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Tissue Elemental Levels in Fin-Fishes from Imo River System, Nigeria: Assessment of Liver/Muscle Concentrations Ratio

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Abstract: Fishes are important bioindicators of the integrity of aquatic ecosystems and were used to evaluate the status of heavy metal pollution in an oil impacted aquatic ecosystem (Imo River) located within the Niger Delta region of Nigeria. The concentrations of Cd, Cr, Cu, Fe, Pb, Mg, Mn, Ni and Zn were determined using inductively coupled plasma spectrometer (Optima 3000-Perkin Elmer). The metal concentrations in liver and muscle tissues of *Ethmalosa fimbriata* (bonga fish), *Chrysichthyes nigrodigitatus* (catfish), *Lutiana ava* (pink snapper), *Stellifer lancelatus* (croaker) and *Tilapia guineensis* (Tilapia) were consistently higher in the livers than in the muscle tissues of all the five fishes. Magnesium concentration was anomalously higher in the muscle tissue than liver of *C. nigrodigitatus*, *E. fimbriata* and *L. ava* but not in *S. lancelatus* and *T. guineensis*. Muscle-liver ratios (MLRs) of the respective heavy metals ranged between 0.089 (CuM:CuL) and 1.299 (MgM:MgL) for *C. nigrodigitatus*, 0.186 (CrM:CrL) and 1.401 (MgM:MgL) for *E. fimbriata*, 0.194 (CuM:CuL) and 1.498 (MgM:MgL) for *L. ava*, 0.131 (CuM:CuL) and 0.646 (NiM:NiL) for *S. lancelatus*, 0.009 (CuM:CuL) and 0.916 (MgM:MgL) for *T. guineensis*. Interestingly, copper indicated least MLR in almost all the investigated fishes except in *E. fimbriata*. Magnesium showed the highest MLR in all fish species except in *S. lancelatus*. On the other hand, the cadmium/zinc ratios were higher in the muscle tissues than livers of all the fishes analyzed except in *E. fimbriata*. The threshold contamination value for human dietary risk was however, not exceeded.

Key words: Heavy metals, fish, muscle-liver ratio, cadmium/zinc ratio, Imo river

Introduction

In recent years, contamination of aquatic environment by heavy/trace metals has risen as a result of increased industrial activities and attendant population surge especially around littoral zones which indirectly influences the quantity of domestic waste laden with heavy metals. Despite the natural sources of heavy/trace metals in the environment, anthropogenic supply to aquatic ecosystems from industrial effluents/wastes, agricultural and domestic wastewaters laden with metal toxicants out weights the former. Heavy metal pollution is an important environmental problem (Ryams-Keller *et al*., 1998; Ho and Hui, 2001; Yilmaz, 2005), considering that some are hazardous substances and can bioaccumulate in the environment, plant and animal tissues (Zweig *et al*., 1999; van den Broek *et al*., 2002). Fishes are major faunal components of aquatic environments and are usually used as excellent environmental bioindicator of the health of aquatic systems (Stiassny, 1996; Wildianarko *et al*., 2000). In recent times, there has been increasing interest in the utilization of fishes as indicative indicators of the integrity of aquatic environmental systems (Fausch *et al*., 1990; Whitefield, 1996; Toham and Teugels, 1999; King and Jonathan, 2003) because aquatic environments and the associated fish faunal assemblages are potentially affected by a wide array of anthropogenic

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perturbations (King and Jonathan, 2003). Many studies have indicated that aquatic organisms can accumulate and bioconcentrate heavy metals in their tissues many times above ambient levels (Voight, 2003; Kucuksezgin *et al*., 2006).

In aquatic ecosystems, heavy metals may enter fin-and shell-fishes through direct absorption from the water through their gills and other exposed biomembranes (Matagi *et al*., 1998). However, most pollutants in aquatic organisms arrive there through the food chain. First, phytoplankton, bacteria, fungi and other small organisms absorb these substances and are in turn eaten by fishes.

Moreover, nature has provided aquatic fauna with effective defense against heavy metals. Metals may be eliminated through the gut or by detoxification in the kidney, spleen and liver by metallothioneins (MTs), synthesized in the fauna in response to changes in Heavy Metals Balance (HMB) in the organism (Matagi *et al*., 1998). Fishes are known to concentrate heavy metals in their body tissues in varying proportions, depending upon environmental conditions, type of tissue and inhibitory processes (Hossain and Khan, 2001). Moreover, since they constitute an important human food, they are potentially an indirect source of heavy metals entering the body but they may in addition suffer wide range of ecological, physiological, metabolic and behavioral defects (Cücük and Engün, 2005).

Several studies have been conducted on the heavy metal concentrations in fishes from rivers in Nigeria. The presence of unacceptable levels of Hg and Pb in the tissues of the African catfish, *Clarias gariepinus* from River Niger has been reported (Lawani and Alawode, 1996). Omoregie *et al.* (2002) also reported enhanced levels of Pb, Cu and Zn in *O. nilotica* (Nile Tilapia) from River Delimi. Higher concentrations of Cd, Cu, Fe, Mn and Zn have been shown to bioaccumulate in muscle, liver and gill tissues of *O. nilotica* and *Clarias gariepinus,* cultured in some disused mining lakes (Akueshi *et al*., 2003). However, literatures on elemental burdens in fishes from Imo River are not available.

In the present study, the levels of cadmium, chromium, copper, iron, lead, magnesium, manganese, nickel and zinc in muscle and liver tissues of different species of commercially available fishes (bonga fish-*Ethmalosa fimbriata*, catfish-*Chrysichthyes nigrodigitatus*, croaker-*Stellifer lancelatus*, pink snapper-*Lutianus ava* and Tilapia-*Tilapia guineensis* caught at three stations within the Imo River system were investigated as possible bioindicators of heavy metal pollution. These species of fishes constitute an important source of protein to the local consumers and the entire country. Species of fishes used in this study differ in their habitats and feeding habits. *E. fimbriata* is a highly commercial species and occurs in inshore waters, lagoons, brackish and marine environments. It feeds by filtering phytoplankton, chiefly diatoms (Whitehead, 1985).

Chrysichthyes nigrodigitatus (Catfish), a major commercial fish species occurs in demersal, potamodromous and freshwater environments (Risch, 1986). It is an omnivorous species that feeds on seeds, insects, bivalves and detritus and have been reported in lower and upper Niger ecosystem (Paugy *et al*., 1994). The habitat of *L. ava*, which is a carnivore, is pelagic and are found in freshwater, brackish and marine environments. Most species are predators of crustaceans and fishes, while several are planktivores. *S. lancelatus* (Croaker) is commonly found over shallow, muddy or sandy mud bottoms of estuaries. They occur in brackish and marine environments (Cervigen, 1993). On the other hand, *T. guineensis* are benthopelagic, usually occurring in freshwater and brackish ecosystems. It is a commercial species and feeds on shrimps, plankton, bivalves and detritus. The occurrence of *T. guineensis* in aquatic ecosystems of Niger Delta is widely documented to include amongst Qua Iboe River, Cross River, Imo River and Otamiri Rivers. In general, *E. fimbriata*, *C. nigrodigitatus* and *T. guineensis species* are most important in the artisanal/commercial fishery in the coastal water.

Materials and Methods

Study Area

The Imo River is one of the numerous lowland rivers of the Niger Delta located within 4° 25'N, 7° 19'E. The river is one of the major hydrographic features of the Niger-Benue river system. It has a shallow depth ranging from 5-8 m at flood and ebb tides and is characterized by extensive interconnection of tributaries and creeks. The river extends along the coast from the River Niger in the North and discharges into the Atlantic Ocean in the South at the Bight of Bonny. The river is a multi-use resource for artisanal and commercial fishing and transportation. Other economic activities in and around the river include oil exploration and exploitation and aluminium smelting.

Samples Collection

Samples of fishes from different locations from the upper and lower reaches of the Imo River were collected for analysis. The common fish species collected were bonga fish *(Ethmalosa fimbriata)*, catfish *(Chrysichthyes nigrodigitatus)*, croaker (*Stellifer lancelatus*), pink snapper (*Lutianus ava*) and Tilapia *(Tilapia guineensis)*. The fishes collected were labeled with an identification number, the date and place of collection, before transportation in ice packed plastic coolers to the laboratory for analysis.

Heavy Metal Analysis

For the determination of heavy metals, fish samples were carefully dissected to remove the liver and parts of the muscle. The livers and pieces of edible muscle tissues (8 g in weight) were separately digested with nitric and perchloric acids in a silica beaker and evaporated to dryness on a hot plate. The white residue was dissolved in 10 mL of 20% nitric acid. To the replicates and blanks, 10 mL of 20% nitric acid was added. At the completion of digestion, the samples were filtered into acid-washed volumetric flasks and diluted to 50 mL for elemental analysis. Concentrations of cadmium, chromium, copper, iron, lead, magnesium, manganese, nickel and zinc were then determined using inductively coupled plasma spectrometer (Optima 3000-Perkin Elmer). In order to ensure quality control, certified international reference material was also subjected to the above treatment to ensure that adequate percentage of the originally bound metals were recovered by the laboratory treatment. Laboratory standards of known concentrations for each metal were also prepared and analyzed using the AAS. The detection limits were cadmium, 0.1 mg kg^{-1}, chromium, 0.1 mg kg^{-1}, copper, 0.1 mg kg^{-1}, iron, 0.1 mg kg^{-1}, lead, 0.1 mg kg^{-1}, magnesium, 0.01 mg kg^{-1}, manganese, 0.01 mg kg^{-1}, nickel, 0.1 mg kg^{-1} and zinc, 0.01 mg kg^{-1}.

Results and Discussion

Concentrations of cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), nickel (Ni) and zinc (Zn) in the fish liver and muscle tissues given in Tables 1-5.

The results for Cd, Cr, Cu, Fe, Mg, Ni and Zn concentrations in the different fish species have revealed levels consistently higher in the liver than in the muscle tissues. This is in agreement with the earlier report by Koli and Whitmore (1983). However, magnesium demonstrated an anomalous trend in the fish samples. Magnesium concentrations were comparatively higher in the muscle than in the liver of *Lutianus ava* (Table 1), *Ethmalosa fimbriata* (Table 3) and *Chrysichthyes nigrodigitatus*

Table 1: Heavy metal concentration (mg kg^{-1}) and muscle-liver ratio (MLR) of *Lutianus ava*

Trace element	Muscle	Liver	MLR
Manganese	11.65	17.87	0.652
Zinc	14.02	49.27	0.285
Copper	1.167	6.022	0.194
Nickel	0.751	1.699	0.442
Lead	0.152	0.517	0.294
Cadmium	0.097	0.209	0.464
Iron	30.57	76.99	0.397
Chromium	0.997	3.115	0.320
Magnesium	354.94	236.91	1.498

Table 2: Heavy metal concentration (mg kg^{-1}) and muscle-liver ratio (MLR) of *Tilapia guineensis*

Trace element	Muscle	Liver	MLR
Manganese	0.886	1.177	0.753
Zinc	13.32	65.95	0.202
Copper	1.93	22.57	0.009
Nickel	0.895	1.132	0.791
Lead	0.047	0.125	0.376
Cadmium	0.036	0.085	0.424
Iron	5.011	13.95	0.359
Chromium	0.073	0.196	0.372
Magnesium	320.78	350.19	0.916

Table 3: Heavy metal concentration (mg kg^{-1}) and muscle-liver ratio (MLR) of *Ethmalosa fimbriata*

Trace element	Muscle	Liver	MLR
Manganese	0.949	1.739	0.546
Zinc	7.779	26.47	0.294
Copper	1.208	4.286	0.282
Nickel	1.212	1.359	0.892
Lead	0.187	0.551	0.339
Cadmium	0.104	0.396	0.263
Iron	3.161	10.45	0.302
Chromium	0.152	0.817	0.186
Magnesium	394.26	281.33	1.401

Table 4: Heavy metal concentration (mg kg^{-1}) and muscle-liver ratio (MLR) of *Stellifer lancelatus*

Trace element	Muscle	Liver	MLR
Manganese	1.203	5.148	0.235
Zinc	10.15	57.09	0.178
Copper	2.004	15.29	0.131
Nickel	0.489	0.757	0.646
Lead	0.013	0.051	0.255
Cadmium	0.025	0.082	0.305
Iron	20.16	73.29	0.275
Chromium	0.09	0.314	0.287
Magnesium	294.7	528.9	0.557

Table 5: Heavy metal concentration (mg kg^{-1}) and muscle-liver ratio (MLR) of *Chrysicthyes nigrodigitatus*

Trace element	Muscle	Liver	MLR
Manganese	0.208	1.291	0.161
Zinc	17.13	49.61	0.346
Copper	1.122	12.61	0.089
Nickel	0.016	0.043	0.372
Lead	0.015	0.029	0.517
Cadmium	0.008	0.013	0.615
Iron	36.85	107.91	0.341
Chromium	0.058	0.246	0.236
Magnesium	429.58	330.61	1.299

(Table 5). Surprisingly however, this anomalous trend of magnesium concentration was not found in *T. guineensis* (Table 2) and *S. lancelatus* (Table 4). In these fish species, Mg levels were higher in the liver than in the muscle. The anomalous Mg bioaccumulation and storage potential in *C. nigrodigitatus*, *E. fimbriata* and *L. ava* could be attributed to the Mg binding proteins of muscle tissue (Koli and Whitmore, 1983). Absorbed Mg cannot be distributed quickly to other target organs probably due to its complexed form within the muscle tissues, thus it accumulate anomalously.

The Muscle Liver Ratios (MLRs) of the respective heavy metals accumulated by the fishes (Tables 1-5) ranged between 0.089 (CuM:CuL) and 1.299 (MgM:MgL) for *C. nigrodigitatus*; 0.186 (CrM:CrL) and 1.401 (MgM:MgL) for *E. fimbriata*; 0.194 (CuM:CuL) and 1.498 (MgM:MgL) for *L. ava*; 0.131 (CuM:CuL) and 0.646 (NiM:NiL) for *S. lancelatus* and 0.009 (CuM:CuL) and 0.916 (MgM:MgL) for *T. guineensis*. Essential trace elements (Mg, Fe, Zn and Cu) indicated preferential bioaccumulation in the liver than muscle tissue. Interestingly, the values revealed that the least MLRs were generally recorded for copper element except in *E. fimbriata* where the ratio calculated for chromium was the least (Table 3). The muscle-liver ratio for magnesium (MgM:MgL) was the highest in most of the fish species except in *S. lancelatus*, where nickel muscle-liver ratio (NiM: NiL) was very high (0.646) (Table 4).

The concentrations of cadmium in the liver (CdL) exceeded the concentrations in the muscle tissue (CdM) of all the fish species analyzed (Tables 1-5). The variation of the calculated ratio CdM:CdL (0.263-0.615), for all species considered in this study confirms reports that cadmium mainly accumulates in the liver than muscle tissues (Lemaire and Lemaire, 1992; Soengas *et al*., 1996; Voight, 2003; Cücük and Engün, 2005). In fish, cadmium is absorbed both from the surrounding water by the gills and from the food by digestion and then transported through the blood, mainly to the liver and kidneys (van den Broek *et al*., 2002). Although it is a non-essential heavy metal, Cd has cumulative polluting effect in aquatic ecosystems and could lead to interruption of development and growth, skeletal deformations and pathological changes in aquatic organisms (Cücük and Engün, 2005). The levels of nickel in all investigated species were considerably higher in the liver than muscle tissues. The calculated ratio of nickel in muscle (NiM) to liver (NiL) ranged between 0.372 in *C. nigrodigitatus* and 0.892 in *E. fimbriata*. Similarly, the concentrations of copper, iron and lead in the livers exceeded that of the muscle tissues of the fishes investigated. Moreover, the calculated ratios for Cu, Fe and Pb varied for all species: CuM:CuL (0.009-0.282), FeM:FeL (0.275-0.397) and PbM:PbL (0.255-0.517). However, Cu though an essential element has limited range above which toxic effects is observed (Arellano *et al*., 1999) and possible sources to aquatic systems include domestic, agricultural use and industrial processes (Mason *et al*., 2002).

Muscle-liver ratio is an indicator of heavy metal cleansing mechanism in fish, owing to the rates of accumulation and removal from the fish body system (Koli and Whitmore, 1983). Thus, MLR could be a useful bio-monitoring indicator of heavy metal contamination in fishes within an aquatic system. Although, the muscle tissue of fishes is not known to accumulate enhanced levels of heavy metals, therefore heavy metals concentrations in the muscle is a reflection of their content in the transporting heam.

Cadmium is known to be among the most toxic heavy metals to aquatic organisms (Castano *et al*., 1998; Beauvails *et al*., 2001). Equally, zinc have been shown to be toxic to aquatic organisms arising mainly from domestic sources and natural occurring processes into aquatic systems (Zweig *et al*., 1999; van den Broek *et al*., 2002). Although, cadmium and zinc are chemically very similar (Scheyer, 2000), the difference, however, is that cadmium has a higher affinity for thiol (SH) groups in human physiology (Mengel and Kirby, 1982) which may cause more health problems when enhanced concentrations are taken in, through the consumption of fishes. Zinc is an essential biological mineral, which is regulated and maintained at certain concentrations in fish (Widianarko *et al*., 2000) due to physiological requirements for survival (homeostatic regulation) (Sorensen, 1991).

Cadmium and zinc content levels were generally higher in the liver tissues of the fish species than in the muscle parts (Tables 1-5). However, estimation of Cd to Zn ratio summarized in Table 6, indicated that cadmium/zinc ratio in muscles were higher than those estimated for liver tissues in most of the species considered except in *E. fimbriata* where Cd/Zn ratio of 0.0149 for liver was greater than 0.0134 obtained from muscle tissue. *C. nigrodigitatus* particularly indicated very weak ratios in both

Table 6: Cadmium to zinc ratio in different species of fish from Imo river, Nigeria

Species	Muscle	Liver
Ethmalosa fimbriata	0.0134	0.0149
Chrysichthyes nigrodigitatus	0.0005	0.0003
Lutianus ava	0.0069	0.0042
Stellifer lancelatus	0.0025	0.0014
Tilipia guineensis	0.0027	0.0013

muscle and liver tissues. Moreover, the threshold contamination limit of 0.015 considered as dietary risk for humans was not exceeded.

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References

Akueshi, EU., E. Oriegie, N. Ocheakiti and S. Okunsebor, 2003. Levels of some heavy metals in fish from mining lakes on the Jos Plateau, Nigeria. Afr. J. Nat. Sci., 6: 82-86.

Arellano, J.M., J.B. Ortiz, D. Capeta Da Silva, M.L. Gonzalez de Canales, C. Sarasquete and J. Blasco, 1999. Levels of copper, zinc, manganese and iron in two fish species from salt marshes of Cadiz Bay (Southwest Iberian Peninsula). Bol. Inst. Esp. Oceanogr., 15: 485-488.

Beauvias, S.L., S.B. Jones, J.T. Parris, S.K. Brewer and E.E. Little, 2001. Cholinergic and behavioural neurotoxicity of Carbayl and cadmium to larval Rainbow Trout (*Oncorhynchus mykiss*). Ecotoxicol. Environ. Safety, 49: 84-90.

Castano, A., W. Carbonell, G. Carbalo, C. Fernandez, S. Boleas and J.V. Tarazona, 1998. Sublethal effects of repeated intra peritoneal cadmium injections on Rainbow Trout *Oncorhynchus mykiss*). Ecotoxicol. Environ. Safety, 41: 29-35.

Cervigon, F., 1993. Los peces de Venezuela. Vol. 2. Fundacion Cientifica Los Roques, Caracas, Venezuela, pp: 497.

Cücük, B. and K. Engün, 2005. The effects of cadmium on levels of glucose in serum and glycogen reserves in the liver and muscle tissues of *Cyprinus carpio* (L., 1758). Turk. J. Vet. Anim. Sci., 29: 113-117.

Fausch, K.D., J. Lyons, J.R. Karr and P.L. Angermeier, 1990. Fish communities as indicators of environmental degradation. Am. Fish. Symp., 8: 123-144.

Ho, K.C. and K.C.C. Hui, 2001. Chemical contamination of the east river (Dongjiang) and its implication on sustainable development in the Pear River Delta. Environ. Intl., 26: 303-308.

Hossain, M.S. and Y.S.A. Khan, 2001. Trace metals in penaeid shrimp and spiny lobster from the Bay of Bengal. Sci. Asia, 27: 165-168.

King, R.P. and G.E. Jonathan, 2003. Aquatic Environmental Perturbations and Monitoring. African Experience, USA., pp: 166.

Koli, A.K. and R. Whitmore, 1983. Anomalous behaviour of trace element magnesium in fish tissues. Environ. Intl., 9: 125-127.

Kucuksezgin, F., A. Kontas, O. Altay, E. Uluturhan and E. Darilmaz, 2006. Assessment of marine pollution in Izmir Bay: Nutrient, heavy metal and total hydrocarbon concentrations. Environ. Intl., 32: 41-51.

Lawani, S.A. and J.A. Alawode, 1996. Concentrations of lead and mercury in river Niger and its fish at Jebba, Nigeria. Biosci. Res. Commun., 8: 47-49.

Lemaire, G.S. and P. Lemaire, 1992. Interactive effects of cadmium and benzo (a) pyrene on cellular structure and biotransformation enzymes of the liver of the European eel. Aquat. Toxicol., 22: 145-160.

Matagi, S.V., D. Swai and R. Mugabe, 1998. A review of heavy metal removal mechanisms in wetlands. Afr. J. Trop. Hydrobiol. Fish., 8: 23-35.

Mason, A.F., C.C. Cerqueira and M.N. Fernandez, 2002. Gill cellular changes induced by copper exposure in the South American tropical freshwater fish *Prochilodus scrofa.* Environ. Res., 88: 52-63.

Mengel, K. and E.A. Kirby, 1982. Principles of Plant Nutrition. 3rd Edn., International Potash Institute. Worblaugen-Bern, Switzerland, pp: 655.

Omeregie, E., M.O. Okoronkwo, A.C. Eziashi and A.I. Zoakah, 2002. Metal concentrations in water column, benthic macroinventerbrates and tilapia from Delimi river, Nigeria. J. Aquatic Sci., 17: 55-59.

Paugy, D., K. Traore and P.S. Diouf, 1994. Faune ichtyologique des eaux douces d'Afrique de l' Ouest, pp: 35-66. In: Teugels, G.G., J.F. Guegan and J.J. Albaret, (Eds.), Biological Diversity of African fresh and Brackish Water Fishes. Geographical overviews presented at the PARADI Symposium, Senegal, 15-20, Nov. 1993. Ann. Mus. R. Afr. Centr., Sci. Zool., 275: 177.

Risch, L.M., 1986. Bagridae. In: Daget, J., J.P. Gosse and D.F.E. Thysvan den Audenaerde (Eds.), Checklist of the Freshwater Fishes of Africa (CLOFFA), 2: 2-35.

Ryams-Keller, A., K.E. Olson, M. Mc Gaw, C. Oray, J.O. CarIson and B.J. Beaty, 1998. Effects of heavy metals on *Aedes aegypti* (Diptera: Culicidea) Larvae. Ecotoxicol. Environ. Safety, 39: 41-47.

Scheyer, J.M., 2000. Estimating Dietary Risk from Soils in Urban Gardens. In: Burghardt, W. and C. Dornauf (Eds.), Proceedings of the First International Conference on Soils of Urban, Industrial, Traffic and Mining Areas. Essen, Germany, pp: 479-484.

Soengas, J.L., M.J. Agra-Lago, B. Carballo, M.D. Anders and J.A. Veira, 1996. Effect of an acute exposure to sublethal concentrations of cadmium on liver carbohydrate metabolism of Atlantic salmon (Salmo salar). Bull. Environ. Contam. Toxicol., 57: 625-631.

Sorensen, E.M.B., 1991. Metal Poisoning in Fish. CRC Press Inc., Boca Raton, Florida.

Stiassny, M.L., 1996. An overview of freshwater biodiversity with some lessons from African fishes. Fishier, 21: 7-13.

Toham, A.K. and G.G. Teugels, 1999. First data on an index of Biotic Integrity (IBI) based on fish assemblages for the assessment of the impact of deforestation in a tropical West African river system. Hydrobiologica, 397: 29-38.

van den Broek, J.L., K.S. Gledhill and D.G. Morgan, 2002. Heavy metal concentrations in the mosquito fish, *Gambusia holbrooki*, in the Manly Lagoon Catchment. In: UTS Freshwater Ecology Report, pp: 25.

Voight, R.H., 2003. Concentrations of mercury and cadmium in some coastal fishes from the Finnish and Estonian parts of the Gulf of Finland. Proceedings Estonian Acad. Sci. Biol. Ecol., 52: 305-318.

Whitefield, A.K., 1996. Fishes and the environmental status of South African estuaries. Fish. Manag Ecol., 3: 45-57.

Whitehead, P.J.P., 1985. FOA species catalogue. Vol. 7. Clupeoid fishes of the world (Suborder Clupeioidei). An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, shads, anchovies and wolf-herring. Part 1- Chirocentridae, Clupeidae and Pristigasteridae. FOA Fish. Synop., 125: 1-303.

Widianarko, B., C.A.M. Van Gestel, R.A. Verweiji and Van N.M. Straalen, 2000. Associations between trace metals in sediment, water and Guppy, *Poecilia reticulata* (Peters), from urban streams of Semarang, Indonesia. Ecotoxicol. Environ. Safety, 46: 101-107.

Yilmaz, A.B., 2005. Comparison of heavy metals of Grey Mullet (*Mugil cephalus* L.) and Sea Bream (*Sparus aurata* L.) caught in Iskenderun Bay (Turkey). Turk. J. Vet. Animal Sci., 29: 257-262.

Zweig, R.D., J.D. Morton and M.M. Stewart, 1999. Source of Water Quality for Aquaculture: A Guide for Assessment. The World Bank. Washington, DC.