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Bioaccumulation of Lead in Wildlife Dependent on the Contaminated Environment of the Kafue Flats

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The Kafue flats cover an area of approximately 154,000 km^2 in the southern province of Zambia and are supplied by the Kafue river, the largest and longest inland river in the country. The river constitutes an important water reservoir which is used for many purposes including drinking water for humans, livestock and wildlife, irrigation systems and production of hydroelectric power. The river is a major tributary of the Zambezi river and drains through Zambia's Copperbelt mining area. This results in the transportation of both metals and pesticides from point sources to ecologically important and protected areas i.e. the Kafue National Park, Lake Itezhi-tezhi, Kafue flats and finally into the Zambezi river (figure 1).

The concentrations of heavy metal pollutants in the Kafue river water upstream were reported to be very high compared to the Average World River (Norrgren et al., 1999). Lead is one of these heavy metal contaminants and mining activity in the Copperbelt mining area of Zambia has been singled out as the main source of these pollutants. However, another major source of lead contamination which has largely remained unmentioned is commercial hunting in the Kafue flats and more specifically the Lochnivar and Blue Lagoon National Parks. Every year hundreds of wild animals are sold under licensed hunting by the Zambia Wildlife Authority. The scheme is done to control the population of wildlife as well as realize money for the local communities as a way of empowerment and motivation to conserve wildlife (Tembo 1995). Despite this positive aspect to the community, the scheme has its own disadvantages. The major one being that during each hunting season a lot of lead shots are discharged into the environment. These pellets accumulate in the environment and the lead finds its way into wildlife where its effects are largely undocumented. In other countries, contamination and poisoning of wild fowl, freshwater fish and small mammals in polluted areas is well documented (White and Stendell 1977; Hall and Fischer 1985; Roscoe et al. 1989; Pascoe et al. 1994)). The main route of exposure of wild animals to heavy metals in a contaminated environment is through consumption of food.

Among wild mammals, the Kafue lechwe (*kobus leche kafuensis*), is the most abundant species in the flats and is closely linked to livestock in its economical

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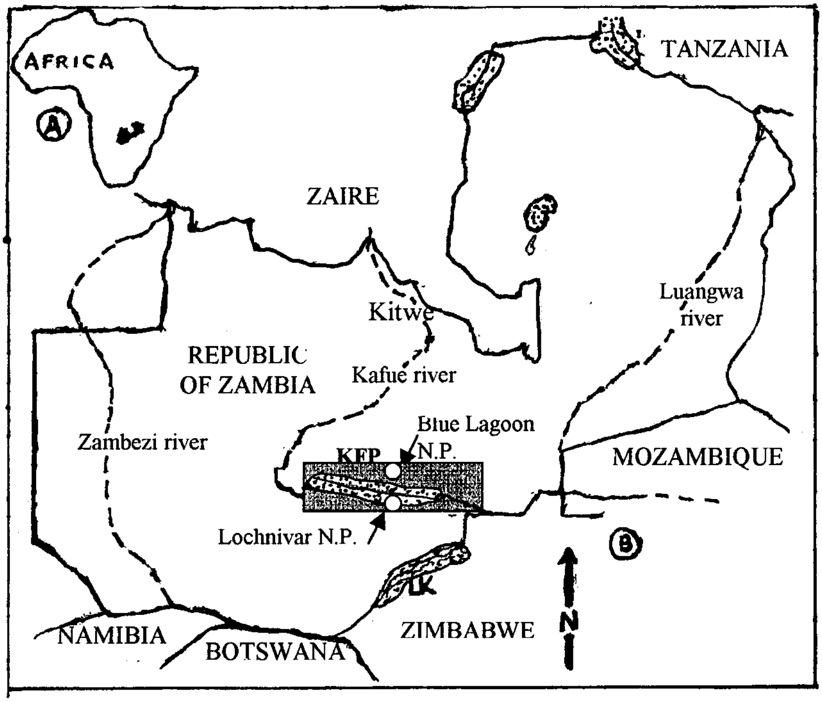

Figure 1 A simplified geographical map of Zambia showing the course of the Kafue river from the Copperbelt mining area of Kitwe through the Kafue flood pains (KFP), which was the study area (shaded box), down into Zambezi river. Sampling sites were the Blue Lagoon N.P and Lochnivar N.P. shown as circles.

and traditional importance to local peasant communities. Furthermore, the lechwe and livestock in the area share grazing and drinking areas and thus are likely to suffer similar adverse effects (Suzuki et al. 1995). Therefore, studies on the organ metal loads in the lechwe may also serve as indicators of levels in livestock. The data may also provide useful information on the biological availability of lead that can be used for hazard assessment.

The above approach to hazard assessment is used in this study because lead poisoning has not been documented in the area. A lot of pathological conditions attributed to mining activity upstream such as reproductive abnormalities, granulomas and even cattle deaths have however, been reported along the Kafue river without incriminating a single heavy metal *per se* (Mwase et al. 1994; Mwase et al. 1998; ZCCM 1982). It is therefore the intention of this paper to carry out a preliminary survey of the levels of lead in water, grasses and lechwe liver samples in order to assess exposure and the likely risks.

MATERIALS AND METHODS

Water was collected at drinking sites, especially areas where there is mingling of livestock and wildlife. Most animals move a few meters from the edge and drink water on the surface of the water. Samples were thus collected in the same manner. The water was stored in polythene bags and refrigerated at -20 °C until analysis.

Commonly grazed grass (*Echinochloa spp.*) at Lochnivar and Blue Lagoon, were sampled. Any mention of grass hereafter refers to the above species. Lechwe and cattle have similar grazing habits. They maw grass on the surface but may uproot a few. This mode was used when sampling to ensure representative samples were collected. Grass was not washed to remove soil in order to emulate the grazing habits and subsequent exposure of the Kafue lechwe. The grass was then stored in polythene bags and refrigerated at -20 °C until processing.

Three common fish species were sampled. These included: *Tilapia rendalli*, *Clarias gariepinus* and *Brycinus lateralis*. They were collected from fish camps near the sampling sites. The fish of each species were pooled. The fish were not distinguished as having been collected from Lochnivar or Blue Lagoon because these are just north and south banks of the same river and as such they mingle during feeding. The fish were also refrigerated at -20 °C pending analysis.

Lechwe, which are the commonest mammalian wildlife species in the area were targeted. Twelve male lechwe (the only sex allowed by government under commercial hunting legislation) were hunted in game management areas. Twelve liver specimens were sampled, packed in polythene bags and stored in a refrigerator at -20 °C until processing.

Processing and analyses were done as follows: Plant, fish and animal specimens were put in an oven at 120 °C overnight. The resultant dry matter was minced to powder and oven dried to remove all moisture at 70 °C for 4 hours and then cooled in a silica dessicator. One gram of this powder was added to 10 mL concentrated nitric acid and digested on a hot plate at approximately 250 °C until all organic matter had been dissolved. It was then cooled and then mixed with 10 mL of distilled water followed by 10 mL of perchloric acid added. The resultant fluid was again put on a hot plate and digested until the solution was clear or when white fumes emerged. It was further cooled and 24 mL of water added then brought to boil. It was again cooled and the solution made up to 100 mL with distilled water then used for the flame atomic absorption spectrophotometry (Perkin Elmer 2380). The measurements were made against standards over a suitable range after diluting each in dilute nitric acid (1:10). The solutions were read in mg/L of each element and translated into parts per million (ppm).

No digestion was necessary for water. Water was directly taken for atomic absorption spectrophotometry and measured in ppm.

RESULTS AND DISCUSSION

The pooled averages for water samples collected at Lochnivar and Blue Lagoon National Parks were 0.29±3.0 and 0.36±1.0 ppm of Pb, respectively. The pH of water at Lochnivar and Blue Lagoon was 6.8 and 6.95 at 27.2 ^{0}C, respectively. The most commonly grazed grass at Lochnivar had a pooled average of 26.0±1.0 ppm dry weight of Pb and the commonly grazed grass at Blue Lagoon had a concentration of 48.0±2.5 ppm of Pb dry weight. The three fish types namely: *Tilapia rendalli, Clarias gariepinus* and *Brycinus lateralis* had whole body pooled lead concentrations of 28.0±1.0, 23.0±3.0 and 33.0±2.5 ppm dry weight lead, respectively. The mean concentrations of lead in lechwe liver samples from Lochnivar and Blue lagoon were 18.3±5.8 and 16.2 ±2.3 ppm of Pb dry weight, respectively. The results are summarized in table 1.

Table 1. Lead concentrations in water, fish, grasses and Kafue lechwe liver samples taken from Lochnivar and Blue Lagoon National parks

Sample	Sample size	Lead (Pb)
Liver-L (ppm)	6	7.0-19.0
mean±SEM		18.3 ± 5.8
Liver-BL (ppm)	6	9.0-25.0
mean±SEM		16.2±2.3
Grass-BL (ppm)	1*	48.0±2.5
Grass-L (ppm)	1*	26.0±1.0
Fish-CG (ppm)	1*	23.0±3.0
Fish-TR (ppm)	1*	28.0±1.0
Fish-BL (ppm)	1*	33.0±2.5
Water-L (ppm)	1*	0.29±3.0
Water-BL (ppm)	1*	0.36±1.0

Liver-L: lechwe liver samples from Lochnivar, Liver-BL: lechwe liver samples from Blue Lagoon, Grass-L: grass from Lochnivar, Grass-BL: grass from Blue Lagoon, Fish-CG: *Clarias gariepinus*, Fish-TR: *Tilapia rendalli*, Fish-BL:

Brycinus lateralis, Water-L: water from Lochnivar, Water-BL: water from Blue Lagoon, 1*: pooled samples analyzed in duplicate.

The normal food web in the Kafue river is shown in figure 2. Some of the Pb from mining activity and spent lead shots pollutes the water and is suspended while the rest remains in the sediments. Lower organisms in the food chain, such as plants (algae, plankton, etc.) and fish, get exposed to the lead in

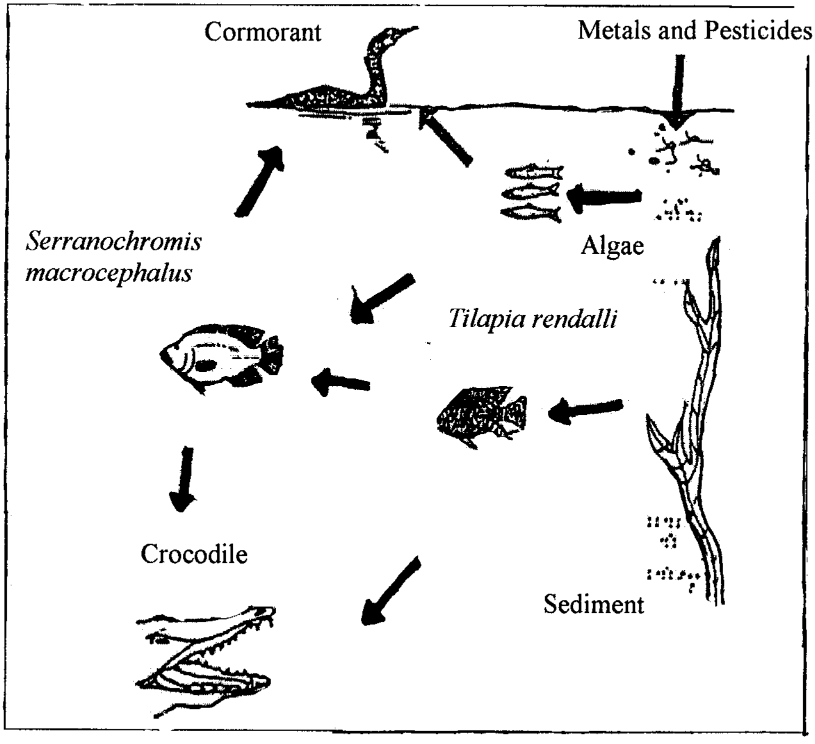

Figure 2. The typical food web in the Kafue river water. Terrestrial herbivores (which are mainly higher trophic levels) are not shown.

suspension or in the sediment. Uptake by plants is mainly via the sediment, especially during flooding when the whole grazing area is in water. Uptake by plants is important for making the metal bioavailable as it bioaccumulates. On the other hand, fish take up the metals mainly via their food but gills and skin are known to be routes of entry of metals directly from water (Coombs 1979; Renfro et al 1975). Higher levels of the food chain like herbivores then get their metals from plants and water while carnivores are exposed via their prey and water. Water is a common medium of exposure at all levels of the food chain. Crocodiles and cormorants, which are prominent components of the food web, were not sampled because of strict government regulations restricting their slaughter, as their populations are very limited.

The average water Pb levels in this study of 0.29 and 0.36 ppm for Lochnivar and Blue Lagoon, respectively were higher than 0.01 ppm recommended under the WHO guidelines for drinking water. The WHO recommended value is meant for humans and no report was available for water meant for wildlife. It is therefore not known if such a value exists and whether the value for humans can be adopted as a standard in this case. If that were to be done then the levels in the study are high and would be regarded detrimental to wildlife. However, Butcher (1996) reported that lead levels of 1.0 ppm in water can cause acute toxicity in ornamental fish while levels lower than this have potential for subclinical adverse effects. Compared to that of our study, this level is much higher for acute clinical disease but able to result in chronic toxicity, since lead has great potential for bioaccumulation. It is therefore possible that subclinical disease is widespread in the area although not clearly documented in relation to Pb. The Pb levels in the sediment were not analyzed in this particular study but in an earlier report by one of our co-authors (Mwase et al. 1998), levels of all heavy metals in the sediment of the Kafue river were abnormally high. Those findings are used in this report for any reference to levels in the sediment.

As earlier stated, plants take up lead from the sediment and soil and this is then available to animals that graze on them. Lead ingested by animals from plants includes the one absorbed by the plants and that adsorbed on the surface of the plant in form of dust, sediment, or contaminating soil. The grass in this study was not washed prior to analysis and was thus contaminated with soil particles. This was done in order to emulate the feeding habits of the lechwe. Therefore, the levels of 26.0 ppm and 48.0 ppm at Lochnivar and Blue Lagoon, respectively, represent lead in and on the plant as consumed by the animals. The daily lead intake from plants will thus depend on the total amount of grass consumed. The amount absorbed in the animal has been reported to be only 2% of the total ingested (Humphreys 1988).

In this study, whole fish were analyzed and each fish species was pooled before processing and analysis. No distinction was made between fish of the same species from different sampling sites because normally fishing is done throughout the river regardless of location of fishing camp. With lead levels in water of about 0.29-0.36 ppm and the ability of lead to bioaccumulate, the fish tissue levels ranging from 23.0-33.0 ppm reported in our study seem rather high and are likely a consequence of chronic exposure. This is a further indication of the likely existence of subclinical and clinical effects in these fish. An earlier study by Mwase et al (1994) has reported various abnormalities in fish in the river that are related to pollution with heavy metals. Although the main focus of the study was zinc and cobalt, other heavy metals such as Pb were found to be high indicating a possible role in these abnormalities. Possible interactions between metals may be responsible for the masked adverse effects but the potential for serious side effects should always be borne in mind especially in view of likely changes in the ecosystem.

The Kafue lechwe is the most economically important wildlife species of the Kafue flats. Any adverse effects resulting from heavy metal contamination would therefore have serious social repercussions. The liver was analyzed because lead is known to accumulate mainly in the liver and kidney but also to a lesser extent in other tissues such as lung, spleen, brain, heart, teeth and hair (Humphreys 1988). The lead levels in animals, which have not been exposed to harmful quantities of Pb, have been said to be less than 0.1 ppm in general (Humphreys 1988). In cattle the maximum normal concentration of lead in the liver before adverse effects are observed has been put at 1.6 ppm. However, clinical signs of toxicity are only observed when levels reach 18.9 - 23.2 ppm in the liver of cattle (Humphreys 1988). In this study, liver Pb levels ranged from 7.0 - 46.0 ppm, the average being 17.3 ppm dry matter. The Kafue lechwe's susceptibility to lead toxicity is not documented but if it is similar to that of cattle the results were generally below the levels known to cause acute clinical signs of toxicity but above the maximum acceptable levels. Because levels were higher than the maximum acceptable liver levels, it is expected that subclinical adverse effects associated with lead toxicity exist in these animals. This can only be substantiated by a controlled study that relates toxicity signs to lead.

In conclusion, wildlife dependent on the Kafue flats are exposed to Pb levels that have the potential of accumulating thus causing adverse effects. In particular the fish species and Kafue lechwe have declined over the years and uncontrolled fishing and poaching have been singled out as the main causes for this decline (Mwima 1995). However, the contribution of other factors especially the role of heavy metal pollutants like lead has rarely been considered. With the continuos pollution of the Kafue flats by mining waste and spent lead shots the role of these pollutants is likely to increase and as such generation of data that can help in monitoring and prevention of adverse effects should be made a priority. Furthermore, since humans, livestock and wildlife co-exist in the Kafue flats data generated to highlight pollution will have an impact on public health and economic strategies.

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REFERENCES

Butcher RL (1996) Manual of Ornamental Fish, 2nd Edition, British Small Animal Veterinary Association, Gloucestershire, pp. 103-105

Coombs TL (1979) Cadmium in aquatic organisms. In: Webb M (ed.) The chemistry, Biochemistry and Biology of Cadmium, Elsevier, Amsterdam, pp. 93-139

Hall SL, Fischer FM (1985) Heavy metal contamination of duck tissue in relation to ingestion of spent shot. Bull Environ Contam Toxicol 35: 163-172

Humphreys DJ (1988) Veterinary toxicology, 3rd Edition, Bailliere Tindall, London, pp. 49-58

Mwase M (1994) Biological impact of anthropogenic emissions on tropical fish living in the Kafue river, Zambia; with special reference to metals and pesticides. Masters thesis Uppsala ISBN 91-576-4925-1

Mwase M, Vicktor T, Norrgren L (1998) Effects on tropical fish of soil sediment from Kafue River, Zambia. Bull Environ Contam Toxicol 61:96-101

Mwima HK (1995) Wildlife research and management in Zambia with special reference to some protected areas where wild and domestic animals co-exist. Proceeding of the symposium "The effects of enlargement of domestic animal pasture on the wildlife in Zambia". Lusaka. Zambia, pp. 41-64

Norrgren L, Pettersson UT, Orns S, Bergqvist PA (2000) Environmental monitoring of the Kafue River, Zambia, using caged threespot Tilapia (*oreochromis andersonii*). Arch Environ Contam Toxicol 38: 334-341

Pascoe GA, Blanchet RJ, Linder G (1994) Bioavaliability of Metals and Arsenic to small mammals at a mining waste-contaminated wetland. Arch Environ Contam Toxicol 27: 44-50

Renfro WC, Fowler SW, Heyraud M, La Rosa J (1975) Relative importance of food and water in long-term zinc 65 accumulation by marine biota. J Fish Res Board Canada 32: 1339-1345

Roscoe DE, Widjeskog L, Stansley W (1989) Lead poisoning of northern pintail ducks feeding in a tidal meadow contaminated with shot from a trap and skeet range. Bull Environ Contam Toxicol 42: 226-233

Suzuki AK, Pandey GS, Takahashi S (1995) Contact between domestic and wildlife using computer imaging analysis in Lochnivar National Park in Zambia. Proceeding of the symposium "The effects of enlargement of domestic animal pasture on the wildlife in Zambia". Lusaka. Zambia, pp. 35- 40

Tembo A (1995) Wetlands conservation and management in Zambia. Proceedings of the symposium "The effects of enlargement of domestic animal pasture on the wildlife in Zambia". Lusaka. Zambia, pp. 65-74

White DH, Stendell RC (1977) Waterfowl exposure to lead and steel shot on selected hunting areas. J Wildl Manage 41: 469-475

ZCCM (Zambia Consolidated Copper Mines) (1983) A review of factors relevant to the reported incidence of cattle losses on farms bordering the Mwembeshi River. Minin Industry Technical Services. Pollution Control Department. MITS/PA/30/82