Environ Monit Assess (2010) 160:47–59
DOI 10.1007/s10661-008-0656-0

Trace metal levels in *Prochilodus lineatus* collected from the La Plata River, Argentina

Paula E. Lombardi · Silvia I. Peri ·
Noemí R. Verrengia Guerrero

Received: 11 February 2008 / Accepted: 5 November 2008 / Published online: 5 December 2008
© Springer Science + Business Media B.V. 2008

Abstract Most of the industrial, urban and sewage discharges are released into the La Plata River, Argentina without any previous treatment. However, few works have investigated the extent of metal contamination. The aim of this study was to assess the levels of cadmium, copper, lead and zinc in liver and gills of adults *Prochilodus lineatus* collected from three sampling stations along the coast of the La Plata River: Berazategui, Berisso and Atalaya (from north to south). Samplings were performed during 2002 and 2004. Berazategui and Berisso were located nearby the main ducts that discharge the urban and domestic waste disposal from the cities of Buenos Aires and La Plata, respectively. The third station, Atalaya, was free of sewage discharges. Levels of cadmium and copper in liver were always higher than those found in gills. Instead, for lead and zinc, high levels were observed either in liver or gills, depending on the sampling station and the sampling period. In both tissues, the concentrations of metals did not differ significantly between male and female fish. In liver samples, the concentrations of cadmium, copper and zinc tended to increase from north to south. Instead, the levels of lead followed an opposite pattern. No clear tendencies were observed in gill samples. The data may be useful as reference levels of metal contaminants in *P. lineatus*, the most important fish species in the La Plata River system.

Keywords Cadmium · Copper · Metal accumulation · Lead · *Prochilodus lineatus* · Zinc

Introduction

The basin of the La Plata River is one of the most important in South America. The La Plata River is formed by the confluence of the Paraná and Uruguay rivers, and it is the last lotic system of the basin. The river flows into the Atlantic Ocean as a big estuary, with a highly variable width ranging from about 40 up to 200 km at its mouth, whilst its total length is approximately 300 km (Dagnino Pastore 1973; Bazán and Arraga 1993).

Buenos Aires, capital city of Argentina, is the biggest city located along the coast, approximately 30 km from the origin of the river. This capital

---

P. E. Lombardi · N. R. Verrengia Guerrero (✉)
Departamento de Química Biológica,
Facultad de Ciencias Exactas y Naturales,
Toxicología y Química Legal, Universidad de Buenos
Aires, 4^{o} piso, Pabellón II, Ciudad Universitaria,
1428 Buenos Aires, Argentina
e-mail: noev@qb.fcen.uba.ar

P. E. Lombardi · S. I. Peri
Química Biológica, Facultad de Ciencias
Naturales y Museo, Universidad Nacional de La Plata,
Calles 60 y 122, 1900 La Plata, Argentina

city and surroundings are the highest population density areas, with almost 17,000,000 inhabitants. La Plata, located about 50 km to the south from Buenos Aires, is the capital city of Buenos Aires Province, and has a population of 711,000 inhabitants. Together, these cities and their surroundings concentrate nearly 47% of the country population. Therefore, in this area, many industries to satisfy the demands of the continuously increasing population are located. In addition, two of the principal ports of the country are located there. Unfortunately, most of the industrial, domestic and urban discharges are released into the La Plata River without any previous treatment. As a consequence, it is believed that the aquatic system and its resources have been severely affected. On the other hand, the river provides the drinking water supply for the population.

Despite the extension of the basin, the high population density, the anthropogenic activities, together with the minor water effluents that are heavily contaminated, comparatively few studies have been conducted to assess the extent of contamination and the water quality of the La Plata River. Perhaps the most important monitoring program was conducted almost 20 years ago, sampling the principal navigation channel located about 4–5 km from the coast (CARP-SINH-SOHMA 1990). According to this study, levels of many contaminants in water samples were in general within the range of concentrations allowed for superficial freshwaters. Many reasons can influence this behaviour, such as the hydrological dynamic of the river and the content of suspended material (CARP-SINH-SOHMA 1990). However, a trend to higher levels of contaminants was observed in coastal areas, especially for trace metals. The levels of cadmium concentrations were within the range of 0.1–9.1 μg L^{-1}, and 82% of the samples presented values higher than the reference level for protecting the aquatic wildlife (0.2 μg Cd L^{-1}) according to the recommendations for the La Plata basin (CARP-SINH-SOHMA 1990). The range for copper was 0.7–21.9 μg L^{-1}, with a high percentage of the samples presenting values higher than the reference level of 2 μg Cu L^{-1}, especially at the vicinity of Buenos Aires port (CARP-SINH-SOHMA 1990). For lead, a range of 1.0–42.8 μg L^{-1} was found, values equal or higher than the reference level of 1.0 μg L^{-1} (CARP-SINH-SOHMA 1990). The highest levels of lead were found in the samples collected near the sewage discharges at Berazategui. In the case of zinc, the values varied between 1.3 and 46.0 μg L^{-1}. For this metal, 7% of the samples were above the reference level (30 μg Zn L^{-1}) for protecting the aquatic wildlife (CARP-SINH-SOHMA 1990).

In addition, only a few works have reported levels of metals in fish tissues from the La Plata River (Marcovecchio et al. 1991; Verrengia Guerrero and Kesten 1993; Villar et al. 2001; Marcovecchio 2004), but none of these studies sampled the areas of the sewage discharges.

At Buenos Aires city, total suspended matter may reach values of 70–80 mg L^{-1}. These values significantly increase at the south of La Plata city as a consequence of turbulences that result from the marine currents, but they decrease close to the river mouth due to sedimentation processes (Bazán and Arraga 1993). Therefore, most of the contaminants that are released to the aquatic system become associated with the suspended matter and bottom sediments, posing a risk for the benthic organisms. Sediment samples collected in a coastal site to the south from Buenos Aires port during 1991 presented the following ranges of metal concentrations: 7.4–88.6 μg g^{-1} for copper; 25.8–132.5 μg g^{-1} for lead and 36.5–137.2 μg g^{-1} (on a wet weight basis; Verrengia Guerrero 1995). Although cadmium was not detected (<0.01 μg g^{-1}; Verrengia Guerrero 1995), it showed a great ability to accumulate in the soft tissues of a bivalve mollusk species (Verrengia Guerrero and Kesten 1997).

Prochilodus lineatus is a neotropical fish, widely distributed in the La Plata basin, where it represents 50–60% of the total ichthyomass (Oldani 1990; Palma de Croux 1994). This species is a bottom feeder fish that is able to incorporate contaminants present not only in the water column but also in sediment particles. For this reason, the species has been considered as a suitable bioindicator organism to assess simultaneously the water and sediment quality (Almeida et al. 2005; Santos et al. 2005; Camargo and Martinez 2006). However, the dynamic of its population may constitute a disadvantage. Under normal conditions, sexually mature fishes migrate 200–600 km upstream the La Plata River for reproductive purposes (Oldani 1990). Apparently, the temperature of the water would be the principal stimulus that elicits the migration. These migrations usually start in autumn–winter (south hemisphere). The reproductive cycle occurs during the spring–summer seasons (from October to March), and after the spawning, the animals return to the La Plata River (Sverlig et al. 1993).

The purpose of this work was to determine the levels of cadmium, copper, lead and zinc in different tissues of *P. lineatus* collected from three sampling stations along the La Plata River. Liver and gill tissues were selected because they may reflect the extent of metal bioaccumulation. Two of the sampling stations, Berazategui and Berisso, are located at the vicinity of the main ducts that discharge the urban and domestic waste disposal from the cities of Buenos Aires and La Plata, respectively. The third station, Atalaya, is located downstream and is free from sewage effluents, but it may be also subjected to minor industrial effluents and non-point agricultural runoffs. It could be argued that this last site would not be a proper election for comparative purposes. However, the areas upstream to Buenos Aires are severely affected by port activities, and they could not be regularly sampled due to the low fish population. In addition, due to the particular characteristics of the river (almost as wide as large) and the influence of the marine currents that are opposite to the river current, the concept of upstream–downstream is not easily applicable to this aquatic system.

The condition index and the liver somatic index were also calculated in order to estimate the physiological status of the fishes.

Materials and methods

Samples of *P. lineatus* were obtained from three sampling stations, Berazategui, Berisso and Atalaya, along the coastal area of the La Plata River, and they are presented in Fig. 1.

Samplings were performed during spring 2002, autumn 2003, spring 2003 and autumn 2004 (south hemisphere). In all cases, fish was obtained from

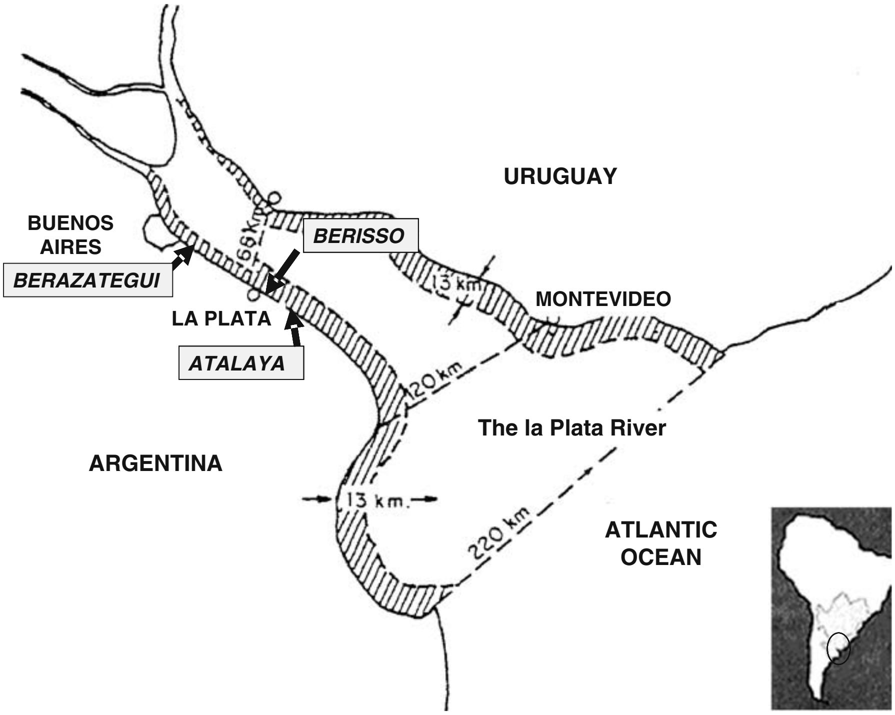


Fig. 1 Map showing the sampling stations

local fishermen. The animals were transported alive to the laboratory in plastic aquaria (50 L) containing river water.

Once the animals reached the laboratory, their length and weight were determined. The values are presented in Table 1. Only adult specimens were processed for metal analyses. The sex was determined by observation of the gonads. Afterwards, the animals were killed by excision of the spinal cord behind the operculum. Liver and gill tissues were dissected and weighed at 2–4°C. Approximately 1–2 g (wet weight) of each tissue was placed in acid prewashed borosilicate tubes. The digestion procedure was performed immediately after dissection in the presence of 5–10 mL of ultrapure concentrate nitric acid (Merck Laboratories, Argentina) at 100–120°C until the complete destruction of the organic material. Then, the samples were diluted to a final volume of 5 mL with 1% (v/v) ultrapure nitric acid and centrifuged to remove any residue. Each tissue was analysed at least by duplicate. For each ten samples, a blank was performed and processed simultaneously.

Metal concentrations were measured in a 575 AA Varian atomic absorption spectrophotometer with background correction, applying the method of direct flame atomization in an air-acetylene flame. Detection limits were 0.04 μg Cd g^{-1}, 0.2 μg Cu g^{-1}, 0.3 μg Pb g^{-1} and 0.03 μg Zn g^{-1}. Values of metal accumulation were expressed as micrograms of metal per gram wet tissue.

All the glassware was prewashed with 5% nitric acid, thoroughly rinsed with double-distilled water and dried. Blank values were negligible for all the elements studied. To check the accuracy of the analyses, standard addition methods were used to overcome matrix effects.

The fish condition factor (CF) was calculated according to Bagenal and Tesch (1978):

$$\mathrm{CF} = \frac{\mathrm{Wt}}{L^3} \times 100$$

where Wt is the total weight of the fish (grams), and L is the total length (centimetre).

The hepatic somatic index (HSI) was calculated as (Sloff et al. 1983):

$$\mathrm{HSI} = \frac{\mathrm{Wl}}{\mathrm{Wt}} \times 100$$

Table 1 Mean values (±SD) of body length and weight of *P. lineatus* collected during 2002–2004

		Berazategui			Berisso			Atalaya		
		n	Length (cm)	Weight (g)	*n*	Length (cm)	Weight (g)	*n*	Length (cm)	Weight (g)
Spring 2002	F	10	45.3 ± 7.4	3,164 ± 1,462	3	49.0 ± 1.0	2,920 ± 46	3	43.8 ± 0.3	2,250 ± 265
	M	8	44.1 ± 3.0	2,655 ± 633	6	39.9 ± 5.2	1,696 ± 433	3	51.3 ± 3.9	3,050 ± 212
Autumn 2003	F	7	49.8 ± 3.1	3,903 ± 852	7	40.9 ± 7.8	1,921 ± 1,053	4	41.7 ± 4.7	1,720 ± 627
	M	3	48.5 ± 1.8	3,391 ± 1,265	4	39.6 ± 8.0	1,513 ± 769	3	41.0 ± 7.1	1,300 ± 283
Spring 2003	F	8	47.5 ± 4.3	3,254 ± 1,075	8	40.6 ± 3.8	1,925 ± 619			
	M	6	44.7 ± 3.7	2,866 ± 616	3	37.3 ± 3.1	1,467 ± 633			
Autumn 2004	F	4	49.4 ± 1.6	3,490 ± 308				3	41.6 ± 2.4	1,732 ± 243
	M	4	43.6 ± 4.1	2,628 ± 957				5	42.7 ± 3.0	1,940 ± 494

n number of samples, *F* female, *M* male where Wl is the weight of the fish liver (grams), and Wt is the total weight of the fish (grams).

Pearson correlation factors were calculated using the Excel® software package (Microsoft, US). Metal concentrations in fish tissues had heterogeneous variances (Bartlett's tests); therefore, comparisons among different sampling periods and sampling stations were performed using Kruskal–Wallis non-parametric tests (Sokal and Rohlf 1969). Comparisons among the condition factors and among the hepatic somatic indices were performed using analysis of variance tests (Sokal and Rohlf 1969). The significance level was set at $p = 0.05$.

Results and discussion

It is widely accepted that levels of metals bioaccumulated by aquatic organisms depend on both environmental and biological factors. However, when sampling a particular area at a given period, environmental factors are supposed to elicit the same influence. In these cases, metal levels may vary according to the age, size, gender, general health condition, spawning status and individual susceptibility of the collected organisms (Peakall and Burger 2003). Whilst individual susceptibility cannot be easily evaluated by simple parameters, relationships between metal bioaccumulation and some of the other variables may be investigated.

In all the sampling stations, significant correlations factors (r) were found between the length and the whole body weight. Values were $r = 0.89$ for Berazategui, 0.94 for Berisso and 0.77 for Atalaya.

The condition factor has been used to relate the consequences of biochemical and physiological alterations to observed changes in the individuals and population (Goede and Burton 1990). This index may decrease as a result of several environmental stressors due to a depletion of the energy reserves such as stored liver glycogen or body fat. However, it should be taken in mind that energy reserves may also fluctuate seasonally as a consequence of changes in feeding activity and nutrient availability. In addition, this index may change with the physiological development and sexual maturation of the fish (Goede and Burton 1990). According to Table 2, the condition factors for *P. lineatus* did not present significant differences either seasonally or among the three sampling stations ($p > 0.05$). In addition, the values were not influenced by the sex of the animals ($p > 0.05$).

The hepatic somatic index is another common parameter that may be regarded as a general health indicator. It is sensitive to stress induced by environmental pollutants (Almeida et al. 2005). This index may decrease as a consequence of the depletion of the energy reserves stored in the liver to cope with stressors. However, its value may also increase due to several chemical contaminants. The increase is commonly seen for those chemicals that induce hyperplasia or hypertrophy of the liver (Goede and Burton 1990; Almeida et al. 2005). In Berazategui, the hepatic somatic index varied between 1.1 and 1.3 (Table 2), and no significant differences were found among the sampling periods ($p > 0.05$). Mean values were 1.2 ± 0.4 for both male and female fish. Similar values were observed in fishes collected in Berisso (Table 2; $p > 0.05$). A different pattern was observed in Atalaya, where lower levels were observed in comparison with the other sites in spring 2002 and autumn 2004 ($p < 0.05$).

It is worth noting that Berazategui and Berisso are the recipients of high amounts of untreated sewage discharges during the whole year. Therefore, it may be reasonable to assume that the availability of nutrients, specifically organic matter, remained temporally unchanged, so the fishes could not experience any deprivation condition. Instead, a different situation could experience the specimens collected in Atalaya. On the other hand, even the adult organisms collected from the three sites in the spring season (spawning period) did not show any evidence of sexual maturity for reproductive purposes. This could explain the similar values observed for male and female fish.

Although the gender is an important factor that may influence the bioaccumulation of metals in biota (Burger 2007; Vahter et al. 2007), few works have investigated this variable in depth. Al-Yousuf et al. (2000) reported that the average metal concentrations for copper, manganese and zinc in liver, skin and muscle of the female fish *Lethrinus lentjan* were higher that those found

Table 2 Mean values (± S.D.) of condition factors (CF) and hepatic somatic indices (HSI) of *P. lineatus* collected during 2002–2004

		Berazategui			Berisso			Atalaya		
		n	CF	HSI	*n*	CF	HIS	*n*	CF	HIS
Spring 2002	F	10	3.0 ± 0.6	1.1 ± 0.2	3	2.5 ± 0.1	1.2 ± 0.9	3	2.7 ± 0.3	0.5 ± 0.3*
	M	8	3.0 ± 0.2	1.1 ± 0.2	6	2.7 ± 0.7	1.6 ± 0.4	3	2.3 ± 0.7	0.4 ± 0.1*
Autumn 2003	F	7	3.1 ± 0.3	1.3 ± 0.3	7	2.6 ± 0.4	1.0 ± 0.3	4	2.3 ± 0.5	1.5 ± 0.4
	M	3	2.9 ± 0.8	1.2 ± 0.2	4	2.3 ± 0.2	1.2 ± 0.2	3	1.9 ± 0.6	1.5 ± 0.7
Spring 2003	F	8	2.9 ± 0.4	1.2 ± 0.4	8	2.8 ± 0.3	1.0 ± 0.3			
	M	6	3.2 ± 0.1	1.3 ± 0.4	3	2.7 ± 0.6	1.1 ± 0.3			
Autumn 2004	F	4	2.9 ± 0.3	1.2 ± 0.2				3	2.4 ± 0.3	0.4 ± 0.1*
	M	4	3.0 ± 0.3	1.1 ± 0.2				5	2.5 ± 0.5	0.6 ± 0.1*

n number of samples, *F* female, *M* male
$^*p < 0.05$

in male fish. However, the authors did not find significant differences for cadmium. In agreement with this last result, no significant differences were observed in liver and gills of *P. lineatus* collected from any of the three sampling stations and during the different sampling periods for all the metals analysed ($p > 0.05$). This result is in agreement with the sexual immaturity of the fishes. For this reason, data from both genders were pooled.

The levels of cadmium in liver and gills of *P. lineatus* collected from the three sampling stations are shown in Fig. 2a and b, respectively. The data are presented using the box plots, where the whiskers outside the box represent the range of metal concentrations, and the box is limited by the 25th and 75th percentiles (lower and upper quartiles, respectively).

For liver samples, no significant differences were observed among the sampling stations in spring 2002 and autumn 2003 ($p > 0.05$). Instead, the higher concentrations of cadmium were found in Atalaya in spring 2003 and autumn 2004 ($p < 0.05$).

In Berazategui, levels of cadmium in liver tended to decrease from spring 2002 to autumn 2003, although these values were not significantly different between them ($p > 0.05$). However, significant lower values were found in autumn 2004 ($p < 0.05$). A similar pattern was observed in Berisso, where the lower levels were found in spring 2003 ($p < 0.05$). On the contrary, in Atalaya, no significant differences were observed among the sampling periods studied ($p > 0.05$). However, it should be worth noting that as only three or four samplings were conducted, the data were not enough to establish any relevant temporal variation.

In contrast to the results found in liver, lowest values of cadmium were observed in gill samples ($p < 0.05$). In addition, no significant differences were observed among the three sampling stations, except for the samples collected from Berazategui in spring 2003, which presented the highest levels of the metal ($p < 0.05$).

The levels of copper in liver and gill samples of *P. lineatus* are shown in Fig. 3a and b, respectively.

In general, the lower concentrations of copper were recorded in the liver samples collected from Berazategui ($p < 0.05$), where no significant

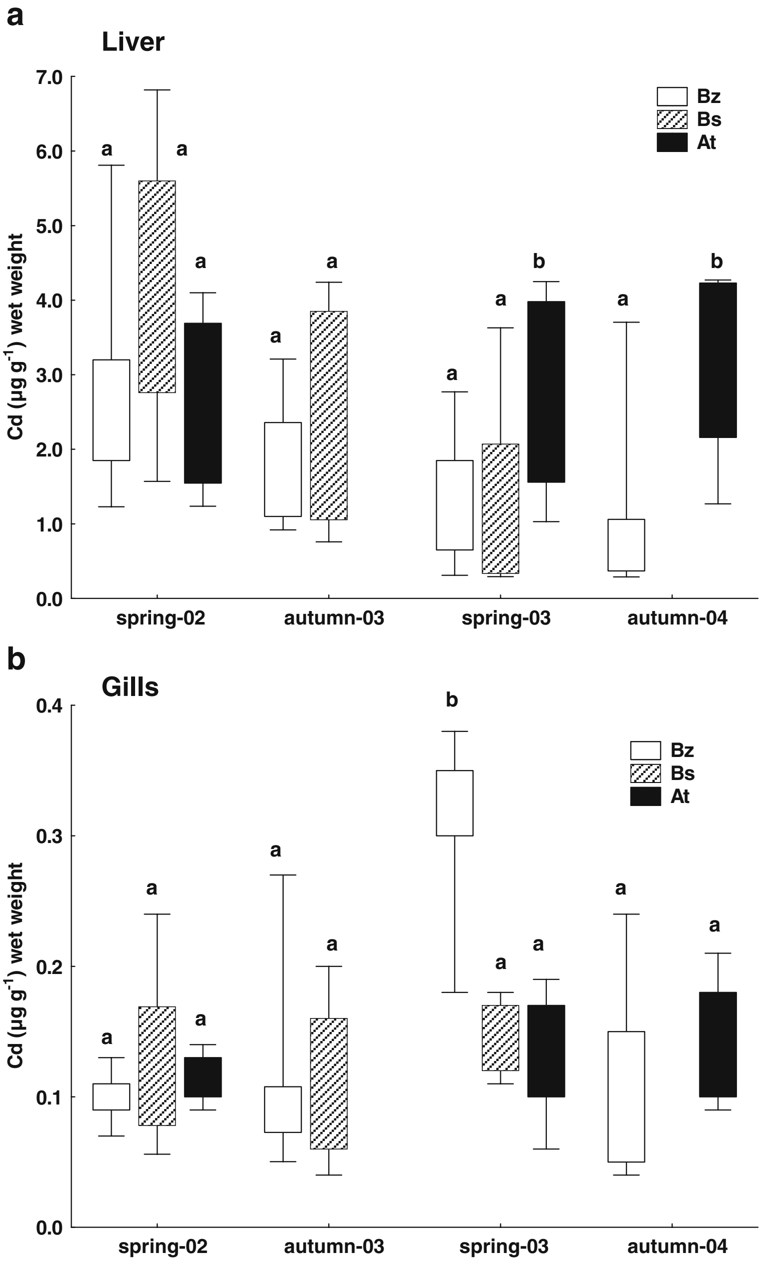


Fig. 2 Levels of cadmium in **a** liver and **b** gills of *P. lineatus* during 2002–2004. *Bz* Berazategui, *Bs* Berisso, *At* Atalaya. *Different letters* indicate significant differences ($p < 0.05$) among the sampling stations but only within each sampling period

differences were observed among the sampling periods ($p > 0.05$). Higher levels were found in the samples from Atalaya ($p < 0.05$), which did not present either significant difference among the sampling periods ($p > 0.05$). Intermediate values were found in liver samples from Berisso. Whilst in spring 2002 and autumn 2003 the levels were not significantly different from those recorded in Berazategui ($p > 0.05$), they increased in spring 2003, reaching similar values than those observed in Atalaya ($p > 0.05$).

As in the case of cadmium, gill samples presented lower levels of copper than the liver samples ($p < 0.05$). Comparing Berazategui and Atalaya, the lower values were found in the samples from Atalaya in spring 2002 and spring 2003 ($p < 0.05$), following an opposite pattern to those observed for liver samples. Between Berazategui

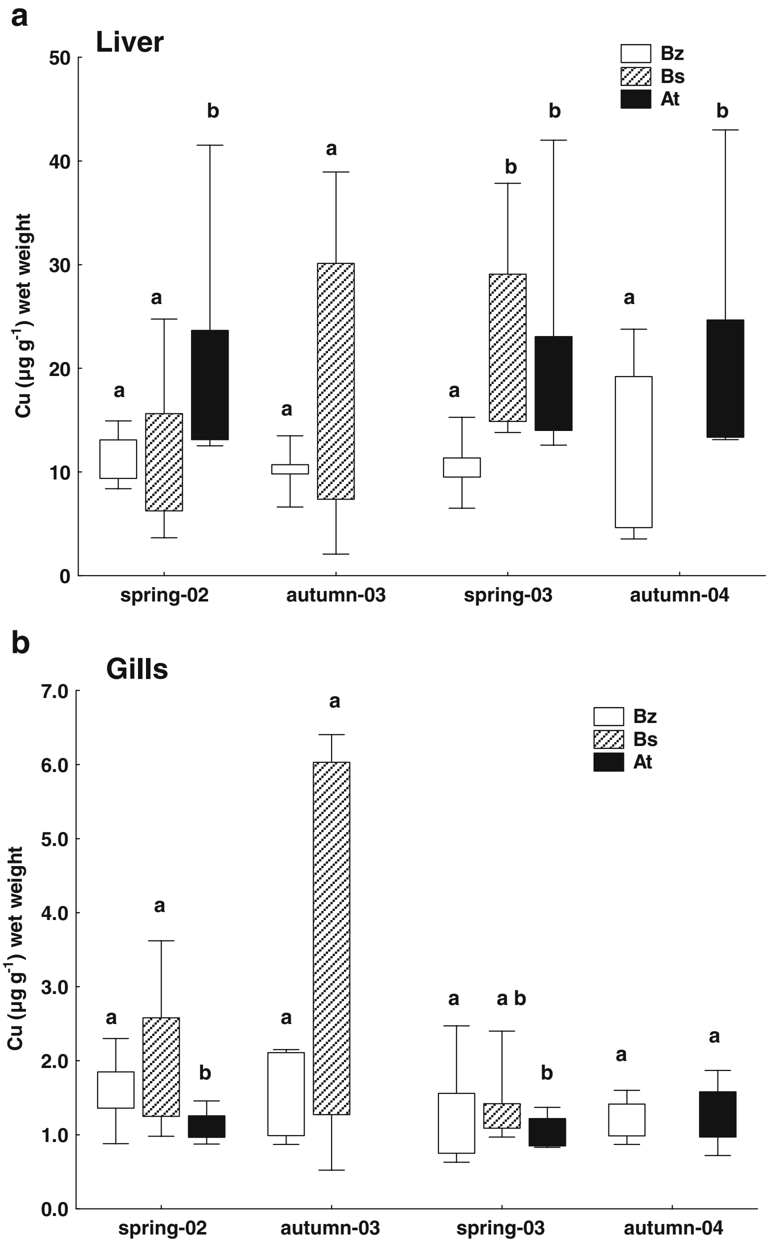


Fig. 3 Levels of copper in **a** liver and **b** gills of *P. lineatus* during 2002–2004. *Bz* Berazategui, *Bs* Berisso, *At* Atalaya. *Different letters* indicate significant differences ($p < 0.05$) among the sampling stations but only within each sampling period

and Berisso, the levels of copper did not differ significantly ($p > 0.05$). On the other hand, no significant temporal variations were observed for any of the sampling stations ($p > 0.05$).

The results for lead concentrations in liver and gills are presented in Fig. 4a and b, respectively.

During all the sampling periods, excepting for autumn 2003, higher levels of lead were observed in liver samples from Berazategui ($p < 0.05$), whilst the lowest values were found in the samples collected in Atalaya ($p < 0.05$). In spring 2002, the samples from Berisso presented intermediate values ($p < 0.05$), whilst in autumn 2003 and spring 2003, liver samples from Berazategui and Berisso showed similar lead levels ($p > 0.05$).

A more complex and variable pattern was observed for lead in gill samples. Firstly, the values found in gills overlapped to those found

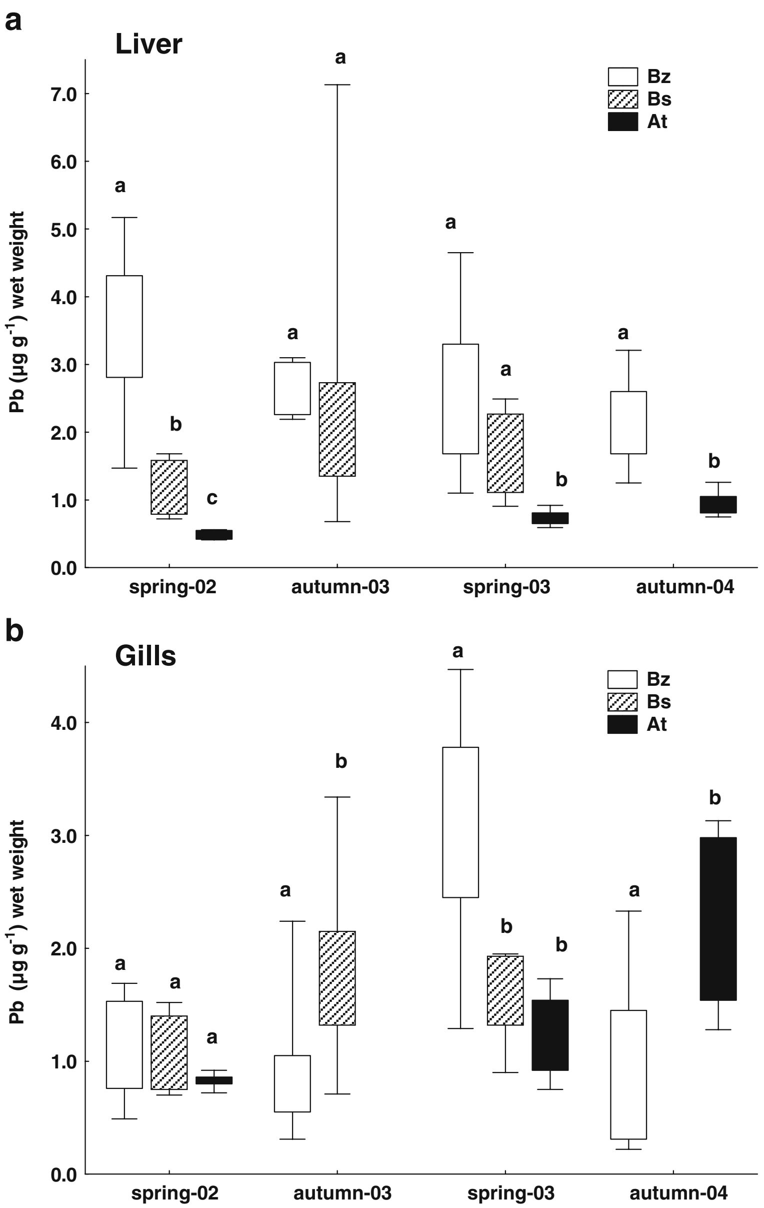


Fig. 4 Levels of lead in **a** liver and **b** gills of *P. lineatus* during 2002–2004. *Bz* Berazategui, *Bs* Berisso, *At* Atalaya. *Different letters* indicate significant differences ($p < 0.05$) among the sampling stations but only within each sampling period

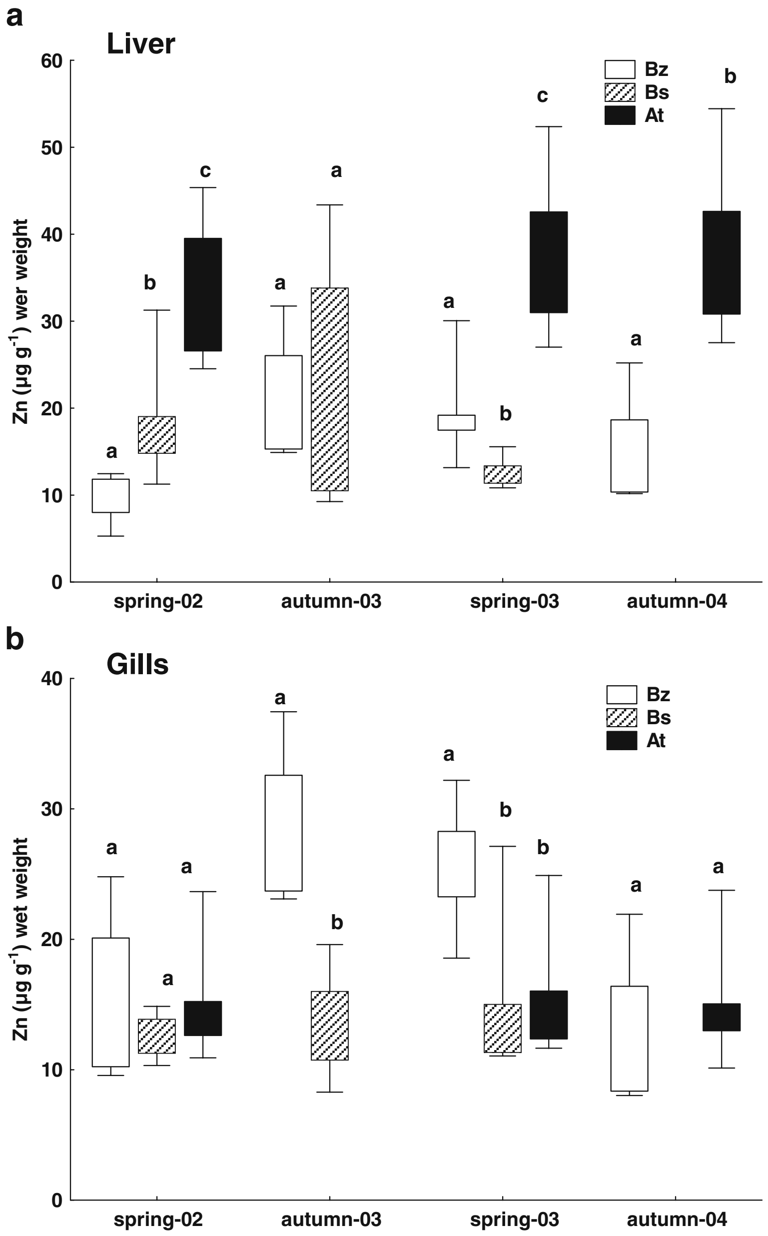
in liver samples. On the other hand, in spring 2002, lead concentrations were similar among the three sampling stations ($p > 0.05$). In autumn 2003, the higher levels were observed in samples from Berisso ($p < 0.05$), whilst in spring 2003, the higher levels were observed in the samples from Berazategui ($p < 0.05$). Instead, in autumn 2004, higher levels were found in the samples from Atalaya ($p < 0.05$).

The levels of zinc are presented in Fig. 5a and b for liver and gill tissues, respectively.

Liver samples from Atalaya presented the highest levels of zinc among all the sampling periods ($p < 0.05$). Samples from Berazategui presented the lowest values in spring 2002 and autumn 2004 ($p < 0.05$), whilst in autumn 2003, the values were similar to those found in the samples from Berisso ($p > 0.05$). Instead, in spring 2003, samples from Berisso presented the lowest zinc concentrations ($p < 0.05$).

As it was found for lead, the concentrations of zinc in liver and gills overlapped each other.

Fig. 5 Levels of zinc in **a** liver and **b** gills of *P. lineatus* during 2002–2004. *Bz* Berazategui, *Bs* Berisso, *At* Atalaya. *Different letters* indicate significant differences ($p < 0.05$) among the sampling stations but only within each sampling period



The highest levels of zinc in gill samples were recorded in Berazategui during autumn 2003 and spring 2003 ($p < 0.05$). Instead, in spring 2002 and autumn 2004, lower levels were observed ($p < 0.05$), which were similar to the values found in Berisso and Atalaya ($p > 0.05$).

In summary, higher concentrations of cadmium (in spring and autumn 2004), copper and zinc were observed in liver samples of *P. lineatus* collected in Atalaya. In general, samples from Berazategui presented the lowest values of those metals. An opposite pattern was found for lead since the higher levels were observed in the liver samples from Berazategui. In this site, water samples also presented the highest levels of lead concentrations (CARP-SINH-SOHMA 1990). In general, liver samples from Berisso presented intermediate levels, which sometimes were similar to those found in Berarazategui or in Atalaya, depending on the metal and the sampling period. For gill samples, no clear tendencies were observed among the sampling stations.

Comparisons of the present data with other reports from literature are rather difficult. Metal bioaccumulation by aquatic organisms is highly species dependent, and it is affected by the physico-chemical characteristics of the environment that influence the bioavailability and hence the resulting accumulation (Rainbow 2002; Peakall and Burger 2003). Marcovecchio (2004) reported values of cadmium and zinc in liver samples of another iliophagous fish species, *Mugil liza*, collected in the Samborombón Bay, in the outer zone of the La Plata River estuary. The bay receives the contribution of several rivers and channels through which waters from the Buenos Aires province drain (Marcovecchio 2004). Therefore, important amounts of contaminants may enter the bay from industrial and agricultural activities. Mean values were 9.15 μg Cd g^{-1} (range 7.85–12.4 μg Cd g^{-1}) and 52.0 μg Zn g^{-1} (range 40.8–59.8 μg Zn g^{-1}) on a wet weight basis. For both metals, these values were higher than those found in *P. lineatus*.

Previously, we have analysed samples of *P. lineatus* collected in Corrientes city, Argentina, located along the coast of the Paraná river (one of the two main tributaries of the La Plata River) about 1,000 km to the north from Buenos Aires city. For liver samples, the mean values (±SD) of metal concentrations were 3.0 ± 0.5 μg Cd g^{-1}, 8.5 ± 1.2 μg Cu g^{-1}, 0.56 ± 0.11 μg Pb g^{-1} and 24.54 ± 3.56 μg Zn g^{-1} on a wet weight basis (Lombardi 2008). For cadmium, copper and zinc, these levels were lower than those found in the samples from Atalaya. Instead, the levels of lead were lower in the samples from Corrientes than those from Berazategui. For gill samples, the values were 0.20 ± 0.11 μg Cd g^{-1}, 0.97 ± 0.14 μg Cu g^{-1}, 0.93 ± 0.04 μg Pb g^{-1} and 13.42 ± 1.66 μg Zn g^{-1} (Lombardi 2008), approximately the same than the levels found in fish from the La Plata River.

Metal distribution within different tissues is also difficult to predict. Chandra Sekhar et al. (2003) reported higher levels of cadmium, copper, lead and zinc in gills of three different fish species than the values found in liver. On the contrary, levels of cadmium, copper and lead in liver were higher than in gills (at least by a factor 10) of several species of deep-sea fish species (Mormede and Davies 2001). In another detritivorous (or iliophagous) species, gills presented lower values of copper and higher values of zinc than liver (Fernandes et al. 2007). According to our results, levels of cadmium and copper in liver of *P. lineatus* were always higher than those observed in gills. In addition, levels of lead and zinc in liver samples were higher, lower or similar that those found in gills depending on the sampling station and the sampling period. It is generally accepted that liver represents a storage site for several metals, and concentrations may therefore reflect a long-term exposure history (Savory et al. 1987; Schmitt et al. 2007). On the other hand, accumulation of metals in gills may reflect the extent of metal concentration in the aqueous phase (Farag et al. 1998).

Even when the specimens sampled for this study could be classified as male or female, they did not show evidence of sexual maturity. Sewage effluents are known to contain complex mixtures of chemicals, some of them release in large quantities (Matthiessen and Law 2002). Many substances have been widely recognised as endocrine-disrupting chemicals for aquatic wildlife such as human hormone steroids, synthetic hormones (e.g., diethylstilbestrol, used as a contraceptive), other pharmaceuticals, several pesticides, detergent surfactants, aromatic hydrocarbons, polychlorinated byphenols and many plasticizers (Tolar et al. 2001; Ying et al. 2002; Matozzo et al. 2007). It has been reported that fishes collected from Berazategui presented high levels of organic contaminants such as aliphatic hydrocarbons (Colombo et al. 2007a) and polychlorinated biphenyls (Colombo et al. 2007b).

In addition, urban sewerage systems rarely transport not only domestic sewage but also industrial and storm-water runoffs (Singh and Agrawal 2008). Even when sewage is treated, the insoluble residue remaining, the sewage sludge, still contains large amounts of not easily degradable organic compounds and different toxic metals (García-Delgado et al. 2007; Singh and Agrawal 2008). Therefore, at least partly, it could be hypothesised that the total contaminant body burden could induce some kind of endocrine disruption, preventing or delaying the sexual maturity in

P. lineatus. More research is needed to clarify this aspect. This species plays not only an important role within the biological communities but it also constitutes a significant economical resource.

Acknowledgements This work was partially supported by grants X-147 and X-233 from the University of Buenos Aires and PICTR 2002-00203 from the Agencia Nacional de Promoción Científica y Tecnológica. We thank the anonymous reviewers for their valuable comments that helped improve the manuscript.

References

Al-Yousuf, M., El-Shahawi, M., & Al-Ghais, S. (2000). Trace metals in liver, skin and muscle of Lethrinus lentjan fish species in relation to body length and sex. *The Science of the Total Environment, 256*, 87–94. doi:10.1016/S0048-9697(99)00363-0.

Almeida, J., Meletti, P., & Martinez, C. (2005). Acute effects of sediments taken from an urban stream on physiological and biochemical parameters of the neotropical fish *Prochilodus lineatus*. *Comparative Biochemistry and Physiology, 140*(Part C), 356–363.

Bagenal, T., & Tesch, F. (1978). Methods for assessment of fish production in fresh water. In T. Bagenal (Ed.), *Age and growth* (pp. 101–136). Oxford: Blackwell Scientific.

Bazán, J., & Arraga, E. (1993). El Río de La Plata, ¿un sistema fluviomarítimo frágil? Acercamiento a una definición de la calidad de sus aguas. In A. Boltovskoy & H. L. López (Eds.), *Conferencias de Limnología* (pp. 71–82). Limnology Institute Dr. Ringuelet RA, La Plata.

Burger, J. (2007). A framework and methods for incorporating gender-related issues in wildlife risk assessment: Gender-related differences in metal levels and other contaminants as a case study. *Environmental Research, 104*, 153–162.

Camargo, M., & Martinez, C. (2006). Biochemical and physiological biomarkers in *Prochilodus lineatus* submitted to in situ test in an urban stream in southern Brazil. *Environmental Toxicology and Pharmacology, 21*, 61–69. doi:10.1016/j.etap.2005.07.016.

CARP-SINH-SOHMA Comisión Administradora del Río de la Plata-Servicio de Hidrografía Naval Argentina-Servicio de Oceanografía, Hidrografía y Meteorología de la Armada, Uruguay (1990). *Estudio para la evaluación de la contaminación en el río de la Plata.* Buenos Aires.

Chandra Sekhar, K., Cari, N., Kamala, C., Suman Raj, D., & Sreenivasa Rao, A. (2003). Fractionation studies and bioaccumulation of sediment-bound heavy metals in Kolleru lake by edible fish. *Environment International, 29*, 1001–1008. doi:10.1016/S0160-4120(03)00094-1.

Colombo, J., Cappelletti, N., Migoya, M., & Speranza, E. (2007a). Bioaccumulation of anthropogenic contaminants by detritivorous fish in the Rio de la Plata estuary: 1—aliphatic hydrocarbons. *Chemosphere, 68*, 2128–2135. doi:10.1016/j.chemosphere.2007.02.001.

Colombo, J., Cappelletti, N., Migoya, M., & Speranza, E. (2007b). Bioaccumulation of anthropogenic contaminants by detritivorous fish in the Rio de la Plata estuary: 2—polychlorinated biphenyls. *Chemosphere, 69*, 1253–1260. doi:10.1016/j.chemosphere.2007.05.073.

Dagnino Pastore, L. (1973). *Mi Galaxia: Mi País*. (Nobis, Argentina; vol.2).

Farag, A., Woodward, D., Golstein, J., Brumbaugh, W., & Meyer, J. (1998). Concentrations of metals associated with mining waste in sediments, biofilm, benthic macroinvertebrates, and fish from the Coeur d'Alene River Basin, Idaho. *Archives of Environmental Contamination and Toxicology, 34*, 119–127. doi:10.1007/s002449900295.

Fernandes, C., Fontaínhas-Fernandes, A., Peixoto, F., & Salgado, M. (2007). Bioaccumulation of heavy metals in *Liza saliens* from the Esmoriz-Paramos coastal lagoon, Portugal. *Ecotoxicology and Environmental Safety, 66*, 426–431. doi:10.1016/j.ecoenv.2006.02.007.

García-Delgado, M., Rodríguez-Cruz, M. S., Lorenzo, L. F., Arienzo, M., & Sánchez-Martín, M. J. (2007). Seasonal and time variability of heavy metal content and its chemical forms in sewage sludges from different wastewater treatment plants. *The Science of the Total Environment, 382*, 82–92. doi:10.1016/j.scitotenv.2007.04.009.

Goede, R., & Burton, B. (1990). Organismic indices and an autopsy-based assessment as indicators of health and condition of fish. In S. Marshal Adams (Ed.), *Biological indicators of stress in fish. American fisheries symposium 8* (pp. 93–108). Maryland: Bethesda.

Lombardi, P. E. (2008). *ALA-D como biomarcador de exposición a plomo en peces: Variabilidad natural y de origen antrópico*. PhD Thesis, Facultad de Ciencias Naturales y Museo, Universidad Nacional de La Plata, Argentina.

Marcovecchio, J. (2004). The use of *Micropogonias furnieri* and *Mugil liza* as bioindicators of heavy metals pollution in La Plata river estuary, Argentina. *The Science of the Total Environment, 323*, 219–226. doi:10.1016/j.scitotenv.2003.09.029.

Marcovecchio, J., Moreno, V., & Perez, A. (1991). Metal accumulation in tissues of sharks from the Bahía Blanca Estuary, Argentina. *Marine Environmental Research, 31*, 263–274. doi:10.1016/0141-1136(91)90016-2.

Matozzo, V., Gagne, F., Marin, M. G., Ricciardi, F., & Blaise, C. (2007). Vitellogenin as a biomarker of exposure to estrogenic compounds in aquatic invertebrates: A review. *Environment International, 34*, 531–545. doi:10.1016/j.envint.2007.09.008.

Matthiessen, P., & Law, R. J. (2002). Contaminants and their effects on estuarine and coastal organism in the United Kingdom in the late twentieth century. *Environmental Pollution, 120*, 739–757.

Mormede, S., & Davies, I. (2001). Heavy metal concentrations in commercial deep-sea fish from the Rockall Trough. *Continental Shelf Research, 21*, 899–916. doi:10.1016/S0278-4343(00)00118-7.

Oldani, N. (1990). Variaciones de la abundancia de peces del valle del río Paraná. *Revue d'Hydrobiologie Tropicale, 23*(1), 67–76.

Palma de Croux, M. (1994). Some haematological parameters in *Prochilodus lineatus* (pisces, Curimatidae). *Revue d'Hydrobiologie Tropicale, 27*(2), 113–119.

Peakall, D., & Burger, J. (2003). Methodologies for assessing exposure to metals: Speciation, bioavailability of metals, and ecological host factors. *Ecotoxicology and Environmental Safety, 56*, 110–121. doi:10.1016/S0147-6513(03)00055-1.

Rainbow, P. (2002). Trace metal concentrations in aquatic invertebrates: Why and so what? *Environmental Pollution, 120*, 497–507. doi:10.1016/S0269-7491(02)00238-5.

Santos, R., Martins, M., Marengoni, N., Francisco, C., Piazza, R., Takahashi, H., et al. (2005). *Neoechinorhynchus curemai* (Acanthocephala: Neoechinorhynchidae) in *Prochilodus lineatus* (Osteichthyes: Prochilodontidae) from the Paraná River; Brazil. *Veterinary Parasitology, 134*, 111–115. doi:10.1016/j.vetpar.2005.06.025.

Savory, J., Bertholf, R., & Wills, M. (1987). Toxicity of metals. In H. G. Selier, H. Sigel & A. Sigel (Eds.), *Handbook on toxicity of inorganic compounds* (pp. 29–31). New York: Marcel Dekker.

Schmitt, C., Brumbaugh, W., & May, T. (2007). Accumulation of metals in fish from lead–zinc mining areas of southeastern Missouri, USA. *Ecotoxicology and Environmental Safety, 67*, 14–30. doi:10.1016/j.ecoenv.2006.11.002.

Singh, R. P., & Agrawal, M. (2008). Potential benefits and risks of land application of sewage sludge. *Waste Management (New York, N.Y.), 28*, 347–358. doi:10.1016/j.wasman.2006.12.010.

Sloff, W., van Kreijl, C., & Baars, A. (1983). Relative liver weights and xenobiotic-metabolizing enzymes of fish from polluted surface waters in the Netherlands. *Aquatic Toxicology (Amsterdam, Netherlands), 4*, 1–14. doi:10.1016/0166-445X(83)90057-7.

Sokal, R. R., & Rohlf, F. J. (1969). *Biometry: The principles and practice of statistics in biological research*. New York: Wh Freeman and Company.

Sverlig, S. A., Espinach Ros, A., & Orti, G. (1993). Sinopsis de los datos biológicos y pesqueros del sábalo *Prochilodus lineatus* (Valenciennes, 1847). FAO, Sinopsis sobre la Pesca (FAO), no. 154. Organización de las Naciones Unidas para la Agricultura y la Alimentación. Roma, Italia, 64 pp.

Tolar, J. F., Mehollin, A. R., Watson, R. D., & Angus, R. A. (2001). Mosquito fish (*Gambusia affinis*) vitellogenin: Identification, purification, and immunoassay. *Comparative Biochemistry and Physiology, C, 128*, 237–245.

Vahter, M., Åkesson, A., Lidén, C., Ceccatelli, S., & Berglund, M. (2007). Gender differences in the disposition and toxicity of metals. *Environmental Research, 104*, 85–95. doi:10.1016/j.envres.2006.08.003.

Verrengia Guerrero, N. R. (1995). *Contaminantes Metálicos en el Río de La Plata: Monitoreo del Sistema Acuático y Estudio de Algunos Efectos Tóxicos en Moluscos Bivalvos por medio de Bioensayos*. PhD Thesis. Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Buenos Aires, Argentina.

Verrengia Guerrero, N. R., & Kesten, E. (1993). Levels of heavy metals in biota from the la Plata river. *Environmental Toxicology and Water Quality, 8*, 335–344. doi:10.1002/tox.2530080310.

Verrengia Guerrero, N. R., & Kesten, E. (1997). Acumulación y distribución de cadmio y plomo en moluscos bivalvos del Río de la Plata. *Anales de la Asociación Química Argentina, 85*, 269–274.

Villar, C., Stripeikis, J., Colautti, D., D'Huicque, L., Tudino, M., & Bonetto, C. (2001). Metal contents in two fishes of different feeding behaviour in the Lower Paraná River and Río de la Plata Estuary. *Hydrobiologia, 457*, 225–233. doi:10.1023/A:1012285820526.

Ying, G., Kookana, R. S., & Ru, Y. (2002). Occurrence and fate of hormone steroids in the environment. *Environment International, 28*, 545–551. doi:10.1016/S0160-4120(02)00075-2.