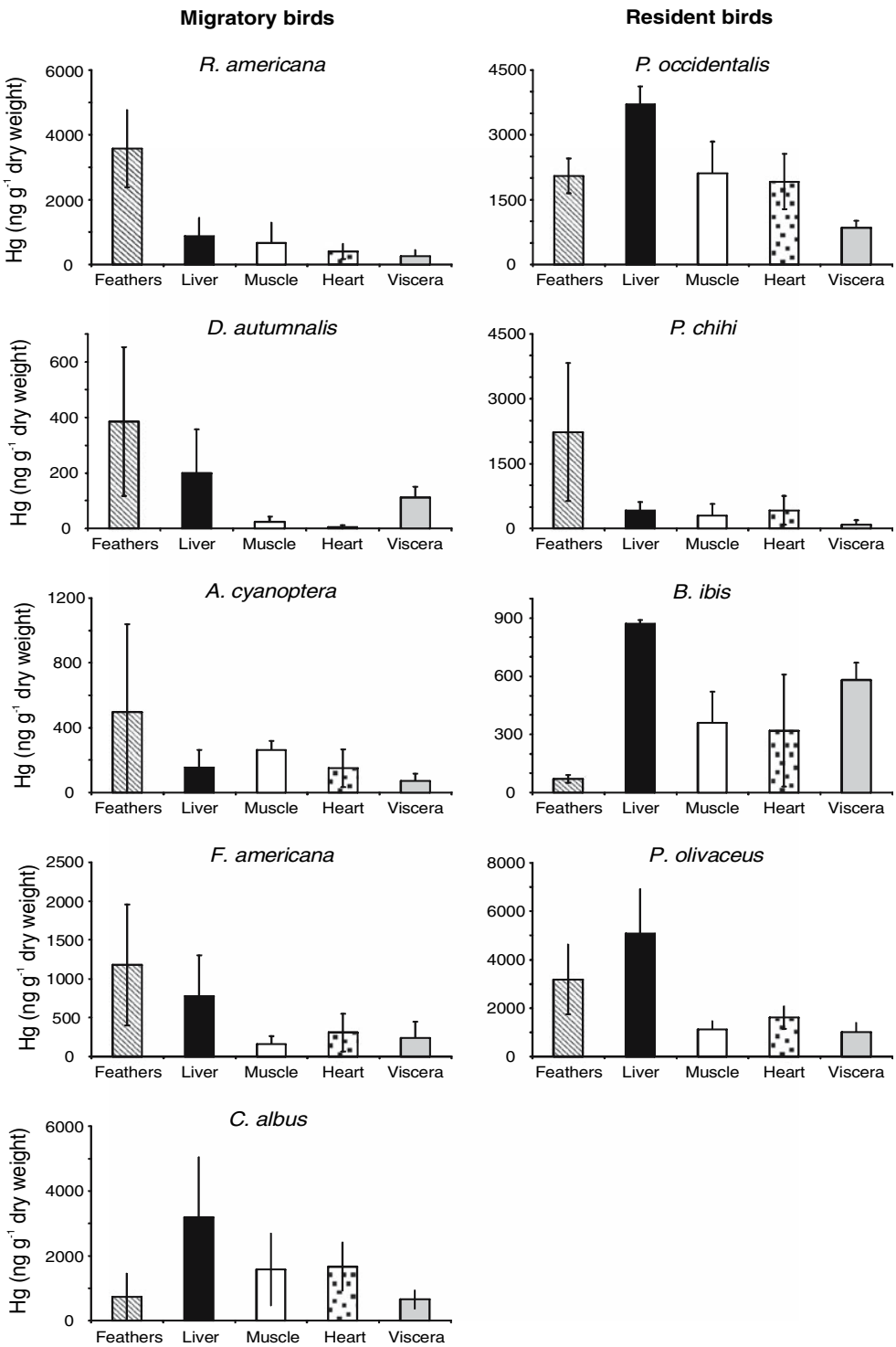


**Fig. 2** Mercury levels in the analyzed tissues of migratory and resident birds from Altata-Ensenada del Pabellón lagoon, Southeast Gulf of California

statistical analyses were performed using GraphPad Prism 2.1 (Graph Pad Software, San Diego, CA).

## Results and Discussion

According to published data concerning morphometric features of aquatic birds (Peterson and Chalif, 1989), and based on the time of the year when birds were collected, all of the birds should have been adults. Migratory specimens were grouped in 3 families (Anatidae, Rallidae, and Recurvirostridae), resident birds belonged to 4 families (Ardeidae, Pelecanidae, Phalacrocoracidae, and Threskiornithidae). Sex of the specimens was not determined. Mercury was detected in all samples (Fig. 2); in

migratory birds, the highest levels of mercury were detected in feathers. In resident birds, the tissue with the highest concentration was the liver (with the exception of *P. chihi*). Liver accumulation is the consequence of a demethylation process that takes place in the liver, so the element is stored in an inorganic form (Kim et al., 1996). If the residence of birds is known during the growing of feathers, monitoring of heavy metal pollution in marine food webs through feathers has been useful since the food webs provide nondestructive sampling and allow retrospective studies (Monteiro and Furness, 1995). In the case of mercury, chemical speciation plays a key role in the accumulation of the element in feathers. Organic mercury, in the form of methylmercury (MeHg), is almost all assimilated by organisms from ingested foods and is accumulated in feathers, whereas most inorganic mercury passes through the alimentary system to be voided in feces.

Specimens with the highest mercury levels (Fig. 2) belonged to piscivorous species; such is the case of the brown pelican (*P. occidentalis*) and the olivaceous cormorant (*P. olivaceus*). In this context, diet is known to play a key role in mercury accumulation (Monteiro and Furness, 1995). In diverse studies, feeding habits are considered an important factor to elucidate mercury variation among waterfowl (De Luca-Abbott et al., 2001; Uryu et al., 2001). Levels of mercury in fish and seabirds that are high on the food chain can be sufficiently high to cause deleterious effects both to themselves and to organisms that consume them, including humans (Burger and Gochfeld, 1997). Because of the sample size of studied specimens, statistical analysis to compare mercury levels was not practiced for all the species. Average mercury concentrations in resident birds that were compared for statistical differences were only the white-faced ibis *P. chihi* (omnivorous) and the cormorant *P. olivaceus* (piscivorous); with the exception of feathers, all the tissues had significantly higher concentrations ($p < 0.05$) in *P. olivaceus*. The only case where the sample size allowed a significant correlation ($p < 0.05$) was *P. chihi*. Tissues that were highly correlated were muscle–heart and feathers–liver (Fig. 3). Though significant relationships among mercury levels in diverse tissues of aquatic birds exist, no generalizations can be made. Augspurger et al. (1998) reported a positive correlation of mercury levels in liver and feathers of the loon *Gavia immer*.

Among migratory birds, *R. americana* (feathers) was the species with the highest levels of mercury; in the resident component *P. olivaceus* (liver) showed the highest concentration (Fig. 2). In general, the sequence of average mercury concentrations in migratory birds was feathers > liver > muscle > heart > viscera; this sequence might suggest that these birds had more exposure to mercury in their original place than in the sites of collection. In the case of resident organisms the order was liver > feathers > heart > muscle > viscera. After averaging mercury levels in every tissue of migratory and resident birds, results showed higher levels in the resident organisms. Perhaps these differences occur because of contrast in the metabolism among the distinct species and the fact that most species of resident birds were piscivorous whereas migratory avifauna consisted of omnivorous species. Concentrations of mercury in the different tissues of analyzed species were comparable to those of other aquatic birds. Levels of mercury in the compared specimens from different sites of the world varied by two orders of magnitude. Species with the highest levels were the Bonin petrel *Pterodroma hypoleuca* and the black-footed albatross *Diomedea nigripes* (19.7 and 19.6 μg $g^{-1}$ d.w., respectively) from the Midway atoll in the USA (Burger and Gochfeld, 2000); the lowest levels of mercury (0.97 μg $g^{-1}$ d.w.) occurred in the brown pelican *Pelecanus occidentalis* from Los Angeles bay (Ohlendorf et al., 1985). A direct comparison of mercury

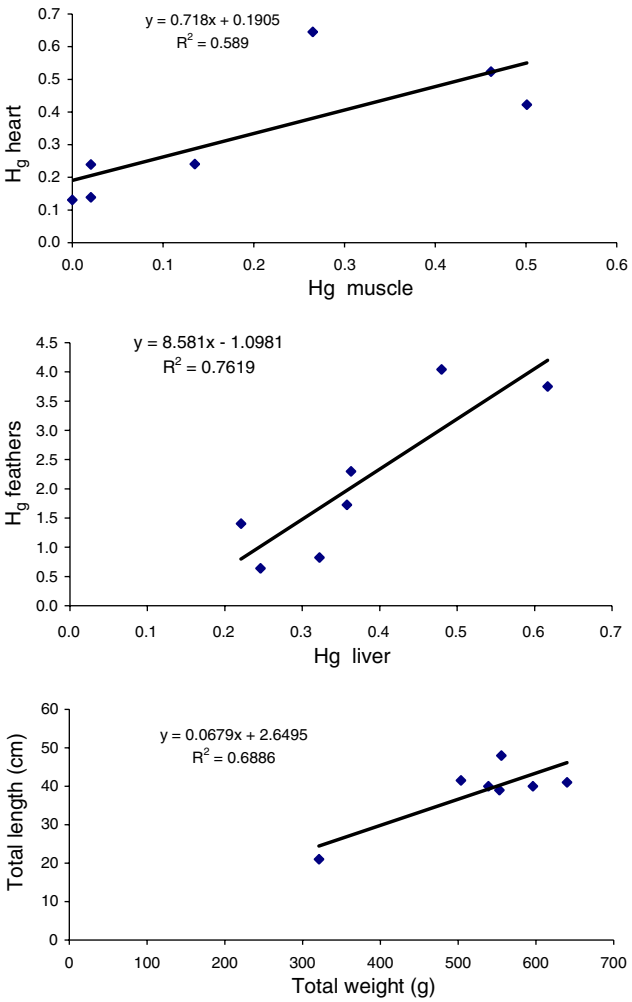


**Fig. 3** Significant correlations among mercury levels in tissues of the white-faced ibis and among size and weight of *P. chihi* from Altata-Ensenada del Pabellón lagoon, Southeast Gulf of California

concentrations in birds of different species is not objective since intraspecific variation is well recognized. In this context, values are a measure of the degree of mercury bioavailability in a given place. Mercury levels of 5 μg $g^{-1}$ d.w. in feathers (Eisler, 1987) are known to cause sublethal and reproductive effects, so some of the compared species might show some sort of damage. In the case of liver, it has been documented (Hui et al., 2001) that shorebird populations with levels greater than 3.0 μg $g^{-1}$ d.w. may be vulnerable to sublethal effects; in the present study, *P. olivaceus* and *P. occidentalis* showed levels greater than 3.0 μg $g^{-1}$ d.w.

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