Bull. Environ. Contam. Toxicol. (2005) 74:988–995

DOI: 10.1007/s00128-005-0677-0

Bulletin of Environmental Contamination and Toxicology

Distribution and Concentration of Trace Metals in Tissues of Different Fish Species from the Atlantic Coast of Western Africa

Z. Sidoumou,[1] M. Gnassia-Barelli,[2] Y. Siau,[3] V. Morton,[2] M. Roméo[2]

[1] Department of Biology, Faculty of Sciences, B.P. 5026, Nouakchott, Mauritania
[2] UMR 1112 INRA-UNSA R.O.S.E., Faculty of Sciences, B.P. 71, 06108 Nice Cedex 2, France
[3] University of Montpellier II, Faculty of Sciences, Place Eugène Bataillon 34095 Montpellier Cedex 5, France

Received: 8 October 2004/Accepted: 16 February 2005

Growing interest has been shown in the fate of metals in estuarine and coastal environments and open ocean ecosystems from all climatological regions in the world (Everaats and Nieuwenhuize 1995). Metals are toxic to most marine organisms as they are to man. They can reach us through seafood. It is, therefore, important to determine the concentration of metals in edible marine organisms. In this respect, few data concern the metal levels in organisms from the African coasts. For a long time, Africa was thought to be safe from aquatic pollution (Biney et al. 1994). Recently, there has been considerable interest in establishing the degree of contamination of African aquatic ecosystems by heavy metals. The need to make an assessment of the contamination in the African environment has led to the initiation of several pollution monitoring programmes and research work at various scientific institutions in the region (Biney et al. 1994). Mauritania coastal waters are among the most productive in the world, supporting abundant fish populations which are harvested as food. Potential contamination of fish with metals might be crucial for the exploitation of this resource. In a previous paper (Roméo et al. 1999), data on metals in some fish species collected off Nouakchott were presented. In the present paper, more fish species were analyzed to have a full insight on metal concentrations of pelagic, benthopelagic and demersal fish.

MATERIALS AND METHODS

Fish from different species were collected by professional fishermen in January 2003, using their traditional methods with pirogues equipped with outboards motors. When boats reach the fishing zone off the town of Nouakchott (18°N, 16°W), motors are switched off and fishermen are angling with lines. Immediately after collection, fish samples were brought to the laboratory. Samples were dissected to separate muscles, gills, livers. Sex was determined and gonads collected when possible. The samples were dried to constant weight 50°C, wrapped in parafilm. Dried samples (ratio wet wt./dry wt. = ca 5) were taken to the Laboratory of Nice, France. Samples were prepared under a laminar flow hood and digested (duplicate digestion in each case) with Suprapur nitric acid 65% Merck in a microwave oven. Cd, Cu and Zn analyses were carried out directly on the digested solution, using an atomic absorption spectrophotometer equipped with an air-acetylene flame or with a graphite furnace.

Correspondence to: M. Roméo

Table 1. Analysis of the reference material lobster hepatopancreas Tort-2 (National Research Council Canada). Mean values ± 1 standard deviation.

Metal	Certified values (μg g^{-1}dry wt)	*n*	Recorded values
Cd	26.7 ± 0.6	5	27.0 ± 0.7
Cu	106 ± 10	5	101 ± 1
Zn	180 ± 6	5	177 ± 2

Deuterium background correction was used when necessary. The analytical procedure was checked using a standard reference material. The results shown in Table 1. The results demonstrate that that metal analyses are in good agreement with the certified values. Moreover, metals are not lost during the digestion procedure. The limits of detection for flame analysis are 0.012 mg Cd l^{-1}, 0.015 mg Cu l^{-1}, 0.005 mg Zn l^{-1}; for furnace analysis 0.3 μg Cd l^{-1} and 3 μg Cu l^{-1}, zinc was always determined with the flame.

RESULTS AND DISCUSSION

Table 2 describes the class, species, the living zone and the feeding habits of fish. One species of cartilaginous fish, *Rhinobatos cemiculus* (Rhinobatidae, guitarfish), was also collected, it is a demersal species eating on invertebrates. Among bony fish, the caught species were either pelagic : *Dicentrarchus punctatus*, benthopelagic (5 species) or demersal (5 species). Moreover, one Serranidae *Epinephelus marginatus* is reef-associated. Table 2 shows the great diversity of food consumed by the different species. Among the fish eating on molluscs, some such as *D. punctatus*, *E. marginatus*, *Mycteroperca rubra*, consume cephalopods whereas others (*Pseudupeneus prayensis*, *Pegusa lascaris*, *Pagrus caeruleostictus*) eat on bivalves. Species can use as prey both cephalopods and bivalves, i.e. molluscs, this is the case of *Parapristipoma humilae*, *Pagrus auriga* and *Diplodus bellottii*. Metal concentration in the muscle was considered since this tissue is consumed locally or exported. Gills and livers were also chosen as target organs for assessing metal accumulation. Gonads from males or females were analyzed when possible. Table 3 gives the concentrations of metals in the muscles and gills of 9 species. When all tissues could be analysed in several specimens of the same fish species, the results are presented in Fig. 1 ; this was the case for the cartilaginous fish *Rhinobatos cemiculus* (n = 3) and the bony fish *D. punctatus* (n = 7), *Cephalopholis taeniops* (n = 10), *Diplodus bellottii* (n = 2), *P. caeruleostictus* (n =7). Mean cadmium concentrations in the muscle (Table 3 and Fig. 1) are ranging from 0.005 μg g^{-1} in *Argyrosomus regius* and the highest in *Pegusa lascaris* (0.273 μg g^{-1}), whereas the other species have a mean cadmium concentration ranging from 0.040 for *Pagrus auriga* to 0.168 μg g^{-1} for *Epinephelus marginatus*. Gills generally present higher Cd concentrations than muscles, values such as 0.272 μg g^{-1} are found for *Pseudupeneus prayensis,* and 0.313 μg g^{-1} *for P. auriga.* The liver (Fig. 1) particularly concentrates cadmium with mean values ranging from 0.988 (*Rhinobatos cemiculus*) to 17.94 μg g^{-1} (*Diplodus bellottii*). As regards gonad concentrations (Fig. 1), they are not elevated in the cartilaginous fish *R. cemiculus* (ca 0.05 μg g^{-1} males and females) and in the pelagic *Dicentrarchus punctatus* (ca 0.08 μg g^{-1} males and females).

Table 2. Bony fish species, their habitat and their feeding habit along the Mauritania coast.

Class	Species	Environment	Feeding habit in the West Africa coast
Haemulidae	*Parapristipoma humile* Guinean grunt	Demersal	Crustaceans, Molluscs
Moronidae	*Dicentrarchus punctatus* Spotted seabass	Pelagic	Fish, Cephalopods, Crustaceans
Mugilidae	*Mugil cephalus* Flathead mullet	Benthopelagic	Zooplankton, benthic organisms and detritus
Mullidae	*Pseudupeneus prayensis* West African goatfish	Demersal	Benthic invertebrates, (mainly Bivalves)
Sciaenidae	*Argyrosomus regius* Meagre	Benthopelagic	Fishes and swimming Crustaceans
Serranidae	*Epinephelus marginatus* Dusky grouper	Reef-associated	Fish, Cephalopods, Crustaceans
Serranidae	*Cephalopholis taeniops* African Hind	Demersal	Fish
Serranidae	*Mycteroperca rubra* Mottled grouper	Demersal	Fish, Cephalopods
Soleidae	*Pegusa lascaris* Sand sole	Demersal	Bivalves, Crustaceans, Polychaetes
Sparidae	*Diplodus bellottii* Senegal seabream	Benthopelagic	Crustaceans and Molluscs
Sparidae	*Pagrus auriga* Redbanded seabream	Benthopelagic	Molluscs, Crustaceans
	Pagrus caeruleostictus Bluespotted seabream	Benthopelagic	Bivalves, Crustaceans, Fish

Some high Cd values are recorded, such as 0.627 in female gonads of *Cephalopholis taeniops* and 0.990 µg g^{-1} in male gonads of *Pagrus caeruleostictus* and ca 0.600 µg g^{-1} in *Diplodus bellottii* (male and female). Mean copper concentrations in the muscle (Table 3 and Fig. 1) are ranging from 0.46 (*Argyrosomus regius*) to high values 6.99 µg g^{-1} (*Pagrus auriga*). As for cadmium, gills generally present higher Cu concentrations than muscles with the highest recorded for 4.17 µg g^{-1} in *Pseudupeneus prayensis*. Liver (Fig. 1) shows higher Cu concentrations than muscle and gills, particularly that of 85.14 in *Diplodus bellottii* and 117.37 µg g^{-1} in *Dicentrarchus punctatus*. The lowest hepatic Cu concentrations are recorded in *Rhinobatos cemiculus* and *Cephalopholis taeniops* (ca 10 µg g^{-1}). Gonads (Fig. 1) have intermediate values, the lowest are found in *R. cemiculus* and *D. bellottii* (male : 1.78 µg Cu g^{-1}) and the highest in *D. punctatus* (female : 15.58 µg g^{-1}) and in *Pagrus caeruleostictus* (male : 52.06 µg g^{-1}).

Table 3. Metal concentrations ($\mu g\ g^{-1}$dry wt) in the muscles and gills in bony fish (N.D. = not determined).

Species/organ	Tissue	Cd (µg/g)	Cu (µg/g)	Zn (µg/g)
Mugil cephalus	Muscle	0.110	1.16	14.16
n = 1	Gills	0.053	1.57	50.72
Pseudupaeneus prayensis	Muscle	0.066 ± 0.054	1.04 ± 0.06	8.92 ± 1.94
n = 4	Gills	0.272 ± 0.060	4.17 ±0.19	67.53 ± 27.51
Parapristipom latifrons	Muscle	0.084 ± 0.013	1.89 ± 0.45	10.12 ± 2.00
n = 3	Gills	0.084 ± 0.046	1.76 ± 0.26	46.78 ± 8.22
Argyrosomus regius	Muscle	0.005 ± 0.005	0.46 ± 0.01	8.63 ± 1.17
n = 3	Gills	N.D.	N.D.	N.D.
Epinephelus marginatus	Muscle	0.168	1.14	15.85
n = 1	Gills	0.051	1.12	64.69
Mycteroperca rubra	Muscle	0.051 ± 0.016	0.72 ± 0.16	11.22 ± 1.98
n = 4	Gills	0.060 ± 0.033	1.29 ± 0.40	67.34 ± 13.29
Pegusa lascaris	Muscle	0.273 ± 0.133	0.89 ± 0.04	15.05 ± 2.36
n = 3	Gills	N.D.	N.D.	N.D.
Pagrus auriga	Muscle	0.040 ± 0.025	6.99 ± 0.74	7.73 ± 1.92
n = 2	Gills	0.313 ± 0.095	9.57 ± 2.21	32.63 ± 15.42

Mean zinc concentrations in the muscle (Table 3 and Fig. 1) are ranging from 7.73 (*Pagrus auriga*) to 15.85 $\mu g\ g^{-1}$ (*Epinephelus marginatus*). As for cadmium and copper, gills concentrate zinc from 32.63 (*P. auriga*) to 105.39 $\mu g\ g^{-1}$ (*Diplodus bellottii*) compared to the muscles. Liver (Fig. 1) has higher values than muscle and gills to some extent. For instance, values range from 34.41 in *Rhinobatos cemiculus,* 160.32 in *Pagrus caeruleostictus* and 207.87 $\mu g\ g^{-1}$ in *Diplodus bellottii.* Zinc is particularly concentrated in gonads (Fig. 1), especially in females from *D. bellottii* (948.57 $\mu g\ g^{-1}$) and *P. caeruleostictus* (1463.14 $\mu g\ g^{-1}$).

The distribution of metals among tissues is not exactly the same according to the considered metal. Concentrations are higher in the gills and especially in the liver compared to the muscle. There is no difference among males and females in the metal concentrations of muscle, gills and liver. The concentrations in the muscle are below the proposed limit values for human consumption of fish which are 0.5 μg Cd g^{-1} dry wt. (CSHPF 1995), 150 μg Cu g^{-1} and 5 mg Zn g^{-1} according the National Health Medical Research Council of Australia (*in* Bebbington et al. 1977).

The concentrations of metals in gills reflect the concentrations of metals in the waters, where the fish species lives ; they are higher than those in the muscles due to the high volume of filtered seawater. The concentrations in liver represent storage of metals. Induction of metallothioneins MTs in the liver is the main form of storage and detoxication of metals in fish (Hamilton and Mehrle 1986 ; Filipović and Raspor 2003).

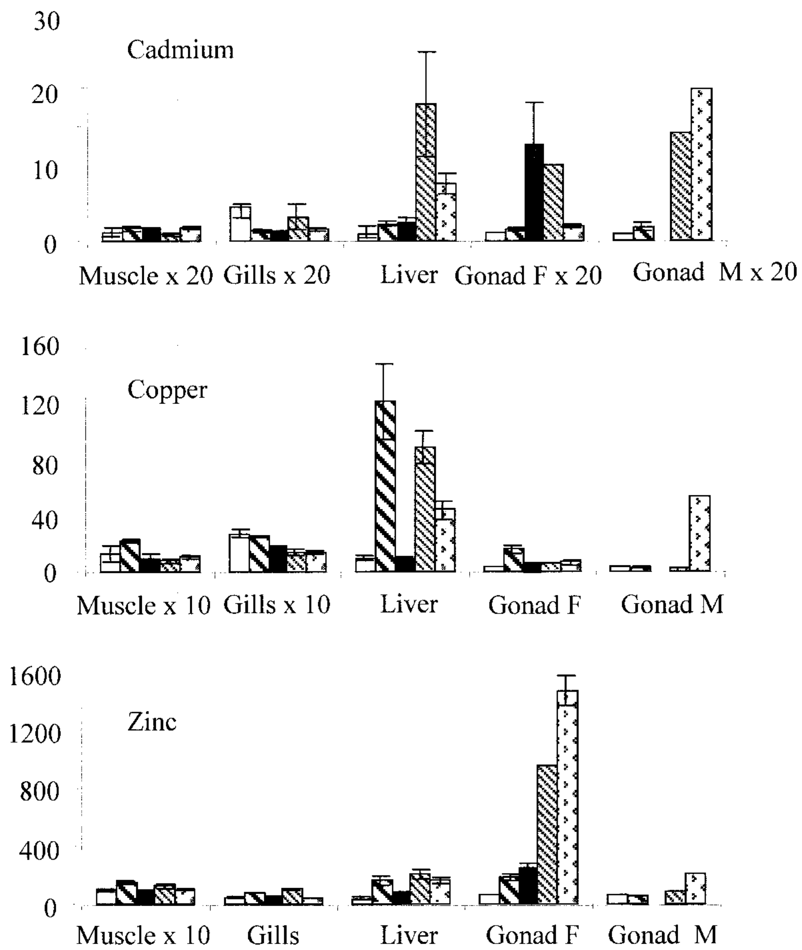

Figure 1. Concentrations (µg g-1dry wt) in *Rhinobatos cemiculus* □ (n = 3, one female, one male, one fish of undetermined sex), *Dicentrarchus punctatus* ◪ (n = 7 with 3 females and 4 males), *Cephalopholis taeniops* ■ (n = 10 females, only one female gonad could be analyzed), *Diplodus bellottii* ▧ (n = 2 with 1 male and 1 female), *Pagrus caeruleostictus* ◻ (n = 6 with 3 males and 3 females).

Cadmium is nearly 100-fold higher in the liver than in the muscle whereas copper is between 10 and 100-fold higher. Zinc seems less enriched in the liver than the two other metals with an increase of 10 to 20.

The problem of higher cadmium concentrations in all tissues, and particularly in livers of fish collected from the Mauritania coast, must be underlined. Data from the literature showed that the cadmium concentrations in the liver of various species are less than 10 μg g^{-1} dry wt and more particularly less than 1 μg g^{-1} (Hamza-Chaffai et al. 1996 ; Roméo et al. 2000a). Hepatic Cd concentrations are higher than 1 μg g^{-1} in all the bony fish shown in Fig. 1. Cadmium could originate from water, sediment and food. High levels of cadmium were already found in the livers of fish collected in the same area (Roméo et al. 1999). These levels were attributed by the authors to natural origin, such as the upwelling of deep waters which takes place along the Western Atlantic coast. Bruland and Franks (1983) showed that Cd but also Zn have nutrient-type distributions in Atlantic waters, dissolved cadmium being correlated with phosphate concentrations in sea water. Moreover, phosphate rocks are very common in Mauritania but also in Senegal which extracts and exports this fertiliser. Waters from Senegal follow a current which reaches the coast of Nouakchott (Margalef 1975). Leaching of phosphate rocks may increase phosphate concentrations of waters. Bustamante et al. 2003 found the same range of cadmium concentrations in the livers of pelagic and benthic fish from sub-Antarctic Archipelago of Kerguelen and observed that these concentrations tend to be higher than those reported in the current literature. The authors suggested that the occurrence of upwelling of deep waters in the Kerguelen region should bring an enrichment of Cd in the surface waters.

Copper hepatic concentrations in fish reported in the literature are highly variable. Values ranging from 8 to 20 μg g^{-1} were reported in the livers of Serranidae (*Serranus scriba*, *Cephalopholis nigri*), and the Mullidae *Pseudupeneus prayensis*, collected in the same area (Roméo et al. 1999). This is in agreement with concentrations measured here in the livers of the Serranidae *Cephalopholis taeniops* and the cartilaginous fish *Rhinobatos cemiculus* (Fig. 1). In these species, copper appears to be under close physiological regulation as generally stated for this essential metal (Thompson 1990). Higher copper values recorded by some authors may indicate a preferential storage in this organ. A high hepatic copper storage (1000 μg g^{-1}), related to a high hepatic metallothionein level, was found in a teleost fish *Morone americana* (Moronidae) by Bunton et al. (1987). In this study, the highest value was found in *Dicentrarchus punctatus* which also belongs to Moronidae.

Gonads seem to be particularly rich in cadmium and zinc, the enrichment for zinc may be explained by the well-known physiological role of zinc in fertilization. Julshamn and Braekkan (1976) found that the zinc level in the ovary of the cod was higher than in any other organ of the fish. Moreover, juvenile cod roe was found to have 3 times more zinc than mature cod roe (Julshamn et al. 1978). Cadmium is often associated with zinc. Eisler and Gardner (1973) found synergy in the metal accumulation of cadmium and zinc in the fish *Fundulus heteroclitus*.

The species which appear to store the highest concentrations of cadmium, copper and, to a less extent, zinc are the pelagic fish *Dicentrarchus punctatus* (eating on fish, crustaceans and cephalopods) and the bathopelagic fish *Diplodus bellottii* and *Pagrus caeruleostictus* eating on crustaceans and molluscs (Table 2). Cephalopods are susceptible to present high levels of cadmium and act as vectors of the transfer of cadmium to top marine predators in the Atlantic (Bustamante et al. 1998). In the Mauritania coast, molluscs are known to present high metal and especially cadmium concentrations (Roméo and Gnassia-Barelli 1988, Sidoumou 1991, Roméo et al. 2000b).

A comparison with already published data on certain fish species from the Mauritania coast (Roméo et al. 1999) shows the same tendency for metal distribution in the different tissues and the same range of concentrations.

Both habitat and feeding habits influenced metal concentrations in fish in this study. Along the Nort-Western African coast, some high metal levels, especially cadmium, were found in tissues of fish such as livers and gonads which are occasionally consumed by man. These levels may be above the proposed limits for human consumption but these considered tissues are eaten in much lower quantities than muscles.

REFERENCES

Bebbington GN, Mackay NJ, Chvojka R, Williams RJ, Dunn A, Auty EH (1977) Heavy metals, selenium and arsenic in nine species of Australian commercial fish. Australian J Mar Fresh Res 28:277-286

Biney C, Amuzi AT, Calamari D, Kaba N, Mbome IL, Naeve H, Ochumba PBO, Osibanjo O, Radegonde V, Saad MAH (1994) Review of heavy metals in the African aquatic environment. Ecotoxicol Environ Saf 28:134-159

Bruland KW, Franks RP (1983) Mn, Ni, Cu, Zn and Cd in the Western North Atlantic In: Wong CS, Boyle E, Bruland KW, Burton JD, Goldberg ED (eds) Trace metals in seawater. Plenum Press, New York, London

Bunton TE, Baksi SM, George SG, Frazier JM (1987) Abnormal hepatic copper storage in a teleost fish *Morone americana.* Vet Pathol 24:515-524

Bustamante P, Caurant F, Fowler SW, Miramand P (1998) Cephalopods as a vector of the transfer of cadmium to top marine predator in the North-east Atlantic Ocean. Sci Total Environ 220:71-80

Bustamante P, Bocher P, Chérel Y, Miramand P, Caurant F (2003) Distribution of trace elements in the tissues of benthic and pelagic fish from the Kerguelen Islands. Sci Total Environ 31:25-39

CSHPF (Conseil Supérieur d'Hygiène Publique de France) (1995) Plomb, cadmium et mercure dans l'alimentation: évaluation et gestion du risque. Ministère du Travail et des Affaires Sociales, Lavoisier Tec et Doc (ed), Paris

Eisler R, Gardner GR (1973) Acute toxicity to an estuarine teleost of mixtures of cadmium, copper and zinc salts. J Fish Biol 5:131-142

Everaats JM, Nieuwenhuize J (1995) Heavy metal in surface sediment and epibenthic macroinvertebrates from the coastal zone and continental slope of Kenya. Mar Pollut Bull 31:281-289

Filipović V, Raspor B (2003) Metallothionein and metal levels in cytosol of liver, kidney and brain in relation to growth parameters of *Mullus surmuletus* and *Liza aurata* from the Eastern Adriatic Sea. Wat Res 37:3253-3262

Hamilton SJ, Mehrle PM (1986) Metallothionein in fish : review of its importance in assessing stress from metal contaminants.Trans American Fish Soc 115:596-609

Hamza-Chaffai A, Roméo M, El Abed A (1996) Heavy metals in different fishes from the middle Eastern coast of Tunisia. Bull Environ Contam Toxicol 56:766-773

Julshamn K, Braekkan OR (1976) The relation between the concentration of some main elements and the stages of maturation of ovaries in cod (*Gadus morrhua*). Fish Dir Skr Ser Ernaering 1:1-15

Julshamn K, Haugsnes J, Eriksen J (1978) Major and minor element (mineral) levels in products and offal from the fishing industries. Fish Dir Skr Ser Ernaering 1:137-44

Margalef R (1975) Composición y distribución del fitoplancton marino en la región de afloramiento del NW de Africa en marzo 1973 campaña 'Artor' del cornide de Saavedra. Inv Pesq Suppl 4:145-170

Roméo M, Gnassia-Barelli M (1988) *Donax trunculus* and *Venus verrucosa* as bioindicators of trace metal concentrations in Mauritanian coastal waters. Mar Biol 99:223-227

Roméo M, Siau Y, Sidoumou Z, Gnassia-Barelli M (1999) Heavy metal distribution in different fish species from the Mauritania coast. Sci Total Environ 232:169-175

Roméo M, Sidoumou Z, Gnassia-Barelli M (2000a) Heavy metals in various molluscs from the Mauritanian coast. Bull Environ Contam Toxicol 65:269-276

Roméo M., Bennani N, Gnassia-Barelli M, Lafaurie M, Girard JP (2000b) Cadmium and copper display different response towards oxidative stress in the kidney of the sea bass *Dicentrarchus labrax*. Aquat Toxicol 48:185-194

Sidoumou Z (1991) Qualité des eaux du littoral mauritanien: étude des métaux traces chez deux mollusques bivalves *Venus verrucosa* et *Donax rugosus*. Thesis, University of Nice Sophia-Antipolis, France

Thompson DR (1990). Metal levels in marine invertebrates. In: Furness RW, Rainbow PS (eds) Heavy metals in the marine environment. CRC Press, Boca Raton