Bio-accumulation of selected metals in African sharptooth catfish *Clarias gariepinus* from the lower Olifants River, Mpumalanga, South Africa

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The level of metal (Cr, Cu, Mn, Ni, Pb and Zn) bio-accumulation in tissues (muscle, gill, kidney, liver and gonads) and bile of the African catfish *Clarias gariepinus*, from the lower Olifants River was investigated. These metals were detected in all the tissues as well as in the bile, with the highest concentration found in either the gills, liver or gonadal tissue. The lowest concentration was usually detected in the muscle tissue. Although statistic comparisons revealed no significant differences between the localities, fish from the Selati River (Locality 1) generally had higher metal levels than fish from the localities along the Olifants River inside the Kruger National Park. The higher levels in the fish from the Selati River may be attributed to anthropogenic activities resulting in point and/or diffuse sources of metal pollution. These sources should be identified and reduced.

Key words: fish, metals, bio-accumulation, river.

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Introduction

Biological systems consist of a vast diversity of habitats and organisms and yet they thrive within relatively narrow physical and chemical limits. Metals play an important role in these systems but there are carefully circumscribed boundaries of tolerable ranges. Those metals essential to life processes pose the joint threat of deficiency diseases at excessively low concentrations and toxic reactions at excessively high ones (Weiss 1978). The biological functions of the essential metals are varied and include (i) the role they play in different physiological processes, (ii) their requirement for respiration or gonad development, (iii) their role as an integral part of protein and (iv) enzyme systems to mention but a few (Heath 1987). However, it must be stressed that essential and non-essential metals are toxic to fish when present at elevated levels.

In natural freshwater ecosystems, metals are typically present in low concentrations and any increase in the levels of bio-available metals in the water may lead to an increase in the bio-accumulation of the metal in tissues of aquatic organisms. The monitoring of metal bio-accumulation is essential because it serves the following purposes: (i) gauging the extent of bio-accumulation both temporal and spatial, (ii) assessing organism health and (iii) assessing fitness for human consumption. Spatial monitoring of bio-accumulation may produce data that would identify unknown areas with high concentrations, while at known discharges it will provide some information regarding the area being affected. The temporal changes in bio-accumulation will provide information regarding the trend of bio-accumulation, which will in turn be used to identify stability, improvement or deterioration. The monitoring of concentration levels in fish or other organisms which are used as food assists in the protection against the consumption of conta-

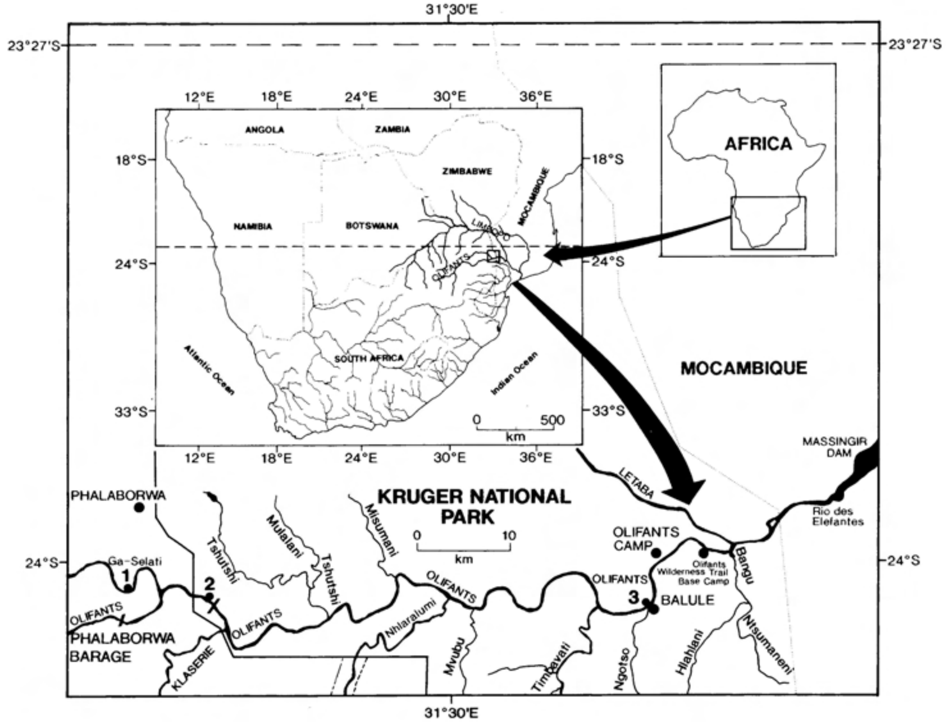

Fig. 1. The study area in the lower Olifants River catchment indicating the sampling localities during 1990 to 1991.

minated food. Furthermore, the detected levels can be judged against standards set for food in general (Mance 1987).

The present study focuses on the bio-accumulation of six metals (Cu, Zn, Cr, Ni, Pb, Mn) in *Clarias gariepinus* from the Olifants River (below the confluence of the Selati River) and the Selati River. The concentrations of these metals in the water from these rivers are generally higher than the guideline values proposed for the protection of aquatic life (Seymore *et al.* 1995) and could therefore have resulted in the bio-accumulation of the metals in the fish.

Materials and methods

Clarias gariepinus were caught with gill nets (70-120 mm stretch mesh size), seine nets and fishing rods every alternative month from February 1990 to February 1992 at Locality 1 in the Selati River and Localities 2 & 3 in the Olifants River (Fig. 1). To minimise the impact of sampling on the resident fish population, a maximum of ten individuals (per locality) were collected during each survey. This precautionary approach was followed because the Selati River is a relatively small river and could possibly not sustain a large resident catfish population, while the localities in the Olifants River were inside the Kruger National Park boundary. Each fish caught was individually weighed, sexed and the total length measured. The fish were then stunned by a sharp blow on the head, and the spinal cord cut behind the head. Dissection took place on a polyethylene work-surface, using stainless steel tools (Heit & Klusek, 1982) and wearing surgical gloves. Muscle, gills, liver, bile, kidneys and gonads were removed for metal analysis. All the samples were kept frozen until laboratory analysis of metal concentration could be undertaken.

Thawed tissue samples were prepared for metal analysis. The gill filaments were removed from the cartilaginous gill arches before being weighed. One gram of tissue was accurately weighed into 100 ml Erlyn-Myer flasks whereafter 10 ml of concentration nitric acid (55 %) and 5 ml perchloric acid (70 %) were added. Digestion was performed on a hotplate (± 200–250 °C) for at least four hours, until the solutions were clear (Van Loon, 1980). The bile, removed from the gall-bladder, was digested in a similar manner. After digestion each solution was filtered using an acid-resistant 0.45 μm filter paper and a vacuum pump. The filter system was then rinsed with doubly distilled water, whereafter the samples were made up to 50 ml each with doubly distilled water. The samples were stored in glass bottles until the metal concentrations could be determined. Prior to use, all glassware was soaked in a 2 % Contrad soap solution (Merck chemicals) for 24 hours, rinsed in doubly distilled water, acid-washed in 1M HCl for 24 hours and rinsed again in doubly distilled water (Giesy & Wiener 1977). A Varian atomic absorption spectrophotometer (Spectra AA-10) was used to determine the metal concentrations in the tissue samples of the fish. Analytical standards were prepared from Holpro stock solutions.

Bioconcentration factors (Wiener & Giesy 1979) between the fish tissues and the water (Bfw) and sediment (Bfs) were determined, using the mean metal concentration in each tissue. The metal concentrations in water and sediment presented in the publication by Seymore *et al.* (1994) were determine for the same localities and date of the fish collection and were therefore used to calculate the bio-accumulation factors. The dry-mass conversion factor was determined in triplicate for each sample of known mass for each of the tissue types by drying it in an oven for 48 h at 60 °C. After the samples were cooled in a desiccator, they were weighted and the percentage moisture was determined. Statistical analysis (parametric) testing was performed by using the STATGRAPHICS computer program. The significance level was $P<0.05$.

Results and discussion

Both male and female fish were captured with the male/female ratio ranging from 1:1.7 to 1.03. During August 1990 no fish were collected at sampling Locality 1 (Table 1). The percentage dry-mass contents of the tissues were 21.3±1.7 % in the muscle, 23.0±1.6 % in the kidney, 27.0±2.3% in the gonads, 27.5±1.2 % in the gills 31.5±2.2 % in the liver.

The selected metals were detected in all the tissues but in variable concentrations (Tables 2–7; Fig. 2). These metals have entered the fish via four possible routes: the gills (Matthiessen & Brafield 1977; Heath 1987), food (Baudin 1987) oral intake of water (Eddy 1981) and the skin (Heath 1987). During the sampling period these metals were higher than the water quality guidelines proposed for the protection of aquatic life (Seymore *et al.* 1994) and therefore could have resulted in bio-accumulation of the metals by the fish. The levels of bio-accumulation of metals in *C. gariepinus* were probably influenced by the high alkalinity (total alkalinity: 131±37 $\mathrm{mg.l^{-1}}$; $CaCO_3$; Van Veelen 1990) of the water of the Olifants and Selati rivers which reduced the absorption of metals. Uptake via the food may also be significant, since *C. gariepinus*, being omnivorous (Willoughby & Tweddle 1978; Bruton 1979), feeds on fish, zooplankton, benthic organisms such as Oligochaetes, chironomids larvae, Ephemeroptera and Hemiptera, aquatic hydrophytes and detritus which have been shown to accumulate high concentrations of metals (Van der Merwe 1990 *pers. comm.*). In the natural environment it is difficult to establish whether the metal entered the fish through dietary routes, through membranes or both. The relative importance of each of these routes varies, but the most significant factor may be the availability of the metal for bio-accumulation.

Despite large variations, the lowest concentrations of these metals were usually detected in the muscle tissue (Tables 2 to 7; Fig. 2). Statistically significant differences ($P<0.05$) between the muscle tissue and other tissue (eg. Zn: gonad, gills, liver, kidneys; Cu: liver; Mn: gills) where detected but no general trend was observed. Only the liver tissue had significantly higher ($P<0.05$) copper concentrations compared to the other tissue. Not one of the selected tissues could be singled out as the tissue which most likely would have the highest concentration of metals. Nevertheless, the highest mean metal concentrations detected varied between the liver, gills and gonadal tissue. As a result of

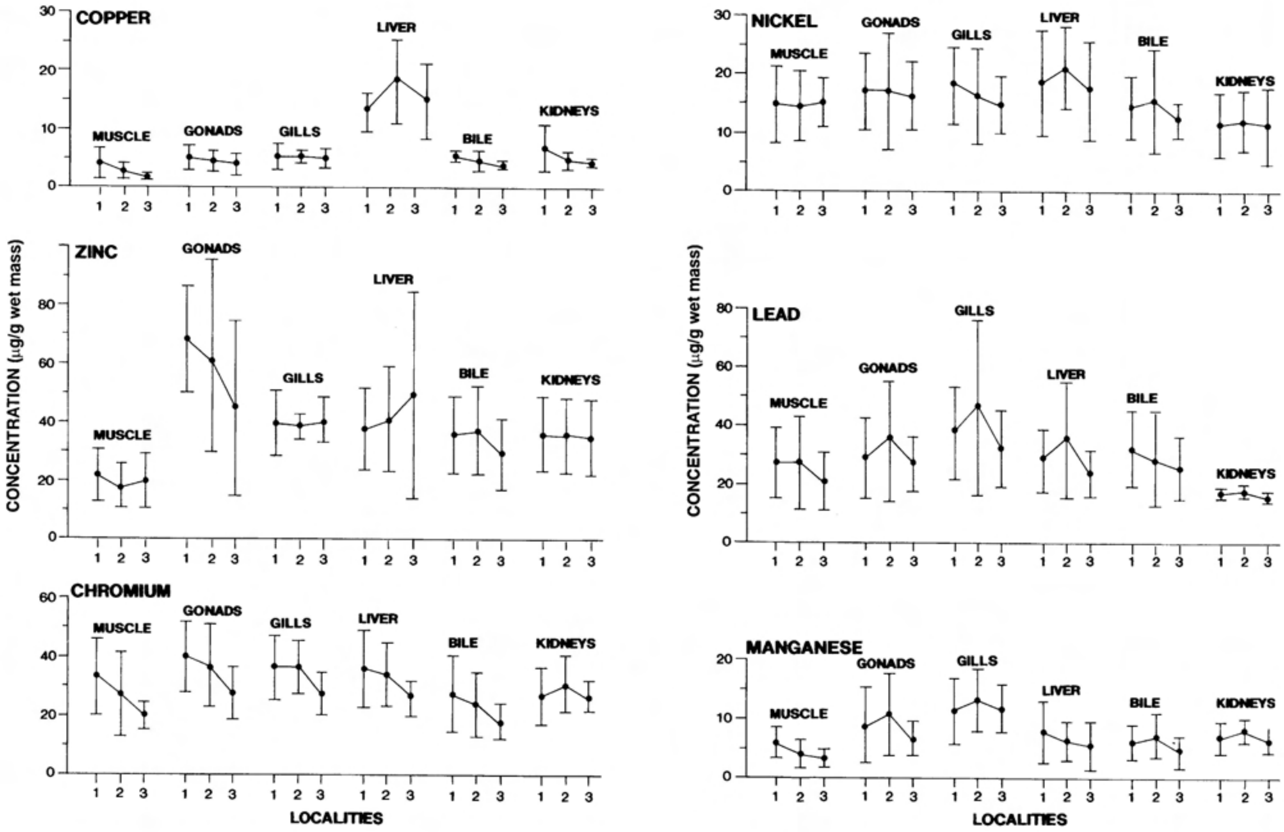

Fig. 2. Mean metal concentrations (g/g wet mass) in the muscle gonads, gills, liver and kidney of *Clarias gariepinus* for the sampling period (Locality 1:Selati River; Locality 2: Olifants River at Mamba Weir, after Selati River confluence; Locality 3: Olifants River at Balule)

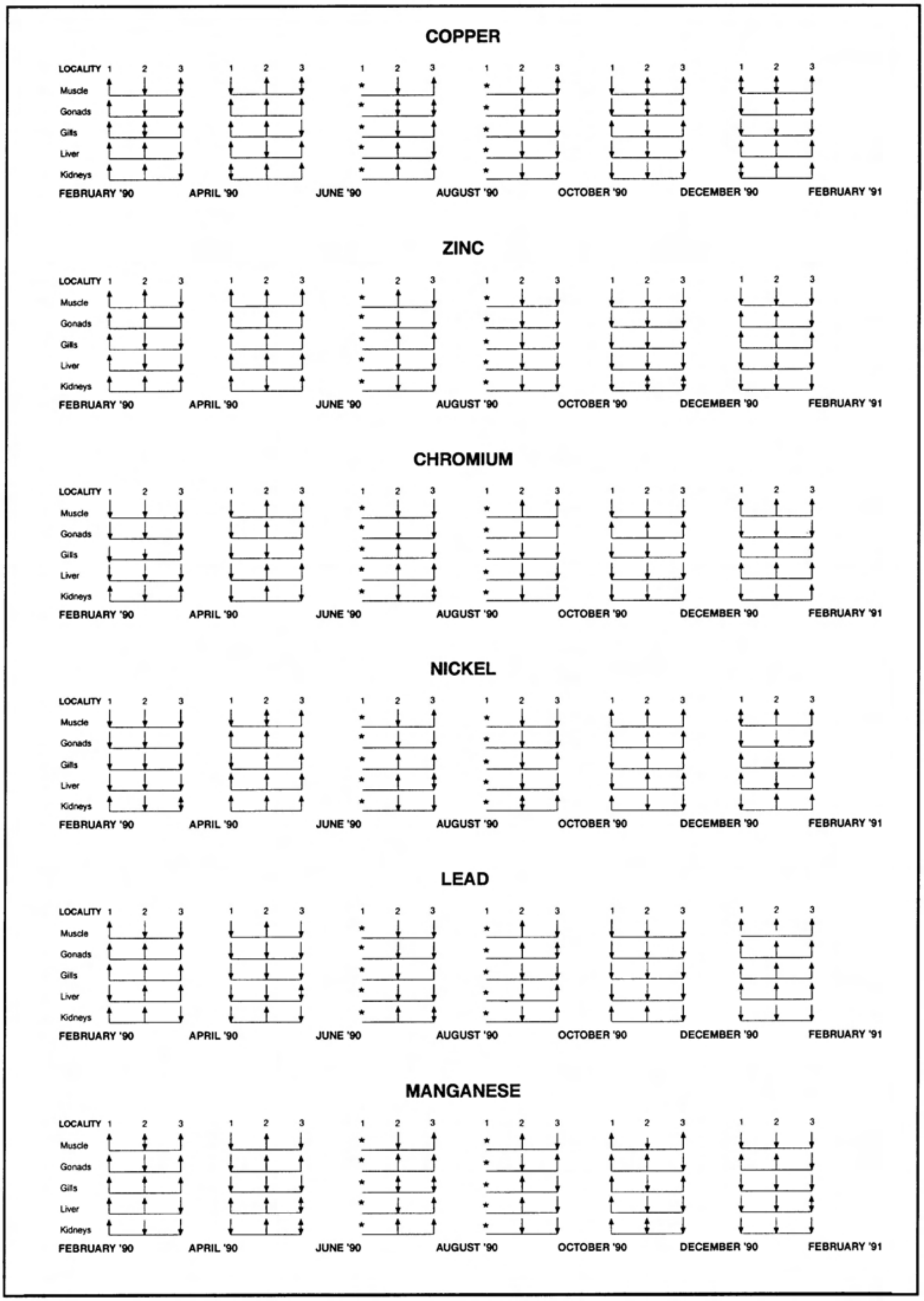

Fig. 3. Trends in metal concentrations between surveys for fish caught at a specific locality, where Locality 1 is Selati River, Locality 2 the Olifants River at Mamba Weir (after Selati River confluence) and Locality 3 Olifants River at Balule. (↑ : increase from one survey to the following; ↓: decrease from one survey to the following; ↕ : no change in concentrations between surveys).

these differences in bio-accumulation of metals by the selected tissues it is suggested that future monitoring assessing the metal pollution in an area should include different tissues/organs. Muscle tissue should always be included to test its fitness for human consumption. The kidneys and bile both had relatively high concentrations of copper and zinc compared with the concentration in the other tissue. There was no significant (P>0.05) difference between copper or zinc concentrations in the bile and the kidneys. The excretion of metals via the urine is unexplored, although it is generally assumed that the kidney excretes some metals (Riechert *et al.* 1979). The kidney frequently accumulates metals to rather high concentrations, but this organ may merely be a location for sequestrating them and need not necessarily indicate excretion. The main excretion route of copper is via the faeces and is excreted into the bile against a concentration gradient (Klaassen 1976). In the case of lead and nickel, the bile had higher (P<0.05) concentrations than the kidneys. Lead tends to be removed at a slow rate from the body of fish (Haux & Larson 1982). The results obtained during the present study indicate that the biliary route is quantitatively more important for removing lead from the body than the urinary route. In conditions where low concentrations of nickel prevail, nickel tends to accumulate in the kidneys (Gottofrey & Borg 1988). Results obtained showed that there was a lower concentration of nickel in the kidney of *C. gariepinus*. This may prove that fish can depurate their body when exposed to low concentrations of nickel. Fish can excrete zinc to some extent and this is supported by the concentration found in the bile and kidney during this study. However, the study by Klaassen (1976) indicated that zinc is mainly excreted via the faeces from the body of the fish.

In most cases chromium concentrations in the kidneys were higher than those in the bile while no significant difference (P>0.05) between the manganese concentrations was detected. Accumulation of chromium in fish does not appear to be a serious problem, with fish being able to eliminate chromium from the body. The high concentrations of chromium found in the gills, liver and the kidneys may well be due to the slow elimination rate of chromium from the fish once accumulated (Buhler *et al.* 1977). Chromium has also been found at elevated levels in the bile of fish during and after ingestion of contaminated food or water-borne chromium (Heath 1987). From the preceding it is evident that fish can eliminate certain metals from the body. This must be considered when the biological significance of the tissue concentrations are being evaluated.

The detected concentrations showed limited trends over the study period (Figs. 2 & 3). Copper, zinc and chromium concentrations in the tissue of the fish from three localities showed a clear decrease from October to December, however, over the same period the nickel, lead and manganese concentrations followed a different pattern. Nevertheless, in many cases the same trends were noted in the different tissues (Fig. 3). Statistic comparisons of the metal concentration for comparable tissue revealed no significant difference between the localities. Generally, however, the trend appeared to be the highest values at Locality 1 (Selati River) followed by Locality 2 (Olifants River at Mamba Weir, after Selati confluence) and Locality 3 (Olifants River at Balule). Seymore *et al.* (1995) generally recorded higher levels of manganese and strontium in fish tissue of fish from the Selati River compared to levels for fish from the Olifants River. Furthermore, Grobler *et al.* (1994) attributed the differences in metals detected in muscle tissue of fish from the Phalaborwa Barrage (upstream of confluence with Selati River) compared to fish from the Olifants River after the confluence with the Selati River to possible metal pollution in the Selati River. Data presented by these investigations as well as the present study, therefore all single the Selati River out as an important contributor of metal pollution in the Olifants River inside the Kruger National Park. In the present study fish from Locality 2 may, on occasion, have higher concentrations of the

Table1

Lengths and mass of Clarias gariepinus *caught in the Selati and Olifants rivers (Kruger National Park) during the period February 1990 - February 1991*

Sampling site	N Male + Female	Total length (cm)				Mass (g)			
		$\bar{X}$	SE	SD	Cv	$\bar{X}$	SE	SD	Cv
February 1990									
1	6 + 2	21.7	1.2	9.6	0.4	107.1	25.9	207.5	1.9
2	6 + 2	49.1	2.0	10.4	0.2	912.6	132.2	661.1	0.7
3	6 + 2	26.5	1.7	7.0	0.2	148.7	29.9	119.5	0.8
April 1990									
1	2 + 4	53.0	2.8	15.7	0.3	1430.0	252.5	1515.3	1.1
2	5 + 5	47.3	1.9	7.8	0.6	756.5	90.0	360.1	0.4
3	8 + 2	31.5	a	a	a	138.9	a	a	a
June 1990									
1	6 + 2	58.4	1.0	8.0	0.1	1550.0	118.5	946.6	0.6
2	6 + 2	52.7	1.4	11.5	0.2	118.0	100.0	800.3	0.6
3	6 + 2	50.0	0.8	6.4	0.1	993.7	57.5	460.1	0.4
August 1990									
1	a	a	a	a	a	a	a	a	a
2	1 + 9	50.5	1.1	9.9	0.2	1006.0	56.2	505.8	0.5
3	4 + 6	68.5	1.6	16.8	0.2	3210.0	22.7	222.8	0.6
October 1990									
1	4 + 1	47.5	20.6	103.2	0.2	1010.0	87.5	437.8	0.4
2	6 + 4	50.2	13.9	139.1	0.2	1325.0	89.7	897.9	0.6
3	6 + 1	47.3	10.9	76.3	0.1	838.5	55.8	391.0	0.4
December 1990									
1	2 + 4	49.4	3.4	20.3	0.1	973.0	25.5	153.1	0.1
2	5 + 5	55.7	8.0	80.1	0.1	1542.0	66.3	663.0	0.4
3	8 + 2	48.0	6.0	60.6	0.1	1079.0	34.7	347.5	0.3
February 1991									
1	2 + 3	53.8	1.8	9.3	0.2	1060.0	72.9	437.4	0.4
2	4 + 2	64.1	3.3	18.8	0.3	2407.5	336.0	2016.4	0.8
3	2 + 1	76.6	4.6	13.8	0.2	3690.0	708.1	2124.4	0.5

$\bar{X}$: mean; SE: standard error; SD: standard deviation; Cv: coefficient of variation; [a] : no data available

selected metal in the same tissue as fish from the Selati River (Fig. 2) possibly as a result of being exposed to lower levels, and subsequent bio-accumulation levels which require less regulation and subsequent higher tissue levels compared to tissue levels of the Selati River.

Although the fish from the Olifants River inside the Kruger National Park are not used as food for human consumption, it is interesting to note that the maximum allowable concentrations for zinc and copper were lower, but lead higher than the standard set for food (1000 µg/g wet mass; 30 µg/g Cu wet mass; 2 µg/g wet mass) by the Australian National Health and Medical Research Council (Anon 1974). No comparable values were available for the other metals investigated. Nevertheless, it cannot be assumed that these fish are fit for consumption by top predators such as fishing owls, fish eagles and crocodiles in the system. Furthermore, the extent of metals transferred to these predators by eating the fish is not known. These aspects should be further investigated and the possible diffuse/point sources of metal pollution in the Phalaborwa area should also be identified and quantified.

Table 2

Mean copper concentration (μg/g wet mass) in the selected tissue and bile of Clarias gariepinus *from the Olifants (Localities 2 & 3) and Selati (Locality 1) rivers*

Sampling Locality		Copper concentration (μg/g wet mass)					
		Muscle	Gonads	Gill	Liver	Bile	Kidneys
February 1990							
1	$\bar{X}$ ± SD	3 ± 0.9	5 ± 3.7	4 ± 0.6	13 ± 2.8	6 ± 0.2	6 ± 1.7
	BCFw & BCFs	23 & 0.35	38 & 0.04	29 & 0.03	109 & 0.11	52 0.06	48 & 0.48
2	$\bar{X}$ ± SD	4 ± 0.1	6 ± 1.5	5 ± 1.9	21 ± 9.8	6 ± 1.1	5 ± 1.2
	BCFw & BCFs	88 & 0.8	154 & 0.14	127 & 0.12	531 & 0.48	140 & 0.13	130 & 0.12
3	$\bar{X}$ ± SD	2 ± 0.1	5 ± 0.7	5 ± 0.5	11 ± 6.8	5 ± 3.2	5 ± 0.9
	BCFw & BCFs	26 & 0.16	64 & 0.39	63 & 0.39	140 & 0.86	68 & 0.40	64 & 0.39
April 1990							
1	$\bar{X}$ ± SD	8 ± 4.0	6 ± 1.2	7 ± 4.9	14 ± 7.9	7 ± 0.2	12 ± 3.5
	BCFw & BCFs	69 & 0.70	47 & 0.47	54 & 0.01	115 & 0.03	62 & 0.02	103 & 0.03
2	$\bar{X}$ ± SD	2 ± 0.5	5 ± 2.6	5 ± 0.2	29 ± 9.2	7 ± 1.3	6 ± 2.9
	BCFw & BCFs	33 & 0.33	72 & 0.72	65 & 0.2	417 & 0.87	143 & 0.27	169 & 0.25
3	$\bar{X}$ ± SD	2	4	4	20	4	4
	BCFw & BCFs	32 & 0.06	52 & 0.52	58 & 0.10	282 & 0.50	60 & 0.11	57 & 0.10
June 1990							
1	$\bar{X}$ ± SD	6 ± 9.6	9 ±1.2	9 ± 0.8	18 ± 4.2	5 ± 2.1	12 ± 5.2
	BCFw & BCFs	36 & 0.02	54 & 0.04	69 & 0.03	114 & 0.06	33 & 0.2	76 & 0.01
2	$\bar{X}$ ± SD	5 ± 0.5	8 ± 1.9	7 ± 0.8	24 ± 13.0	5 ± 3.7	7 ± 3.5
	BCFw & BCFs	53 & 0.25	75 & 0.36	67 & 0.33	243 & 1.15	50 & 0.24	70 & 0.33
3	$\bar{X}$ ± SD	2 ± 0.5	7 ± 2.4	3 ± 0.5	25 ± 3.6	4 ± 9.1	5 ± 1.1
	BCFw & BCFs	23 & 0.07	34 & 0.23	40 & 0.10	250 & 0.76	38 & 0.11	34 & 0.16
August 1990							
1	$\bar{X}$ ± SD	a	a	a	a	a	a
	BCFw & BCFs	a	a	a	a	a	a
2	$\bar{X}$ ± SD	4 ± 0.10	8 ± 2.3	5 ± 1.5	25 ± 13.9	8 ± 2.3	8 ± 2.5
	CFw & BCFs	126 & 0.00	246 & 0.23	170 & 0.15	847 & 0.73	263 & 0.23	256 & 0.22
3	$\bar{X}$ ± SD	5 ± 2.4	7 ± 1	10 ± 0.9	20 ± 1.7	6 ± 3.6	9 ± 3.7
	BCFw & BCFs	159 & 0.12	233 & 0.18	330 & 0.26	681 & 0.54	191 & 0.15	293 & 0.23
October 1990							
1	$\bar{X}$ ± SD	3 ± 0.5	4 ± 1.1	6 ± 1.3	14 ± 5.2	6 ± 2.9	5 ± 1.5
	BCFw & BCFs	69 & 0.09	90 & 0.12	145 & 0.19	360 & 0.45	155 & 0.2	133 & 0.17
2	$\bar{X}$ ± SD	2 ± 0.3	3 ± 0.9	4 ± 0.2	13 ± 6.7	6 ± 3.7	6 ± 3.0
	BCFw & BCFs	50 & 0.08	65 & 0.20	104 & 0.32	330 & 1.02	140 & 3.4	138 & 0.42
3	$\bar{X}$ ± SD	2 ± 0.4	4 ± 3.4	5 ± 0.8	11 ± 4.0	5 ± 1.0	5 ± 0.5
	BCFw & BCFs	53 & 0.09	107 & 0.39	132 & 0.20	275 & 1.00	134 & 0.49	125 & 0.13
December 1990							
1	$\bar{X}$ ± SD	2 ± 0.1	4 ± 1.7	3 ± 0.5	8 ± 2.6	6 ± 3.3	3 ± 1.0
	BCFw & BCFs	16 & 0.03	27 & 0.05	40 & 0.05	60 & 0.13	46 & 0.10	25 & 0.06
2	$\bar{X}$ ± SD	2 ± 0.1	3 ± 1.7	7 ± 0.2	10 ± 3.1	2 ± 1.1	3 ± 0.1
	BCFw & BCFs	100 & 0.03	129 & 0.04	350 & 0.18	483 & 0.17	220 & 0.04	165 & 0.06
3	$\bar{X}$ ± SD	2 ± 0.1	5 ± 3.7	8 ± 3.0	8 ± 3.0	6 ± 3.5	5 ± 0.8
	BCFw & BCFs	11 & 0.04	291 & 1.07	43 & 0.16	43 & 0.16	32 & 0.12	26 & 0.09
February 1991							
1	$\bar{X}$ ± SD	2 ± 0.6	3 ± 0.5	4 ± 0.9	12 0.8	5 ± 1.8	5 ± 0.2
	BCFw & BCFs	24 & 0.02	36 & 0.04	51 & 0.05	171 & 0.15	67 & 0.06	75 & 0.07
2	$\bar{X}$ ± SD	2 ± 0.1	4 ± 2.7	5 ± 1.7	14 ± 0.2	4 ± 2.2	4 ± 0.7
	BCFw & BCFs	72 & 0.07	122 & 0.05	152 & 0.15	475 & 0.46	139 & 0.14	140 & 0.14
3	$\bar{X}$ ± SD	3 ± 0.7	1 ± 0.4	6.1	15 ± 5.6	4 ± 0.7	5 ± 2.2
	BCFw BCFs	125 & 0.13	67 & 0.07	300 & 0.6	750 & 0.75	200 & 0.20	259 & 0.26

$\bar{X}$: mean; SD: standard deviation; BCFw: bioconcentration factor (water); BCFs: bioconcentration factor (sediment); [a]: no data available

Table 4

Mean chromium concentrations (µg/g-wet mass) in the selected tissue and bile of Clarias gariepinus *from the Olifants (Localities 2 & 3) and Selati (Locality 1) rivers*

Sampling Locality		Chromium concentration (µg/g wet mass)					
		Muscle	Gonads	Gills	Liver	Bile	Kidneys
February 1990							
1	$\bar{X}$ ± SD	54 ± 1.5	57 ± 2.3	57 ± 1.0	59 ± 0.66	42 ± 1.2	21 ± 2.8
	BCFw & BCFs	271 & 0.61	285 & 0.65	283 & 0.64	293 & 0.7	209 & 0.47	104 & 0.23
2	$\bar{X}$ ± SD	50 ± 0.3	53 ± 2.5	52 ± 1.6	52 ± 0.9	40 ± 6.8	22 ± 3.4
	BCFw & BCFs	199 & 0.13	211 & 0.14	209 & 0.14	208 & 0.14	160 & 0.11	89 & 0.06
3	$\bar{X}$ ± SD	23 ± 0.4	23 ± 1.6	18 ± 0.4	26 ± 0.9	12 ± 8.7	20 ± 2.1
	BCFw & BCFs	58 & 0.22	59 & 0.23	45 & 0.18	66 & 0.26	32 & 0.12	51 & 0.20
April 1990							
1	$\bar{X}$ ± SD	53 ± 6.0	56 ± 5.7	41 ± 3.4	36 ± 10.7	40 ± 3.8	45 ± 3.7
	BCFw & BCFs	232 & 0.34	242 & 0.36	176 & 0.25	158 & 0.23	175 & 0.26	198 & 0.29
2	$\bar{X}$ ± SD	23 ± 5.2	25 ± 6.4	34 ± 2.1	21 ± 4.5	37 ± 4.5	40 ± 2.7
	BCFw & BCFs	114 & 0.22	123 & 0.25	170 & 0.34	106 & 0.21	147 & 0.37	161 & 0.40
3	$\bar{X}$ ± SD	20	17	27	17	30	31
	BCFw & BCFs	90 & 0.05	76 & 0.04	121 & 0.07	76 & 0.04	136 & 0.08	141 & 0.08
June 1990							
1	$\bar{X}$ ± SD	28 ± 1.3	25 ± 2.3	26 ± 0.6	24 ± 5.1	36 ± 3.9	19 ± 3.6
	BCFw & BCFs	34 & 0.19	30 & 0.18	33 & 0.18	30 & 0.16	45 & 0.25	22 & 0.13
2	$\bar{X}$ ± SD	26 ± 7.8	46 ± 1.4	31 ± 5.5	32 ± 0.9	21 ± 4.1	46 ± 8.8
	BCFw & BCFs	37 & 0.03	63 & 0.50	44 & 0.03	44 & 0.04	29 & 0.02	65 & 0.06
3	$\bar{X}$ ± SD	23 ± 3.7	33 ± 5.7	36 ± 3.5	33 ± 5.7	14 ± 2.0	29 ± 0.3
	BCFw & BCFs	43 & 0.13	62 & 0.19	68 &0.21	63 & 0.20	27 & 0.08	54 & 0.17
August 1990							
1	$\bar{X}$ ± SD	a	a	a	a	a	a
	BCFw & BCFs	a	a	a	a	a	a
2	$\bar{X}$ ± SD	21 ± 8.6	22 ± 3.2	40 ± 2.1	45 ± 2.6	33 ± 3.3	32 ± 4.2
	BCFw & BCFs	31 & 0.12	33 & 0.13	59 & 0.23	25 & 0.3	19 & 0.1	18 & 0.1
3	$\bar{X}$ ± SD	20 ± 2.6	23 ± 7.5	34 ± 7.6	39 ± 2.0	20 ± 1.9	29 ± 2.7
	BCFw & BCFs	32 & 0.22	37 & 0.25	54 & 0.36	42 & 0.2	22 & 0.02	31 & 0.2
October 1990							
1	$\bar{X}$ ± SD	27 ± 2.4	28 ± 3.2	34 ± 9.1	36 ± 4.2	18 ± 4.4	27 ± 3.7
	BCFw & BCFs	43 & 0.22	45 & 0.23	55 & 0.29	58 & 0.30	30 & 0.16	43 & 0.22
2	$\bar{X}$ ± SD	35 ± 12.2	19 ± 5.5	33 ± 3.2	40 ± 6.2	13 ± 1.3	30 ± 4.1
	BCFw & BCFs	97 & 0.42	51 & 0.23	93 & 0.41	110 & 0.49	37 & 0.16	83 & 0.37
3	$\bar{X}$ ± SD	24 ± 1.8	24 ± 2.5	28 ± 2.0	32 ± 4.4	14 ± 2.8	28 ± 2.0
	BCFw & BCFs	29 & 0.44	30 & 0.45	35 & 0.52	40 & 0.60	17 & 0.26	35 & 0.52
December 1990							
1	$\bar{X}$ ± SD	10 ± 4.6	49 ± 6.6	28 ± 8.1	24 ± 1.0	14 ± 5.1	27 ± 5.9
	BCFw & BCFs	17 & 0.08	82 & 0.37	47 & 0.22	40 & 0.18	24 & 0.11	45 & 0.21
2	$\bar{X}$ ± SD	7 3.4	50 ± 2.5	29 ± 6.7	26 ± 3.0	17 ± 3.1	28 ± 8.8
	BCFw & BCFs	29 & 0.08	200 & 0.54	117 & 0.32	105 & 0.28	67 & 0.18	111 & 0.30
3	$\bar{X}$ ± SD	14 ± 1.4	41 ± 3.7	21 ± 4.2	21 ± 3.9	19 ± 3.2	21.0 ± 4.2
	BCFw & BCFs	12 & 0.24	37 & 0.71	19 & 0.36	19 & 0.37	17 & 0.34	19 & 0.36
February 1991							
1	$\bar{X}$ ± SD	27 ± 2.0	28 ± 3.9	33 ± 2.5	39 ± 6.9	17 ± 9.5	24 ± 2
	BCFw & BCFs	160 & 0.39	166 & 0.40	195 & 0.67	228 & 0.58	97 & 0.24	138 & 0.34
2	$\bar{X}$ ± SD	24 ± 3.9	30 ± 2.6	39 ± 6.0	35 ± 1.6	20 ± 3.2	23 ± 4.1
	BCFw & BCFs	134 & 0.13	167 & 0.17	215 & 0.22	194 & 0.19	110 & 0.11	126 & 0.13
3	$\bar{X}$ ± SD	20 ± 4.2	22 ± 4.3	35 ± 4.7	28 ± 3.0	19 ± 3.4	33 ± 3.3
	BCFw & BCFs	163 & 0.16	182 & 0.18	291 & 0.29	234 & 0.23	157 & 0.16	272 & 0.37

$\bar{X}$: mean; SD: standard deviation; BCFw: bioconcentration factor (water); BCFs: bioconcentration (sediment);[a]: no-data available

Table 5
Mean nickel concentrations (µg/g-wet mass) in the selected tissue and bile of Clarias gariepinus *from the Olifants (Localities 2 & 3) and Selati (Locality 1) rivers*

Sampling Locality	Nickel concentrations (µg/g wet mass)					
	Muscle	Gonads	Gills	Liver	Bile	Kidneys
February 1990						
1 $\bar{X}$ ± SD	26 ± 0.9	23 ± 3.0	28 ± 0.6	30 ± 4.4	10 ± 1.0	4 ± 1.3
BCFw & BCFs	124 & 0.47	108 & 0.42	135 & 0.52	142 & 0.5	48 & 0.18	20 & 0.10
2 $\bar{X}$ ± SD	26 ± 0.2	31 ± 2.4	27 ± 1.5	31 ± 0.7	13 ± 2.1	6 ± 2.4
BCFw & BCFs	135 & 0.15	162 & 0.17	142 & 0.16	162 & 0.18	67 & 0.08	32 & 0.14
3 $\bar{X}$ ± SD	22 ± 0.3	25 ± 0.9	16 ± 2.6	25 ± 3.8	9 ± 2.9	3 ± 0.1
BCFw & BCFs	86 & 0.4	94 & 0.46	63 & 0.30	95 & 0.46	35 & 0.18	12 & 0.07
April 1990						
1 $\bar{X}$ ± SD	10 ± 3.6	5 ± 4.4	15 ± 1.5	5 ± 2.2	7 ± 1.0	7 ± 1.5
BCFw & BCFs	44 & 0.09	22 & 0.04	23 & 0.05	23 & 0.12	31 & 0.16	30 & 0.16
2 $\bar{X}$ ± SD	14 ± 0.5	6 ± 1.0	6 ± 4.2	14 ± 2.7	13 ± 2.5	5 ± 2.0
BCFw & BCFs	62 & 0.10	27 & 0.04	26 & 0.04	61 & 0.09	54 & 0.08	22 & 0.12
3 $\bar{X}$ ± SD	12	11	8	10	7	3
BCFw & BCFs	53 & 0.08	47 & 0.07	35 & 0.06	44 & 0.07	30 & 0.03	14 & 0.07
June 1990						
1 $\bar{X}$ ± SD	7 ± 0.7	19 ± 1.0	10 ± 2.1	17 ± 2.4	12 ± 2.8	15 ± 1.4
BCFw & BCFs	12 & 0.09	33 & 0.25	17 & 0.13	30 & 0.22	21 & 0.16	26 & 0.18
2 $\bar{X}$ ± SD	14 ± 5.1	19 ± 1.7	15 ± 2.8	15 ± 5.6	10 ± 1.8	19 ± 2.5
BCFw & BCFs	33 & 1.41	42 & 0.19	36 & 0.15	36 & 0.15	26 & 0.11	46 & 0.19
3 $\bar{X}$ ± SD	13 ± 2.2	18 ± 2.1	10 ± 4.9	12 ± 9.2	14 ± 0.1	15 ± 2.0
BCFw & BCFs	38 & 0.14	54 & 0.20	30 & 0.11	36 & 0.13	42 & 0.16	45 & 0.16
August 1990						
1 $\bar{X}$ ± SD	a	a	a	a	a	a
BCFw & BCFs	a	a	a	a	a	a
2 $\bar{X}$ ± SD	11 ± 1.7	14 ± 1.4	19 ± 2.9	23 ± 4.1	13 ± 8.8	16 ± 4.7
BCFw & BCFs	60 & 0.12	74 & 0.15	99 & 0.20	122 & 0.24	70 & 0.14	82 & 0.16
3 $\bar{X}$ ± SD	14 ± 3.5	15 ± 4.2	15 ± 4.2	12 ± 5.1	16 ± 3.1	14 ± 2.8
BCFw & BCFs	86 & 0.20	94 & 0.21	91 & 0.20	89 & 0.18	97 & 0.22	90 & 0.20
October 1990						
1 $\bar{X}$ ± SD	17 ± 1.3	17 ± 0.4	19 ± 3.3	17 ± 1.4	18 ± 0.8	16 ± 2.6
BCFw & BCFs	109 & 0.29	108 & 0.29	118 & 0.31	106 & 0.28	113 & 0.30	100 & 0.27
2 $\bar{X}$ ± SD	8 ± 2.0	8 ± 2.5	11 ± 1.2	9 ± 0.9	8 ± 2.4	14 ± 1.2
BCFw & BCFs	46 & 0.21	46 & 0.21	62 & 0.29	52 & 0.2	42 & 0.20	78 & 0.35
3 $\bar{X}$ ± SD	11 ± 1.1	11 ± 2.6	17 ± 2.8	11 ± 2.2	13 ± 3.2	17 ± 3.1
BCFw & BCFs	63 & 0.37	67 & 0.39	98 & 0.57	67 & 0.39	73 & 0.43	100 & 0.60
December 1990						
1 $\bar{X}$ ± SD	14 ± 1.0	22 ± 1.1	18 ± 1.8	14 ± 0.9	21 ± 2.2	17 ± 1.3
BCFw & BCFs	29 & 0.05	45 & 0.07	36 & 0.06	29 & 0.05	42 & 0.07	34 & 0.06
2 $\bar{X}$ ± SD	12 ± 4.3	24 ± 5.9	26 ± 5.6	30 ± 3.0	33 ± 3.2	12 ± 2.5
BCFw & BCFs	94 & 0.03	224 & 0.07	200 & 0.07	234 & 0.09	250 & 0.08	92 & 0.03
3 $\bar{X}$ ± SD	16 ± 1.1	21 ± 4.8	21 ± 2.9	14 ± 3.2	15 ± 3.3	11 ± 1.2
BCFw & BCFs	24 & 0.27	30 & 0.33	30 & 0.33	21 & 0.23	21 & 0.23	16 & 0.17
February 1990						
1 $\bar{X}$ ± SD	14 ± 1.7	17 ± 1.0	20 ± 1.4	28 ± 2.2	17 ± 2.3	8 ± 3.3
BCFw & BCFs	116 & 0.12	143 & 0.14	164 & 0.08	234 & 0.23	142 & 0.14	65 & 0.07
2 $\bar{X}$ ± SD	13 ± 2.4	10 ± 2.1	13 ± 1.8	27 ± 4.2	14 ± 3.7	14 ± 4.2
BCFw & BCFs	110 & 0.11	83 & 0.08	109 & 0.11	226 & 0.23	117 & 0.12	118 & 0.12
3 $\bar{X}$ ± SD	17 ± 1.0	12 ± 1.0	17 ± 2.2	30 ± 1.8	13 ± 3.9	17 ± 2.9
BCFw & BCFs	214 & 0.21	151 & 0.15	214 & 0.21	375 & 0.38	116 & 0.17	209 & 0.12

$\bar{X}$: mean; SD: standard deviation; BCFw: bioconcentration factor (water); BCFs: bioconcentration factor (sediment); [a]: data available.

Table 6

Mean lead concentrations (µg/g-wet mass) in the selected tissue and bile of Clarias gariepinus *from the Olifants (Localities 2 & 3) and Selati (Locality 1) rivers*

Sampling locality	Lead concentration (µg/g wet mass)					
	Muscle	Gonads	Gills	Liver	Bile	Kidneys
February 1990						
1 $\bar{X}$ ± SD	40 ± 1.3	41 ± 4.3	44 ± 2.4	43 ± 2.4	30 ± 6.8	15 ± 2.1
BCFw & BCFs	92 & 1.84	95 & 1.9	101 & 2.00	100 & 2.00	70 & 1.40	34 & 0.68
2 $\bar{X}$ ± SD	43 ± 2.8	39 ± 7.5	47 ± 3.9	43 ± 2.8	26 ± 6.2	16 ± 2.7
BCFw & BCFs	102 & 2.06	94 & 1.87	113 & 2.26	101 & 2.03	62 & 1.25	39 & 0.77
3 $\bar{X}$ ± SD	33 ± 2.4	33 ± 2.7	26 ± 2.5	23 ± 3.2	41 ± 2.1	16 & 1.7
BCFw & BCFs	62 & 1.05	61 & 1.04	49 & 0.82	43 & 0.72	77 & 1.27	30 & 0.51
April 1990						
1 $\bar{X}$ ± SD	43 ± 4.2	50 ± 3.1	67 ± 4.7	49 ± 19.0	52 ± 4.0	17 ± 1.3
BCFw & BCFs	186 & 0.68	218 & 0.80	290 & 1.06	215 & 0.79	228 & 2.39	72 & 2.66
2 $\bar{X}$ ± SD	38 ± 4.9	68 ± 27.8	101 ± 8.5	62 ± 13.4	40 ± 6.60	17 ± 1.4
BCFw & BCFs	223 & 0.83	400 & 1.47	481 & 2.19	366 & 1.35	96 & 2.77	99 & 3.64
3 $\bar{X}$ ± SD	32	40	58	32	33	15
BCFw & BCFs	171 & 0.89	211 & 1.05	299 & 1.49	167 & 0.83	172 & 2.61	80 & 4.00
June 1990						
1 $\bar{X}$ ± SD	28 ± 5.0	30 ± 4.1	31 ± 2.0	32 ± 4.6	33 ± 2.03	15 ± 1.3
BCFw & BCFs	40 & 0.77	36 & 0.83	37 & 0.85	38 & 0.89	39 & 0.91	18 & 0.42
2 $\bar{X}$ ± SD	45 ± 6.7	50 ± 3.5	54 ± 3.7	53 ± 3.5	55 ± 4.5	18 ± 1.8
BCFw & BCFs	75 & 1.33	84 & 1.47	89 & 1.57	89 & 1.57	91 & 1.61	30 & 0.52
3 $\bar{X}$ ± SD	23 ± 3.7	31 ± 3.6	30 ± 6.1	32 ± 5.8	26 ± 2.3	17 ± 2.8
BCFw & BCFs	48 & 0.77	65 & 1.04	62 & 0.98	67 & 1.07	53 & 0.86	35 & 0.56
August 1990						
1 $\bar{X}$ ± SD	a	a	a	a	a	a
BCFw & BCFs	a	a	a	a	a	a
2 $\bar{X}$ ± SD	12 ± 1.6	14 ± 2.3	26 ± 6.5	21 ± 2.8	42 ± 4.6	19 ± 2.1
BCFw & BCFs	31 & 0.43	36 & 0.51	68 & 0.95	55 & 0.77	110 & 1.55	50 & 0.71
3 $\bar{X}$ ± SD	21 ± 6.6	20 ± 5.6	43 ± 8.9	15 ± 6.3	30 ± 3.4	17 ± 1.9
BCFw & BCFs	55 & 0.83	51 & 0.8	111 & 1.73	39 & 0.61	77 & 1.21	43 & 0.67
October 1990						
1 $\bar{X}$ ± SD	23 ± 2.8	22 ± 1.2	32 ± 3.5	31 ± 3.2	38 ± 13.6	18 ± 1.8
BCFw & BCFs	73 & 1.22	69 & 1.16	100 & 1.68	96 & 1.62	119 & 2.00	57 & 0.96
2 $\bar{X}$ ± SD	14 ± 3.6	18 ± 3.7	25 ± 2.3	20 ± 1.4	24 ± 6.4	17 ± 2.9
BCFw & BCFs	51 & 0.65	68 & 0.86	91 & 1.17	73 & 0.93	89 & 1.14	60 & 0.88
3 $\bar{X}$ ± SD	16 ± 2.4	20 ± 3.0	28 ± 3.1	27 ± 6.3	26 ± 6.5	18 ± 2.1
BCFw & BCFs	51 & 1.09	54 & 1.30	77 & 1.85	74 & 1.77	101 & 1.76	49 & 1.31
December 1990						
1 $\bar{X}$ ± SD	12 ± 3.1	13 ± 3.5	21 ± 2.9	13 ± 1.6	25 ± 6.7	19 ± 2.1
BCFw & BCFs	267 & 0.46	217 & 0.48	354 & 0.79	213 & 0.47	408 & 0.91	158 & 0.71
2 $\bar{X}$ ± SD	11 ± 2.4	13 ± 1.4	20 ± 1.7	14 ± 2.4	12 ± 4.3	19 ± 3.2
BCFw & BCFs	154 & 0.45	183 & 0.53	285 & 0.83	203 & 0.34	173 & 0.51	267 & 0.78
3 $\bar{X}$ ± SD	8 ± 1.2	16 ± 2.6	20 ± 3.0	13 ± 2.2	14 ± 0.8	14 ± 1.7
BCFw & BCFs	59 & 0.60	125 & 0.45	155 & 0.56	100 & 0.36	104 & 0.37	108 & 0.82
February 1991						
1 $\bar{X}$ ± SD	17 ± 1.2	18 ± 3.1	30 ± 4.1	18 ± 1.3	13 ± 3.5	14 ± 1.4
BCFw & BCFs	113 & 0.11	120 & 0.12	197 & 0.20	118 & 0.12	85 & 0.09	91 & 0.09
2 $\bar{X}$ ± SD	15 ± 2.4	19 ± 2.4	29 ± 4.1	16 ± 2.3	14 ± 4.2	12 ± 0.9
BCFw & BCFs	184 & 0.18	233 & 0.23	362 & 0.36	194 & 0.19	173 & 0.17	154 & 0.15
3 $\bar{X}$ ± SD	13 ± 0.6	19 ± 1.4	29 ± 1.7	16 ± 0.6	12 ± 0.8	13 ± 1.2
BCFw & BCFs	167 & 0.17	238 & 0.24	353 & 0.35	204 & 0.20	151 & 0.15	161 & 0.16

$\bar{X}$: mean; SD: standard deviation; BCFw: bioconcentration factor (water); BCFs: bioconcentration factor (sediment); [a]: data not available

Table 7

Mean manganese concentrations (µg/g-wet mass) in the selected tissue and bile of Clarias gariepinus *from the Olifants(Localities 2 & 3) and Selati (Locality 1) rivers*

Sampling locality		Manganese concentration (µg/g wet mass)					
		Muscle	Gonads	Gills	Livers	Bile	Kidneys
February 1990							
1	X̄ ± SD	2 ± 0.2	3 ± 0.6	7 ± 1.0	3 ± 1.6	5 ± 1.2	7 ± 1.6
	BCFw & BCFs	3 & 0.11	6 & 0.02	14 & 0.05	6 & 0.02	9 & 0.03	13 & 0.02
2	X̄ ± SD	2 ± 0.6	5 ± 2.8	15 ± 2.2	3 ± 1.4	6 ± 1.3	8 ± 1.2
	BCFw & BCFw	72 & 0.43	167 & 0.01	487 & 0.03	111 & 0.67	124 & 0.01	274 & 0.02
3	X̄ ± SD	3 ± 0.7	3 ± 0.8	13 ± 4.2	13 ± 2.5	4 ± 2.1	9 ± 1.8
	BCFw & BCFs	4 & 0.01	4 & 0.01	18 & 6.19	19 & 0.06	6 & 0.02	13 & 0.05
April 1990							
1	X̄ ± SD	8 ± 5.3	6 ± 2.4	11 ± 2.5	6 ± 3.5	3 ± 0.7	8 ± 6.4
	BCFw & BCFs	35 & 0.02	26 & 0.01	49 & 0.03	27 & 0.02	14 & 0.75	36 & 1.97
2	X̄ ± SD	2 ± 0.6	4 ± 0.3	16 ± 2.0	4 ± 3.1	3 ± 0.7	7 ± 3.1
	BCFw & BCFs	10 & 0.01	18 & 0.01	81 & 0.05	22 & 0.02	16 & 0.74	34 & 1.94
3	X̄ ± SD	6	6	14	5	2	7
	BCFw & BCFs	28 & 0.01	30 & 0.01	64 & 0.03	21 & 0.84	11 & 0.44	30 & 1.12
June 1990							
1	X̄ ± SD	6 ± 3.1	5 ± 2.3	9 ± 5.2	8 ± 3.3	10 ± 4.2	7 ± 0.9
	BCFw & BCFs	37 & 0.01	31 & 0.01	58 & 0.02	56 & 0.02	67 & 0.02	49 & 0.02
2	X̄ ± SD	4 ± 2.2	9 ± 1.5	11 ± 8.7	6 ± 0.8	12 ± 1.5	9 ± 2.5
	BCFw & BCFs	100 & 0.95	214 & 0.02	264 & 0.03	159 & 0.02	293 & 0.03	222 & 0.02
3	X̄ ± SD	3 ± 1.4	8 ± 2.7	13 ± 7.4	5 ± 0.6	8 ± 2.3	7 ± 2.9
	BCFw & BCFs	42 & 0.83	134 & 0.03	220 & 0.45	87 & 0.02	129 & 0.03	108 & 0.02
August 1990							
1	X̄ ± SD	a	a	a	a	a	a
	BCFw & BCFs	a	a	a	a	a	a
2	X̄ ± SD	3 ± 2.03	11 ± 2.3	11 ± 2.2	3 ± 1.3	13 ± 2.1	11 ± 2.2
	BCFw & BCFs	93 & 0.07	359 & 0.03	377 & 0.03	113 & 0.01	433 & 0.03	355 & 0.03
3	X̄ ± SD	4 ± 1.6	12 ± 8.9	13 ± 6.6	6 ± 1.1	15 ± 2.2	11 ± 4.5
	BCFw & BCFs	205 & 0.02	578 & 0.04	660 & 0.05	322 & 0.03	736 & 0.06	561 & 0.04
October 1990							
1	X̄ ± SD	6 ± 0.5	6 ± 1.8	16 ± 6.1	5 ± 1.1	5 ± 0.8	4 ± 1.3
	BCFw & BCFs	62 & 0.04	69 & 0.04	182 & 0.11	58 & 0.05	56 & 0.04	46 & 0.03
2	X̄ ± SD	8 ± 3.5	10 ± 1.9	20 ± 4.4	12 ± 0.8	10 ± 4.5	9 ± 2.7
	BCFw & BCFs	420 & 0.07	500 & 0.09	999 & 0.18	600 & 0.11	500 & 0.1	436 & 0.08
3	X̄ ± SD	2 ± 0.7	11 ± 4.0	11 ± 2.7	4 ± 1.3	1 ± 0.5	6 ± 1.4
	BCFw & BCFs	8 & 0.02	57 & 0.10	55 & 0.10	21 & 0.04	2 & 0.01	30 & 0.06
December 1990							
1	X̄ ± SD	9 ± 0.5	13 ± 2.3	20 ± 2.5	18 ± 7.4	9 ± 0.5	10 ± 1.6
	BCFw & BCFs	116 & 0.02	156 & 0.02	250 & 0.04	225 & 0.03	103 & 0.02	121 & 0.02
2	X̄ ± SD	5 ± 0.9	12 ± 6.7	12 ± 1.0	7 ± 1.0	4 ± 1.3	9 ± 2.9
	BCFw & BCFs	35 & 0.01	89 & 0.02	83 & 0.02	48 & 0.01	31 & 0.01	66 & 0.02
3	X̄ ± SD	4 ± 1.7	6 ± 1.2	15 ± 2.1	2 ± 0.5	7 ± 0.9	4 ± 0.4
	BCFw & BCFs	1 & 0.02	2 & 0.01	4 & 0.03	1 & 0.01	2 & 0.01	1 & 0.01
February 1991							
1	X̄ ± SD	4 ± 0.7	20 ± 3.8	4 ± 1.8	3 ± 0.5	3 ± 1.8	3 ± 3.4
	BCFw & BCFs	16 & 0.02	83 & 0.08	17 & 0.02	13 & 0.01	13 & 0.01	13 & 0.01
2	X̄ ± SD	3 ± 1.2	24 ± 4.2	4 ± 3.3	4 ± 1.5	5 ± 1.8	4 ± 1.2
	BCFw & BCFs	38 & 0.04	300 & 0.03	47 & 0.05	50 & 0.05	63 & 1.8	46 & 0.05
3	X̄ ± SD	1 ± 0.3	5 ± 2.4	4 ± 1.5	2 ± 0.8	2 ± 0.7	3 ± 0.2
	BCFw & BCFs	135 & 0.02	500 & 0.05	367 & 0.04	246 & 0.03	241 & 0.05	311 & 0.03

X̄: mean; SD: standard deviation; BCFw: bioconcentration factor (water); BCFs: bioconcentration factor (sediment); [a]: data not available

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