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A description of mercury in fishes from the Madeira River Basin, Amazon, Brazil

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ABSTRACT

Over the last 20 years several projects carried on the Madeira River basin in the Amazon produced a great amount data on total Hg concentration in different fish species. In this paper we discuss temporal trends in Hg contamination and its relation to body weight in some of those fishes, showing that even within similar groups, such as carnivorous and non-migratory fish, the interspecies variability in Hg accumulation is considerable.

KEYWORDS: Fish, mercury, Biomagnification, Madeira River, Amazon.

Um estudo descritivo do mercúrio em peixes da bacia do Rio Madeira, Amazônia, Brasil.

RESUMO

Vários estudos têm sido desenvolvidos nos últimos 20 anos na bacia do Rio Madeira (Amazônia) com o objetivo de diagnosticar a presença de mercúrio em peixes e compreender o ciclo deste elemento no meio ambiente tropical. Neste artigo são discutidas tendências temporais na concentração de Hg e sua relação com a massa corporal de algumas espécies de peixes com diferentes hábitos alimentares, coletadas no Rio Madeira e no reservatório da hidroelétrica de Samuel, no Rio Jamari, Estado de Rondônia. Foi avaliada uma amostragem de peixes de 14 anos (1987 - 2000) com 86 espécies e um total de 1100 espécimes.

PALAVRAS-CHAVE: Peixe, Mercúrio, biomagnificação, Rio Madeira, Amazônia.

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INTRODUCTION

It has been estimated that between 2000 to 3000 tons of Hg's have been released in the middle of the Amazon environment and nowadays small gold extraction activities using Hg can still be found (Malm, 1998; Lacerda & Salomons, 1998; Lacerda, 2003). About 60% of this mercury is believed to be were lost to the atmosphere and 40% went directly to the watercourses (Pfeiffer & Lacerda, 1988). Although gold mining in the Brazilian portion of the Madeira River basin has decreased significantly from 1995 onwards to about 0.3 to 0.5 $t.yr^{-1}$ nowadays, the activities continued and even increased in the Bolivian side of the basin, and the Hg released there eventually drains into the Madeira River from its major Bolivian tributaries (Maurice-Bourgoin *et al.*, 2000). It is also suggested that burning and deforestation would allow long term atmospheric mercury deposited on soils, to run-off into rivers, justifying the high Hg concentrations in areas without a gold mining history (Veiga *et al.*, 1994; Lacerda, 1995; Malm, 1998). Studies performed in distant areas and without gold mining activities registrations in the high Negro River reveal elevated Hg concentrations, what it carries to consider its natural source (Fadini & Jardim, 2001). Continually, deposited Hg in soils and sediments suffers continuous transformations and interactions with environmental compartments, which eventually transform and remobilize Hg to food chains, including the increase of its bioavailability through methylation (Malm *et al.*, 1990; Roulet *et al.*, 1998; Lacerda, 2003).

The aquatic biota plays an important role in the conservation of life and wealth in an ecological system acting in seed dispersion, nutrient enrichment of the aquatic system by the conversion of vegetable biomass in to animal tissues and excreta that acts as a natural fertilizer in lakes. The complex interaction of biologic factors (fish weight and diet) is species specific and is reflected in the variability of fish-Hg concentrations during high or low water habitats (Bastos *et al*, 2006).

Fish is one of the most important food resources of the Amazonian population, which has 30,000 fishermen and more than 70,000 directly related jobs. Little is known regarding Hg bioaccumulation as a function of hydrological cycles in the Amazonian ecosystem (Dorea & Barbosa, 2007). Moreover, previous studies in the Amazon and other areas have determined that fish is the main route of mercury contamination to the population, especially villages along the river, where contaminated fish is the main protein source (Malm *et al.*, 1995; Bastos *et al*, 2007). The tolerance limit recommended for consumption by the WHO is $0.50mg.kg^{-1}$ for carnivorous and $0.30mg.kg^{-1}$ for non-carnivorous fishes (IPCS, 1990). In Brazil, the Hg limits was set at $0.50mg.kg^{-1}$ for nor-carnivorous and $1.00mg.kg^{-1}$ for carnivorous fishes (MS, 1998).

Therefore, even with decreasing direct emissions, Hg contamination of soils, sediments and aquatic biological resources, fish in particular, is still an environmental concern to local and national environmental authorities.

MATERIAL AND METHODS

Our study concentrates on two main areas in the Rondônia and Amazonas states (Figure 1): The Madeira River and its main tributaries located downstream the Samuel's dam (the

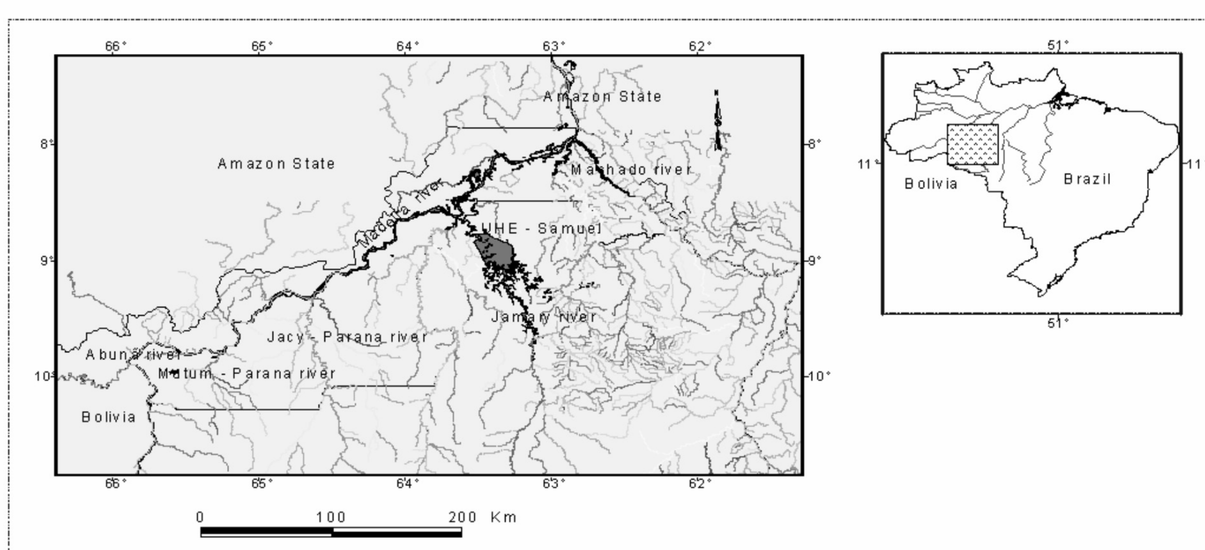

Figure 1 - Study area: The Madeira River basin in the Amazon forest, Brazil

Jamari River), named here Madeira Complex; and the area upstream Samuel's dam concerning the Jamari River and the reservoir itself, named here Jamari River area.

Data presented here were collected in each area over the past 14 years by different groups, in several surveys carried out in both dry (May – October) and rainy seasons (December – March). All of the samples were transported in iceboxes to the Rondonia Federal University (UNIR) where they were catalogued and stored in freezers until analysis. Total mercury was extracted according to Bastos *et al.* (1998). Briefly, about 500 mg of fish were digested in a microwave oven or a water bath (35 min) using H_2O_2, H_2SO_4:$HN0_3$ (1:1) and $KMnO_4$ 5%, with total Hg determinations by cold vapor atomic absorption spectrophotometer (CV-AAS, Flow Injection Mercury System-FIMS-400 Perkin-Elmer, Germany). All samples were done in triplicate and analyzed in parallel with internationally certified material (DORM-2, NRC-Canada) as well as standard samples (APPX-2958, APPX-2960 e AFPX-5130) produced in our own laboratory.

RESULTS AND DISCUSSION

A total of 1,100 fishes from 86 species were collected and analyzed in the Madeira River basin between 1987 and 2000. The summarized data is presented in Table 1.

Table 1 - Mean, standard deviation, number of samples, maximum and minimum concentration (mg.kg^{-1}) of total mercury in Amazonian fishes, organized per species, common name (Santos *et al*., 1984) and preferential feeding habit. Bold fishes exhibit mean values above the threshold limit of 0.50mg.kg^{-1} (WHO, 1990).

Common name	Scientific name	Total Hg (mg.kg^{-1})	n	Max	Min
	PISCIVOROUS				
Peixe-Cachorro	***Acestrorhynchus falcirostris***	**1.292**	02	1.682	0.903
Pirarucu	*Arapaima gigas*	0.343	06	0.730	0.231
Peixe-Cachorro	***Hydrolycus scomberoides***	**0.722**	31	2.473	0.230
Peixe-Cachorro	***Hydrolycus* sp.**	**1.020**	02	1.335	0.705
Apapá-amarelo	***Pellona castealneana***	**1.212**	27	3.921	0.440
Apapá-branco	***Pellona flavipinnis***	**1.597**	06	3.022	0.993
Apapá	***Pellona* sp.**	**1.308**	02	1.807	0.810
Pescada	*Plagioscion squamosissimus*	0.449	41	1.100	0.002
Peixe-Cachorro	***Rhaphiodon vulpinus***	**0.939**	26	2.506	0.405
	CARNIVOROUS				
Mandubé	***Ageneiosus brevifilis***	**0.851**	13	1.390	0.250
Bicuda	***Boulengerella ocellata***	**1.019**	07	2.129	0.303
Piraíba or Filhote	***Brachyplatistoma filamentosum***	**1.359**	18	4.753	0.490
Dourada	***Brachyplatistoma flavicans***	**0.907**	19	3.166	0.142
Piramutaba	*Brachyplatistoma vaillanti*	0.090	01	-	-
Tucunaré	***Cichla monoculus***	**0.524**	13	1.098	0.330
Tucunaré	*Cichla ocellaris*	0.428	96	1.316	0.012
Tucunaré-açú	*Cichla* sp.	0.305	02	0.420	0.189
Tucunaré-paca	*Cichla temensis*	0.419	04	0.532	0.266
Jacundá	*Crenicichla reticulata*	0.406	07	0.556	0.241
Liro or Braço-de-moça	***Hemisorubim platyrhynchos***	**0.575**	19	1.553	0.087
Traíra	*Hoplias malabaricus*	0.432	55	1.188	0.033
Jaú	***Paulicea lukteni***	**0.571**	04	0.722	0.313
Pirarara	***Phractocephalus hemioliopterus***	**0.727**	02	1.301	0.153
Barba-chata	***Pinirampus pirinampu***	**1.232**	24	2.214	0.049
Coroatá or Pirá-tucandira	***Platynematichthys notatus***	**1.195**	10	2.258	0.547
Peixe-agulha	*Potamorrhaphis guianensis*	0.302	01	-	-
Arraia	*Potamotrygon* sp.	0.090	01	-	-
Surubim	***Pseudoplatystoma fasciatum***	**0.660**	38	1.561	0.080
Pintado	***Pseudoplatystoma* sp.**	**0.969**	26	2.890	0.046
Piranha-caju	***Pygocentrus nattereri***	**0.510**	25	1.184	0.036
Piranha	***Serrasalmus. eigenmanni***	**1.697**	01	-	-
Piranha-preta	***Serrasalmus rhombeus***	**0.781**	146	2.168	0.186
Piranha-branca	*Serrasalmus spilopleura*	0.294	09	0.811	0.030
Peixe-lenha	***Sorubimichthys planiceps***	**0.871**	01	-	-
	DETRITIVOROUS				
Curimatã	*Curimata knerii*	0.378	01	-	-
Acari-bodó	*Lipossarcus pardalis*	0.016	05	0.020	0.006
Branquinha	*Potamorhina latior*	0.114	28	0.280	0.049
Curimbá	*Prochilodus* cf. *beni*	0.088	05	0.123	0.059
Curimbá	*Prochilodus nigicaus*	0.342	01	-	-
Curimatã	*Prochilodus theraponura*	0.021	03	0.046	0.006
Acari-bodó	*Pterygoplichthys gibbiceps*	0.464	04	0.644	0.111
Acari-bodó	*Pterygoplichthys* sp.	0.041	01	-	-
	HERBIVOROUS				
Piau	*Laemolyta varia*	0.151	16	0.412	0.035
Pacu	*Mylossoma duriventre*	0.024	03	0.031	0.015
Pacu	*Mylossoma* sp.	0.053	40	0.440	0.001
Piau-cabeça-de-meia	*Schizodon fasciatum*	0.123	14	0.295	0.021
Piau-cabeça-gorda	*Schizodon* sp.	0.117	10	0.404	0.020

Common name	Scientific name	Total Hg ($mg.kg^{-1}$)	n	Max	Min
Piau-botafogo	*Shizodon vittatum*	0.038	03	0.076	0.016
	MICROPHAGOUS				
Mapará	***Hypophthalmus edentatus***	**0.516**	24	0.898	0.084
Cascudo	*Plecostomus* sp.	0.050	06	0.122	0.025
Curimatã	*Prochilodus* sp.	0.118	49	0.338	0.003
Cuiu-cuiu	*Pseudodoras niger*	0.153	02	0.176	0.130
Jatuarana	*Brycon* cf. *melanopterus*	0.054	18	0.123	0.032
	OMNIVOROUS				
Jatuarana	***Argonectes scapularis***	**0.603**	01	-	-
Matrinxã	*Brycon* sp.	0.098	15	0.250	0.050
Pintadinho	***Calophysus macropterus***	**1.381**	11	2.249	0.718
Cará	*Cichlasoma spectabile*	0.291	03	0.594	0.041
Pirapetinga	*Colossoma bidens*	0.057	04	0.121	0.025
Pirapetinga	*Colossoma brachypomus*	0.014	04	0.024	0.010
Tambaqui	*Colossoma macropomum*	0.126	08	0.335	0.020
Acaratinga	*Geophagus proximus*	0.105	01	-	-
Acará	*Geophagus* sp.	0.179	20	0.648	0.028
Aracu-flamengo	*Leporinus fasciatus*	0.229	07	0.439	0.051
Aracu-cabeça-gorda	*Leporinus friderici*	0.334	10	2.040	0.020
Aracu	*Leporinus* sp.	0.100	01	-	-
Bacu	*Lithodoras dorsalis*	0.013	01	-	-
Aruanã	*Osteoglossum bicirrhosum*	0.294	10	1.162	0.026
Cascudinho	*Pareiorhapis duseni*	0.034	08	0.055	0.010
Mandi	*Pimelodus* sp.	0.263	17	0.561	0.082
Rhamdia	*Rhamdia* sp.	0.061	01	-	-
Jaraqui	*Semaprochilodus theraponera*	0.202	27	0.419	0.105
Piranha-branca	***Serrasalmus* sp.**	**0.537**	37	1.725	0.138
Sardinha	*Triportheus elongatus*	0.189	17	0.583	0.017

* Species above the WHO threshold marked in bold.

Fishes were grouped according to preferential feeding habits. Carnivorous fish were the best represented class with 34 species, from which 16 (8 commercially important) present a mean total Hg value above the WHO threshold ($0.50mg.kg^{-1}$). The 9 exclusively piscivorous species, despite low commercial interest, were all above the WHO threshold, showing the importance of the mercury biomagnification. Also among omnivorous fishes (20 species) exhibited 4 species above of the WHO threshold ($0.30mg.kg^{-1}$), but except for jatuarana the other species don't have commercial importance. No herbivorous fish (6 spp.) has exhibited concentrations above the threshold value. In the 8 detritivorous species just 3 overcame the WHO threshold ($0.30mg.kg^{-1}$).

The carnivorous *Serrasalmus rhombeus* (n=146), *Hoplias malabaricus* (n=55), *Cichla ocellaris* (n=96), *Plagioscion squamosissimus* (n= 41); the detritivorous *Prochilodus sp.* (n=49) and the herbivorous *Mylossoma sp.* (n=40) were selected as the most frequent species in this 14 year survey to observe high mercury tendencies.

We have analyzed the correlation of total Hg concentration over the sampled years for these 6 species and the scatter plot with **r** values are presented in figure 2. Only *Plagioscion squamosissimus* and *Hoplias gr. malabaricus* have exhibited significant correlations ($p<0.05$) suggesting a decreasing tendency in the Madeira Complex. *P. squamosissimus* is an estuarine fish which might have a strong migratory behavior making it difficult to explain the observed decreasing pattern. *C. ocellaris*, which is a sedentary specie, has exhibited no pattern at all. *H. malabaricus*, which lives in ponds and still waters, has exhibited a decreasing pattern in spite of a high variation in total Hg concentration observed, for example, in 1996 when sampling was more abundant.

Seasonal variation was tested for each of these 6 selected species during the years of 1996 and 1997 when samples were more abundant and equally distributed all year long. The end of the dry and rainy season periods was characterized from August to October and February to April, respectively, according to the water level of the Madeira River exhibited in Figure 3. Once no significant differences (U test) were observed, both seasons were grouped for the further analysis. We also tested the difference in total Hg concentration for each of these species in the Madeira Complex and the Jamari River and this time *C. ocellaris* exhibited significant higher (U test; $p<0.05$) concentrations in the Madeira Complex while for *S. rhombeus* concentrations in Jamari River were significantly higher.

No significant correlation between length or weight and total Hg was found for any species in the Madeira Complex. According to Roulet & Maury-Brachet (2001), it is rare to observe significant correlations in Amazonian fishes. In the Jamari River *H. malabaricus* and *S. rhombeus* exhibit a significant positive linear correlation. *C. ocellaris* exhibited no significant correlation even for the Jamari River area, where most fishes were sampled at the Samuel's reservoir, what could be important for sedentary specie like this. But it is also worth noting that we used much broader weight criteria than those authors.

We have also found no significant correlation for *Mylossoma sp.* or a significant negative linear relation for *Prochilodus sp.* in the Jamari River, which could be explained by a change in preferential feeding habits experienced from juvenile to adult age, a characteristic of these species. Scatter plots are presented in figure 4.

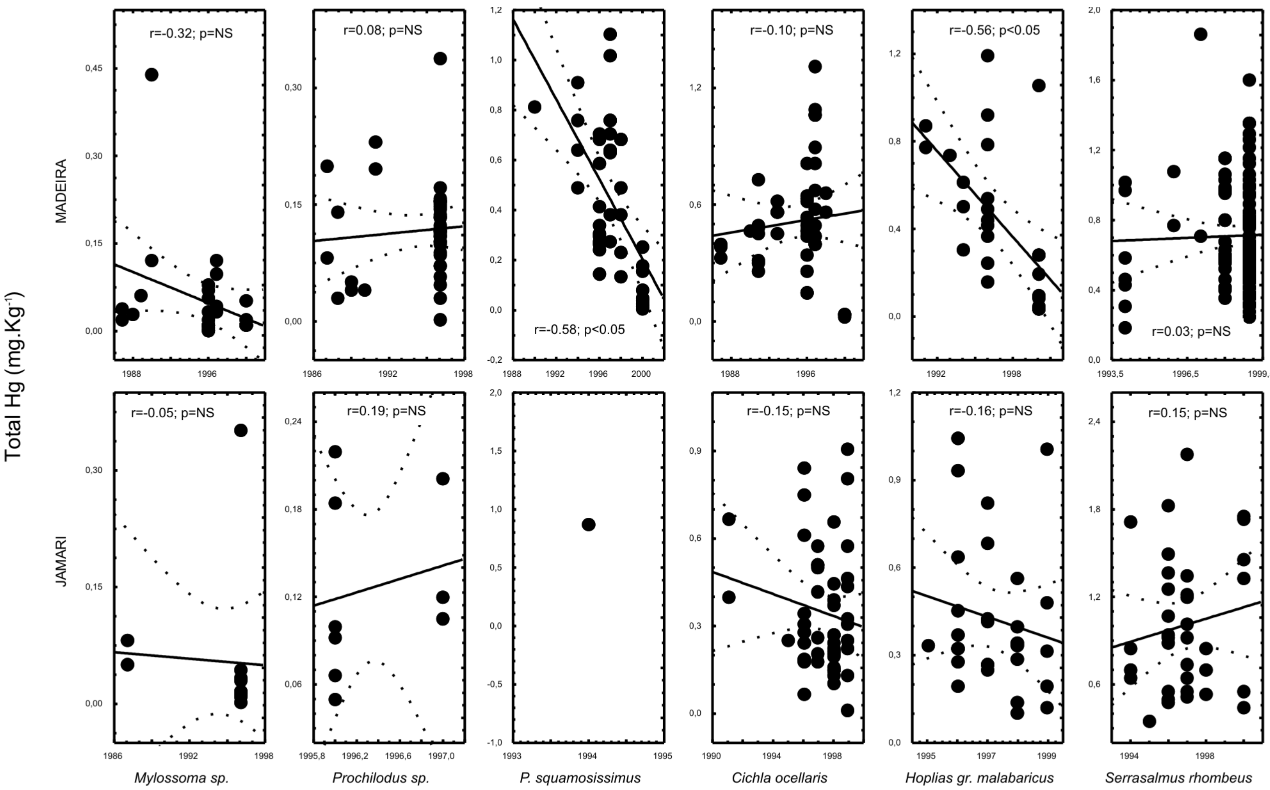

Figure 2 - Scatter plots of total Hg x year in the Jamari River and Madeira Complex. Correlation coefficients are presented in the graphics. Dashed lines are the confidence intervals.

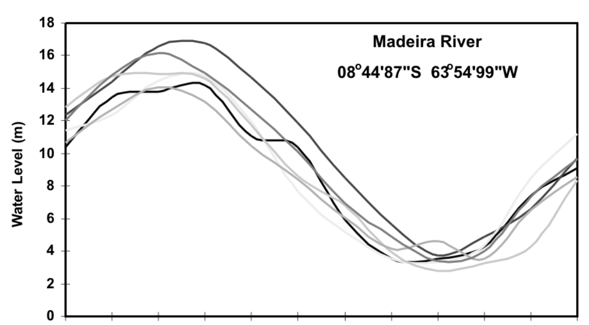

Figure 3 - Water average level in the Madeira River during the years of 1996 at 2001 characterizing the final of the dry and rainy seasons.

CONCLUSIONS

Sampling at a very complex environment like the Amazon for long periods is extremely difficult and expensive. Analyzing data from sporadic surveys over 14 years allows a more descriptive than quantitative assessment of the affect of mercury in fish. Little conclusions can be drawn from such heterogeneous data when parameters controlling mercury availability is so variable between inter and intra-species. It is possible that the choice of fewer species in a stratified sampling from now on would allow a more regular survey and thus, a more regular design of a long-term pattern of accumulation. This huge amount of data will be useful for further modeling approaches for better understanding the trends in Amazonian fishes.

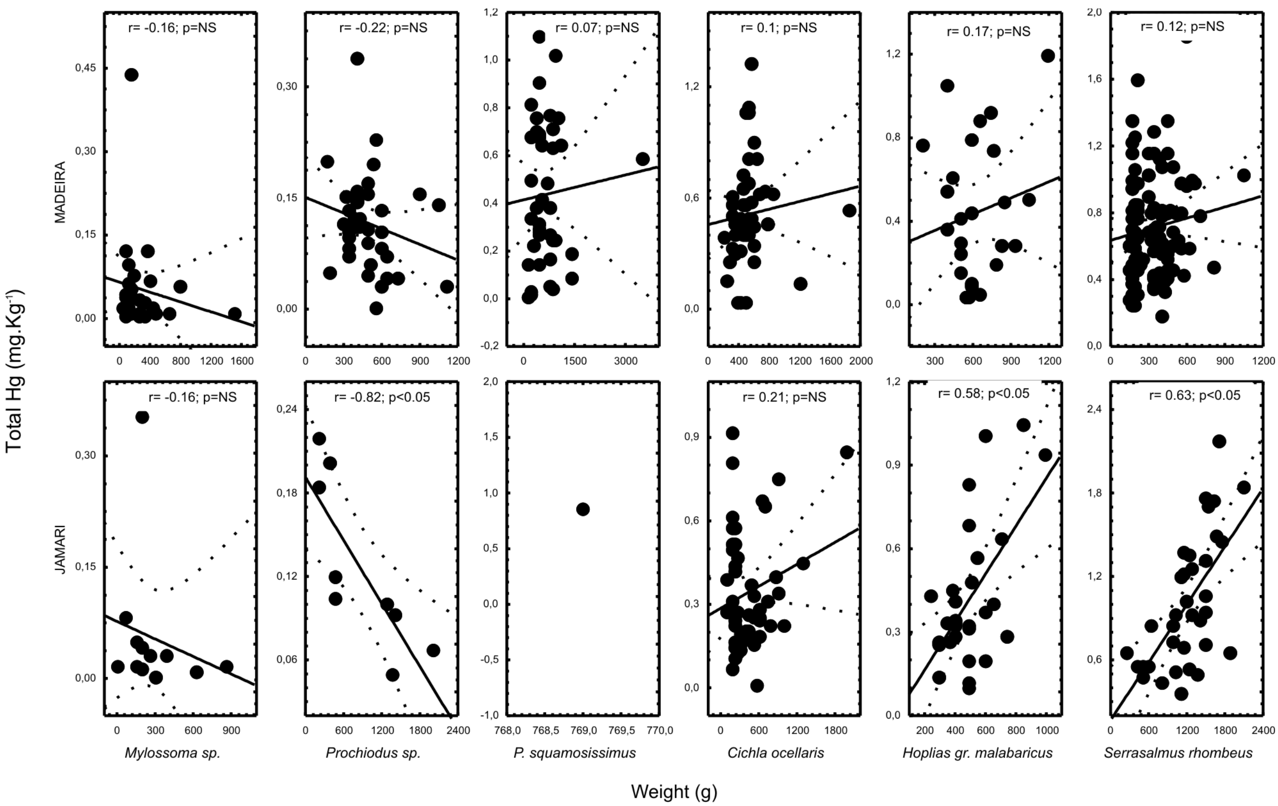

Figure 4 - Scatter plots of total Hg x weight of some fish species in the Jamari River and Madeira Complex. Correlation coefficients are presented in the graphics. Dashed lines are the confidence intervals.

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