Metal concentrations in liver, kidney, bone and blood of three species of birds from a metal-polluted wetland

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Abstract

The concentrations of cadmium, copper, nickel and lead in the liver, kidney, bone and blood of the herbivorous Redknobbed Coot *Fulica cristata*, the piscivorous Reed Cormorant *Phalacrocorax africanus* and the omnivorous Sacred Ibis *Threskiornis aethiopicus* were determined. Specimens were collected from the Natalspruit wetland. This wetland area is polluted by these metals. The tissues were analysed for their metal contents and were processed according to standard analytical procedures. Cadmium levels were lowest in the four tissues analysed of all three species. Highest cadmium occurred in the kidneys of the ibis (3.4 µg/g), the bone of the coot (5.1 µg/g) and the blood of the cormorant (4.7 µg/g). Copper (27 to 33 µg/g) was highest in the liver whilst nickel (11 to 36 µg/g) and lead (32 to 59 µg/g) occurred in the highest concentrations in the bone of all three bird species. Reed Cormorants generally exhibited the highest bone lead concentrations (59.0 µg/g). A high degree of variability in tissue metal concentrations was found among all three species. Except for liver, significant differences ($p<0.05$) were recorded for the four metals in all the other tissues of the three species. The research showed that these three bird species were able to accumulate these metals at abnormal concentrations with no apparent chronic or negative effect on their survival. In this context these birds therefore comply with one of the main criteria required for their potential as indicator organisms of metal pollution in the aquatic environment.

Introduction

The eastern half of Johannesburg, commonly known as the East Rand, is the most highly developed industrial region on the Witwatersrand and probably in South Africa. It is drained by tributaries of the Elsburgspruit, Natalspruit and Blesbokspruit river systems, among others, and these systems also include extensive natural wetlands. More than 1 800 industries, ranging from large chemical industries to small one-man engineering firms, occur in this area (Viljoen et al., 1985). The bulk of the water flowing in most of these streams consists of effluents and seepage waters originating from old mines, slimes dams, ash heaps, industries, sewage purification works, suburban areas and agricultural practices. Such effluents comprise the major sources of a variety of pollutants, including dissolved metals (Viljoen et al., 1985; Jones et al., 1989; Schoonbee and Van der Merwe, 1989). These metal-containing effluents possess the potential to constitute serious hazards to the aquatic flora and fauna, including birds, when these wastes are released into river and wetland ecosystems (White and Kaiser, 1976; Kempf and Sittler, 1977; Bull et al., 1983). Of particular interest are the low breeding success and deformed chicks of various aquatic birds from the Kesterson National Wildlife Refuge (USA), which is seriously polluted by selenium- and boron-containing irrigation drainage waters (Ohlendorf et al., 1986; Hothem and Ohlendorf, 1989).

The wetlands occurring on the Witwatersrand, including those on the East Rand, provide habitats for a wide variety of aquatic and semi-aquatic birds (Tarboton et al., 1987; Ryan and Isom, 1990; Tarboton, 1993). Mismanagement and pollution of wetlands may mean a loss of habitat for a number of bird species. Furthermore, some wetlands may contain endangered biota, including certain bird species recorded in the *South African Red Data Book on Birds* (Brooke, 1984). A number of provincial parks and bird sanctuaries are located within the boundaries of the Witwatersrand (Ryan and Isom, 1990). There are also several aquatic environments, of which the Vlakplaats Water Pollution Control Works (WPCW) is one, which do not receive any formal protection from conservation bodies.

The Vlakplaats WPCW area is relatively rich in bird life with a total of 139 species recorded here (Whitehouse and Whitehouse, 1978; Van Eeden, personal observations). The most commonly occurring aquatic birds associated with this area include the Redknobbed Coot *Fulica cristata*, Reed Cormorant *Phalacrocorax africanus* and Sacred Ibis *Threskiornis aethiopicus*. These three species occupy clearly delineated trophic levels. Reed Cormorants are mainly piscivorous (Brown et al., 1982), Sacred Ibises are omnivorous (Clark, 1979; Clark and Clark, 1979; Brown et al., 1982; Ginn et al., 1989) and Redknobbed Coots are herbivorous (Fairall, 1981; Brown et al., 1982). This particular site borders on the extensive Natalspruit wetlands and is known to contain metals in the abiotic and biotic compartments (Van Eeden, 1990; Van Eeden and Schoonbee, 1991, 1992, 1993; Adendorff, 1992; Fleischer, 1993; Steenkamp et al., 1993).

The association between aquatic birds and the industrial and mining activities of human beings prompted investigations to be carried out on the potential of some bird species, e.g. gulls (Munoz et al., 1976), as biomonitors of metal pollution in aquatic environments. Any bird that is exposed to a metal-contaminated environment can be used to quantify relative levels of metal pollution. This can be achieved by the measurement of the metal in a number of tissues that may sequester metals from the food of the bird. However, a potential bird species to be used as an indicator organism needs to comply with various requirements in order to be a reliable and continuous biomonitor (Hahn et al., 1985; Weyers et al., 1985; Ellenberg et al., 1985). The most important requirement is that birds from any trophic level should be able to accumulate a variety of metals without being killed by the excessively large concentrations encountered. It must be borne in mind that most metal-containing effluents exert a chronic impact on the aquatic avifauna, an impact which the birds should also be able to tolerate.

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This impact might result in an abnormal accumulation of high and potentially toxic concentrations of metals in their tissues.

The considerations outlined above led to the present investigation, that was conducted at the Vlakplaats WPCW. The aim of this study was to determine the concentrations of cadmium, copper, nickel and lead in liver, kidney, bone and blood samples of the Redknobbed Coot, Reed Cormorant and Sacred Ibis. These species were chosen because they each occupied a particular trophic status. The results are used to consider the potential of each species of bird to act as a biological indicator for metals in the aquatic environment.

Description of the study area

Detailed descriptions of the Natalspruit wetland area, including the drainage basin, water flow and composition, representative flora of the area as well as the occurrence and abundance of bird species from this area can be found in Viljoen et al. (1985), Van Eeden and Schoonbee (1991; 1992; 1993) and Van Eeden (1994).

Materials and methods

Samples of the Redknobbed Coot, Sacred Ibis and Reed Cormorant were collected at the study area with the landowner's permission and with the regional permit obtained from the Chief Directorate of Nature Conservation of the Transvaal. Use was largely made of a 0.22 rifle and a shotgun to collect bird specimens. All birds were sampled between 1991 and 1993.

Precautionary steps were taken in order to prevent possible metal contamination during the various procedures of laboratory analysis. The liver, both kidneys and tibio-tarsus (representing the skeleton and henceforth referred to as "bone") were dissected out. Blood samples (consisting mainly of clots found in the thoracic cavity as well as the contents of the heart and hepatic arteries) were carefully collected with the aid of a clean stainless steel spoon. Ovendried material was used for metal analysis as it has been demonstrated that the variations in the metal concentrations of a particular organ can largely be ascribed to variations in the moisture contents of a particular tissue (Adrian and Stevens, 1979). In all cases, the entire tissue samples were used for metal analysis in order to increase the sensitivity of the analytical procedure. "Analytical Reagent" pure chemicals were used during this study. The acids used for wet ashing the samples were a 1:1 (v/v) mixture of concentrated nitric acid and concentrated perchloric acid. The concentrations of metals in all the digestates were determined by air-acetylene flame atomic absorption spectrophotometry (AAS) using a Varian SpectrAA 10 series AAS and following standard operational procedures (Varian, 1989). The mean of five instrument readings was taken for each sample. The metal concentrations in the different samples were determined in mg/ℓ. The results were then converted to µg metal per gram dry mass (d.m.). The detection limits for the metals analysed were: cadmium (0.002 µg/mℓ), copper (0.003 µg/mℓ), nickel (0.01 µg/mℓ) and lead (0.01 µg/mℓ). The percentage moisture for all the tissues analysed is included in order to facilitate the conversion to wet mass (w.m.) values for comparative purposes. The moisture contents of the different tissues of the three bird species as well as their respective dry mass factors are presented in Table 1. For conversion to wet mass metal values multiply the dry mass metal value with the dry mass conversion factor.

The results of this investigation were summarised by determining the minimum and maximum metal concentration values and by calculating the mean concentration ($\bar{x}$), the standard deviation (SD) and the coefficient of variation (CV%). Any concentration value greater than $\bar{x}$+2SD was not included for statistical analysis. Selected statistical methods were used to determine the possible significance of the results. Use was made of the nonparametric analysis of variance by rank's method, namely the Kruskal-Wallis Test (Hassard, 1991), after which the Newman-Keuls Test was used to locate that mean which differed from other means within the same group (Zar, 1974; Hassard, 1991). The significance level used throughout this test was $p<0.05$.

TABLE 1
THE TISSUE MOISTURE CONTENT (%) AND THE DRY MASS FACTOR FOR THREE BIRD SPECIES FROM THE NATALSPRUIT WETLANDS

	Liver	Kidney	Bone	Blood
Redknobbed Coot	79.0% 0.210	80.6% 0.194	14.2% 0.858	77.2% 0.228
Sacred Ibis	72.3% 0.277	79.0% 0.210	19.5% 0.805	72.7% 0.273
Reed Cormorant	73.3% 0.267	79.0% 0.210	20.5% 0.795	75.6% 0.244

TABLE 2
METAL CONCENTRATIONS IN THE KIDNEY OF THREE BIRD SPECIES FROM THE NATALSPRUIT WETLANDS. RESULTS ARE EXPRESSED AS SAMPLE SIZE, $\bar{X}$ ± SD (µg/g DRY MASS), COEFFICIENT OF VARIATION (CV%) AND RANGE (MINIMUM - MAXIMUM)

Metal	Redknobbed Coot	Sacred Ibis	Reed Cormorant
Cadmium	n=12 1.9 ± 1.2 [illegible]6.2% 0.41 - 4.2	n=14 3.4 ± 3.8 111.8% 0.72 - 13.3	n=6 3.2 ± 1.7 53.1% 0.83 - 5.8
Copper	n=12 20.5 ± 8.5 41.5% 2.[illegible] - 34.5	n=16 11.9 ± 3.3 27.7% 6.9 - 20.3	n=6 16.2 ± 2.6 16.0% 12.5 - 19.3
Nickel	n=12 19.7 ± 11.3 57.4% 9.[illegible] - 44.2	n=16 10.1 ± 3.6 35.6% 4.1 - 17.2	n=6 22.8 ± 10.1 44.3% 3.4 - 31.5
Lead	n=11 9.5 ± 2.8 29.5% 6.0 - 15.5	n=15 10.6 ± 3.4 32.1% 4.7 - 19.1	n=6 12.4 ± 3.4 27.4% 7.6 - 16.6

Results

Of the four metals, cadmium was found in the lowest concentration in all the tissues of all three species (Fig. 1). The highest mean

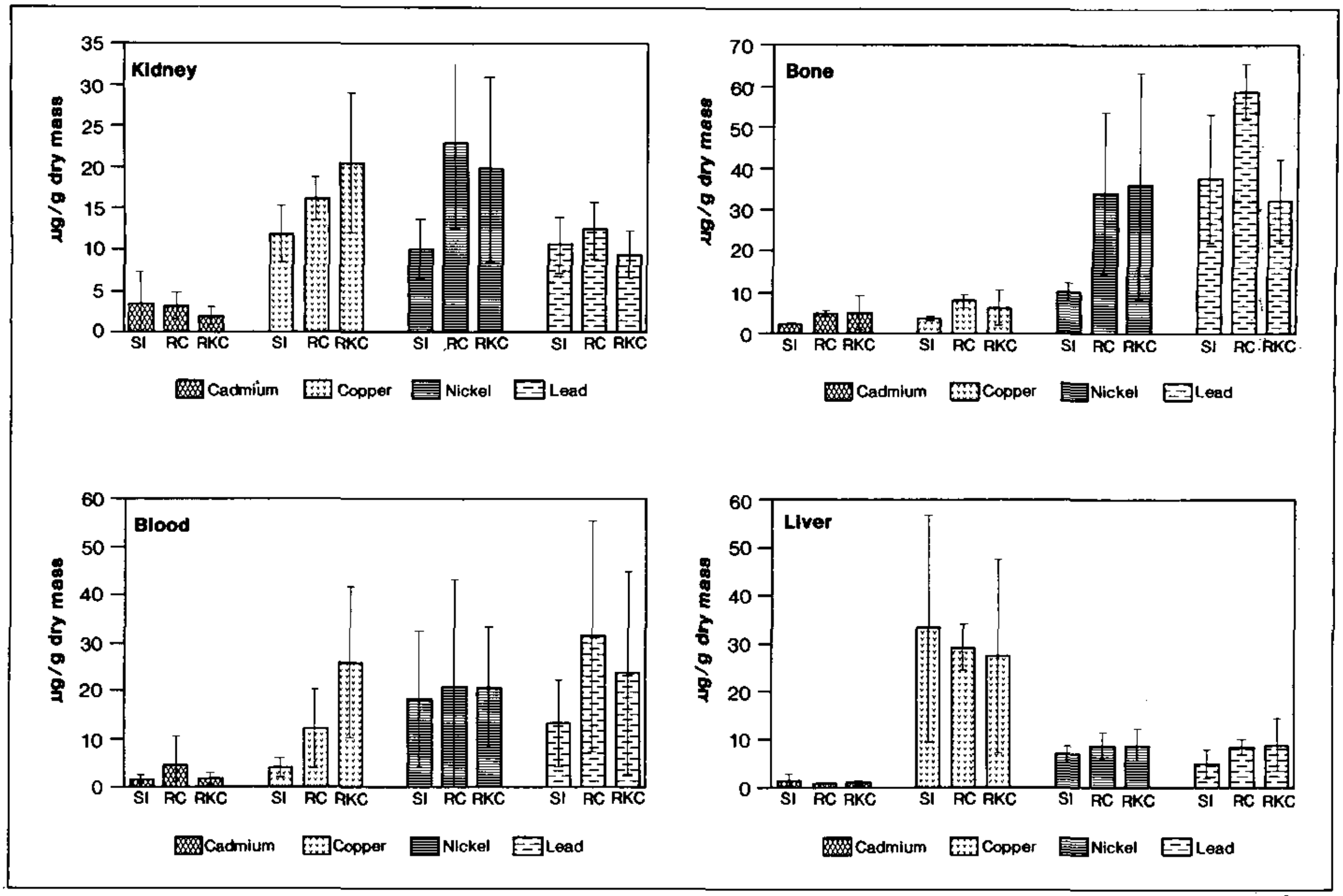

Figure 1

The concentrations (mean ± SD expressed as µg/g dry weight) of cadmium, copper, nickel and lead in tissues of the Sacred Ibis (SI), Reed Cormorant (RC) and Redknobbed Coot (RKC) sampled from the metal-polluted Natalspruit wetlands and Vlakplaats WPCW area

cadmium levels occurred in the kidneys and the bone of all three species as well as in the blood of the cormorants (Tables 2, 3 and 4). Copper was the dominant metal present in the liver of all three bird species with its concentration being approximately 3 to 4 times higher than those of liver cadmium, nickel or lead (Table 5). Copper levels were found in relatively low concentrations in the kidneys (12 to 21 µg/g), blood (4 to 26 µg/g) and bone (4 to 8 µg/g) of all three species (Tables 2, 3 and 4). Nickel and lead were clearly the dominant metals in the bone of all three species (Fig. 1) and their concentrations were approximately 1 to 6 times higher than those of bone cadmium and copper (Table 3). The mean concentration ranges of nickel and lead in both the blood and the kidneys of the three species were approximately 2 to 3 times that found in their liver (Fig. 1).

Variability in the metal concentrations within the tissues of the three bird species can be compared by calculating the coefficient of variation for each sample. The effectiveness of this statistic when employed in this manner was demonstrated by Muirhead and Furness (1988) for sea birds and by Cosson et al. (1988) for aquatic birds. High variabilities in metal concentrations were found for cadmium (e.g. 123% in cormorant blood and 111.8% in ibis kidney), lead (e.g. 88% in coot blood), copper (e.g. 73% in coot liver) and nickel (105% in cormorant blood) (Tables 2 to 5). The tissues with the greatest variabilities in metal levels did not necessarily have the highest mean metal concentrations. However, some metals such as copper and lead in the kidney (Table 2) and nickel in the liver (Table 5) showed little variability in metal concentrations among all three species. These particular results contrast markedly with those found for other metals such as cadmium in bone and kidney, and copper in bone and liver (Tables 2, 3 and 5).

A few individual tissue samples contained metal concentrations that were found to be exceptionally high and which exceeded their respective $\bar{x}$+2SD values. As noted earlier, these exceptional values, falling well outside the normal distribution of the data, were excluded from the results used in the statistical evaluation of the data. A Sacred Ibis liver sample had a copper content of 255.9 µg/g whilst some ibis kidney samples had values of 45.6 and 54.2 µg Cd/g and 112.2 µg Pb/g, respectively. Three Reed Cormorant blood samples contained 133.3 µg Cu/g, 251.1 µg Ni/g and 162.9 µg Pb/g and a liver sample had a value of 274.6 µg Cu/g. High lead values in the kidney (237.7 µg/g), bone (115.9 µg/g) and blood (305.4 µg/g) were obtained for the coot.

From Fig. 1 it can be seen that definite species-specific trends occurred for most of the tissues and metals. The concentration of cadmium in the livers of the three bird species was the only case (1 out of 16) in which no statistically significant ($p<0.05$) difference was found (Table 6). In eight cases no

TABLE 3
METAL CONCENTRATIONS IN THE BONE OF THREE BIRD SPECIES FROM THE NATALSPRUIT WETLANDS. RESULTS ARE EXPRESSED AS SAMPLE SIZE, X ± SD (µg/g DRY MASS), COEFFICIENT OF VARIATION (CV%) AND RANGE (MINIMUM - MAXIMUM)

Metal	Redknobbed Coot	Sacred Ibis	Reed Cormorant
Cadmium	n=12 5.1 ± 4.2 82.4% 2.5 - 18.3	n=16 2.5 ± 0.29 11.6% 2.1 - 3.0	n=6 4.9 ± 0.54 11.0% 4.3 - 5.8
Copper	n=12 6.6 ± 4.4 66.7% 3.9 - 20.3	n=16 4.0 ± 0.36 9.0% 3.3 - 4.4	n=6 8.2 ± 1.5 18.3% 6.0 - 10.6
Nickel	n=12 36.1 ± 27.4 75.9% 12.1 - 110.0	n=16 10.5 ± 2.3 21.9% 7.8 - 15.5	n=6 34.2 ± 19.5 57.0% 15.6 - 58.1
Lead	n=11 32.4 ± 10.1 31.2% 21.1 - 58.2	n=16 37.9 ± 15.5 40.4% 20.3 - 72.3	n=6 59.0 ± 6.8 11.5% 51.3 - 68.9

TABLE 5
METAL CONCENTRATIONS IN THE LIVERS OF THREE BIRD SPECIES FROM THE NATALSPRUIT WETLANDS. RESULTS ARE EXPRESSED AS SAMPLE SIZE, X ± SD (µg/g DRY MASS), COEFFICIENT OF VARIATION (CV%) AND RANGE (MINIMUM - MAXIMUM)

Metal	Redknobbed Coot	Sacred Ibis	Reed Cormorant
Cadmium	n=12 1.1 ± 0.46 41.8% 0.68 - 2.1	n=14 1.4 ± 1.7 121.4% 0.43 - 7.0	n=6 1.0 ± 0.24 24.0% 0.65 - 1.3
Copper	n=12 27.6 ± 20.1 72.8% 14.2 - 84.3	n=13 33.3 ± 23.3 70.0% 13.8 - 84.8	n=5 29.4 ± 4.8 16.3% 24.3 - 37.3
Nickel	n=12 9.1 ± 3.3 36.3% 5.4 - 17.1	n=14 7.2 ± 1.7 23.6% 4.6 - 11.4	n=6 9.0 ± 2.8 31.1% 7.1 - 14.4
Lead	n=12 9.3 ± 5.5 59.1% 3.2 - 22.9	n=14 5.3 ± 2.9 54.7% 1.8 - 12.4	n=6 8.8 ± 1.5 17.0% 6.8 - 10.1

TABLE 4
METAL CONCENTRATIONS IN THE BLOOD OF THREE BIRD SPECIES FROM THE NATALSPRUIT WETLANDS. RESULTS ARE EXPRESSED AS SAMPLE SIZE, X ± SD (µg/g DRY MASS), COEFFICIENT OF VARIATION (CV%) AND RANGE (MINIMUM - MAXIMUM)

Metal	Redknobbed Coot	Sacred Ibis	Reed Cormorant
Cadmium	n=12 1.8 ± 1.3 72.2% 0.55 - 4.4	n=16 1.7 ± 0.91 53.5% 0.74 - 3.8	n=6 4.7 ± 5.8 123.4% 1.2 - 15.7
Copper	n=12 26.1 ± 15.7 60.2% 6.5 - 57.3	n=16 4.2 ± 1.9 45.2% 1.9 - 8.8	n=5 12.2 ± 8.2 67.2% 5.2 - 25.7
Nickel	n=12 20.9 ± 12.5 59.8% 7.4 - 42.9	n=16 18.4 ± 14.1 76.6% 6.6 - 62.7	n=5 21.0 ± 22.0 104.8% 3.7 - 51.4
Lead	n=11 23.8 ± 21.0 88.2% 6.2 - 77.2	n=15 13.3 ± 9.0 67.7% 4.4 - 40.6	n=5 31.6 ± 23.9 75.6% 12.7 - 58.9

significant differences were observed between two of the three species (e.g. the mean liver copper, kidney cadmium and lead as well as blood cadmium levels of the Sacred Ibis and the Redknobbed Coot; Table 6). Similar trends were found for liver nickel and lead, as well as for bone nickel and blood nickel (Table 6). However, in 7 out of 16 cases, statistically significant differences ($p<0.05$) were detected among the mean metal concentrations for a particular tissue of all three bird species (Table 6), e.g. copper in kidney and blood as well as cadmium in bone occurred in decreasing concentrations from the Redknobbed Coot to the Reed Cormorant to the Sacred Ibis.

Discussion

Of the four metals studied in this investigation, cadmium occurred in the smallest concentration in the liver, blood, kidney and bone of all three bird species. Kidney cadmium levels exceeded liver cadmium levels by a factor of 2 to 3 (Tables 2 and 5). Similar trends have been recorded for oceanic sea birds such as albatrosses, petrels, prions and penguins (Lock et al., 1992), near-shore sea birds such as gulls (Nicholson, 1981; Reid and Hacker, 1982) as well as inland birds such as herons and egrets (Hulse et al., 1980; Cheney et al., 1981). Such a situation may well indicate the existence of a chronic, low-level exposure to cadmium in the Natalspruit wetlands rather than an acute cadmium toxicity. According to Scheuhammer (1987) this would result in higher cadmium levels in the liver rather than in the kidney. Toxic effects of cadmium only occur in humans and other mammals when kidney cadmium levels reach about 100 µg/g wet mass (Scheuhammer, 1987), which is well above the concentra-

TABLE 6
ANALYSIS OF VARIANCE (H) AND MULTIPLE COMPARISONS ANALYSIS OF THE CONCENTRATIONS OF FOUR METALS IN TISSUES OF THREE BIRD SPECIES FROM A POLLUTED WETLAND. MEAN METAL CONCENTRATIONS WITHIN A ROW SHARING A COMMON SUPERSCRIPT (a, b or c) ARE NOT SIGNIFICANTLY DIFFERENT AT THE P<0.05 LEVEL OF SIGNIFICANCE

Tissue	Metal	H-Value	Bird species and mean metal value		
Liver	Cd	0.60	SI 1.4^{a}	RKC 1.1^{a}	RC 1.0^{a}
Liver	Cu	2.44	SI 33.3^{a}	RD 29.4^{b}	RKC 27.6^{a}
Liver	Ni	3.23	RKC 9.1^{b}	RC 9.0^{b}	SI 7.2^{a}
Liver	Pb	8.37	RKC 9.3^{b}	RC 8.8^{b}	SI 5.3^{a}
Kidney	Cd	2.18	SI 3.4^{a}	RC 3.2^{b}	RKC 1.9^{a}
Kidney	Cu	14.37	RKC 20.5^{c}	RC 16.2^{b}	SI 11.9^{a}
Kidney	Ni	12.53	RC 22.8^{b}	RKC 19.7^{c}	SI 10.1^{a}
Kidney	Pb	3.35	RC 12.4^{b}	SI 10.6^{a}	RKC 9.5^{a}
Bone	Cd	23.07	RKC 5.1^{c}	RC 4.9^{b}	SI 2.5^{a}
Bone	Cu	23.19	RC 8.2^{b}	RKC 6.6^{c}	SI 4.0^{a}
Bone	Ni	23.87	RKC 36.1^{b}	RC 34.2^{b}	SI 10.5^{a}
Bone	Pb	10.04	RC 59.0^{b}	SI 37.9^{a}	RKC 32.4^{c}
Blood	Cd	1.79	RC 4.7^{b}	RKC 1.8^{a}	SI 1.7^{a}
Blood	Cu	21.70	RKC 26.1^{c}	RC 12.2^{b}	SI 4.2^{a}
Blood	Ni	2.55	RC 21.0^{a}	RKC 20.9^{b}	SI 18.4^{a}
Blood	Pb	4.39	RC 31.6^{b}	RKC 23.8^{c}	SI 13.3^{a}

RKC = Redknobbed Coot; SI = Sacred Ibis; RC = Reed Cormorant

tions recorded for the birds in this study (a maximum of 15.7 µg/g w.m. in coot bones). Thus, when considering the indicator ability of the coot, ibis and cormorant it can be assumed that the current low level of cadmium found in the Natalspruit wetlands (Van Eeden, 1994) poses no immediate threat to these and most likely other avifauna inhabiting or frequenting these aquatic environments.

Large concentrations of cadmium and especially nickel and lead occurred in the bone tissue of all three bird species (Fig. 1). These concentrations generally exceeded the liver cadmium, nickel and lead concentrations by factors of 2 to 5, 1 to 4 and 4 to 7, respectively (Tables 3 and 5). The relatively small variations found in the bone metal concentrations of the three bird species (Fig. 1) may be due to their low availability for redistribution or excretion in the bird's body once these metals are physiochemically bound in the bone matrix. It may thus be that bone would be a poor indicator tissue of acute pollution but may be a more reliable indicator of historical exposure due to its ability to sequester metals from the body of those birds exposed to chronic metal pollution. What is of real importance is the comparatively high concentrations of lead found in the bone of all three species during this investigation. Bone lead levels of >10 µg/g and even >20 µg/g dry mass (Amiard-Triquet et al., 1992) are considered as elevated or threshold values. In this study the mean and even the ranges of bone lead concentrations were consistently higher than 20 µg/g (Table 3).

The coefficient of variation calculated for tissue metal concentrations indicated that the concentrations of all four metals varied greatly in most of the tissues. These results might suggest a high degree of inter-species variability in the ability of the three bird species to regulate the concentrations of essential (copper and nickel) as well as non-essential metals (cadmium and lead). A higher variability was found for blood (Table 4), which might be due to a naturally high species variability or to the possible contamination of some blood samples with other metal-containing body fluids (probably due to gunshot damage).

Muirhead and Furness (1988) showed that the mean coefficient of variability for the essential metals zinc and copper in the kidneys and livers of 185 specimens of 14 species of sea birds from Gough Island was in most cases much smaller than those calculated for the non-essential and toxic metals cadmium and mercury. Similar results were observed in a number of tissues of 10 specimens of the Little Egret (*Egretta garzetta*) from the Camargue, France (Cosson et al., 1988). With this in mind, the coefficient of variation calculated here showed some inconsistencies in the various tissue metal levels of the three species. For instance, all four metals in the kidneys and livers of all three species showed relatively low variabilities, with the sole exception of kidney and liver cadmium in the Sacred Ibis (Tables 2 and 5). This might reflect the dietary habits of this ibis at the Vlakplaats WPCW where these birds forage in the screenings and grit disposed of by the sewage treatment plant. Lead, which is a non-essential metal, showed very little variability in the kidney (mean of 30%) and the liver (mean of 44%) of all three species (Tables 2 and 5). This might suggest that the levels of lead in the environment are sufficiently low enough to enable the birds to bio-regulate lead efficiently. The same reasoning can be applied to the variabilities calculated for nickel in the kidney and liver tissues of all three species.

These high variability values may further suggest an inadequate ability to effectively regulate the concentration of a metal due to the presence and number (or lack thereof in the case of blood) of metal-binding sites in the kidney and liver (Chen and Ganther, 1975). However, a naturally high variability in tissue metal content and a high metabolic turnover should not be ruled out. The fact that these three species of bird are exposed to high metal levels in their food and drinking water should also be taken into consideration. These high metal levels most likely originate from the Natalspruit wetland and adjacent Vlakplaats sewage purification works, which are both known to be highly polluted by metals (Van Eeden, 1994).

Little information is available on the ability of the Redknobbed Coot to accumulate metals from the aquatic environment. The mean dry mass lead concentrations of 6 μg/g in the liver, 14 μg/g in the kidney and 39 μg/g in the sacral vertebrae of coots collected from the Natalspruit wetlands during 1989 (Van Eeden and Schoonbee, 1992) compared relatively well with the results obtained for these particular tissues analysed during the present study (Tables 2, 3 and 5). This would suggest that the coots collected from the Natalspruit wetlands are most likely exposed to chronically low levels of lead toxicity.

The most comprehensive study on metal concentrations in the American Coot *Fulica americana* was conducted by White et al. (1986). They compared the wet mass concentrations of several metals in coots from a control site with those from a pond contaminated by a power plant over a period of three years. For the control site, the maximum metal levels observed by these authors were 15 μg Cu/g, 1 μg Ni/g and 0.6 μg Cd/g in the liver and 6 μg Pb/g in the femur. For the polluted pond site, the maximum metal levels found were 36 μg Cu/g, 4 μg Ni/g and 2 μg Cd/g in the liver and 3 μg Pb/g in the femur. The liver cadmium (0.23 μg/g) and nickel (1.9 μg/g) results of the present study fall between those for the control site and the polluted site for the American Coot, respectively. However, their mean liver copper levels were 2 to 6 times higher and their mean bone lead levels were 4 to 9 times lower compared to the mean liver copper (5.8 μg/g) and bone lead (27 μg/g) of *F. cristata* in this investigation. These comparisons suggest that the Redknobbed Coots were exposed to highly elevated lead contamination, most probably due to anthropogenic activities. The American Coots from the polluted site were exposed to higher levels of cadmium and nickel. This clearly indicates that the Redknobbed Coots from the Natalspruit wetlands are able to withstand elevated levels of cadmium and nickel without any apparent ill effect. This finding supports their use as potential biological indicators of metal pollution. The elevated copper levels in the liver of the coots analysed by White et al. (1986) may possibly be related to some functional aspect of the power plant operation e.g. the use of copper-containing biocides.

No known comparative information is available for the Sacred Ibis apart from that recorded by Van Eeden (1990) on birds sampled from the Natalspruit wetlands during 1989. Van Eeden (1990) recorded mean dry mass concentrations of copper (13 μg/g) and nickel (13 μg/g) in the kidneys, lead (37 μg/g), nickel (13 μg/g) and copper (5 μg/g) in the sacral vertebrae and lead (4 μg/g) and nickel (11 μg/g) in the liver that were comparable with concentrations found in the present study (Tables 2, 3 and 5). Dry mass concentrations of 11 μg Ni/g and 38 μg Pb/g were found in the bone of the Glossy Ibis (*Plegadus falcinellus*) sampled from the highly industrialised Acre Valley area in Israel (Fishelson et al., 1994). These values matched those recorded for the Sacred Ibis in the present study (Tables 3 and 5) and also those recorded by Van Eeden (1990). However, the mean dry mass concentrations of kidney lead (5 μg/g) and liver copper (26 μg/g) found in 1989 (Van Eeden, 1990) increased to 11 μg Pb/g and 33 μ Cu/g respectively, in the present study. The fact that these increases were noted in organs such as the liver and kidney, which are generally good indicators of short-term metal exposure, would seem to indicate that the environmental levels to which the Sacred Ibis was exposed have increased slightly over the last five years (Van Eeden, 1994). The origin of these metals can most probably be related to the specific dietary preferences of the ibises found at the Vlakplaats WPCW. It is a common practice at the Vlakplaats WPCW to dispose of the sewage screenings and other untreated debris in heaps that are only periodically covered with soil. In such cases ibises tend to feed primarily on the sewage screenings (Van Eeden, personal observations) which, by virtue of their origin, might contain higher and more variable concentrations of metals. A similar explanation might apply in the case of the nickel and lead concentrations recorded in the liver (13 μg Ni/g and 33 μg Pb/g) of the Glossy Ibis (Fishelson et al., 1994) which were 1 to 2 (Ni) and 6 to 7 (Pb) times higher than those values recorded for the Sacred Ibis in the present study and by Van Eeden (1990). This was particularly apparent in the case of the liver lead concentrations. Hall and Fisher (1985) found that the White-faced Ibis (*P. chihi*) is capable of ingesting spent lead shot whilst probing the mud for food. Whilst feeding *P. chihi* might be exposed to acute levels of lead, which can result in death due to lead toxicosis (Amiard-Triquet et al., 1992).

During a preliminary survey on the concentrations of metals in a number of bird species from the Natalspruit wetlands, dry mass metal values in the liver (1 μg Pb/g, 24 μg Ni/g, 70 μg Cu/g), kidney (1 μg Pb/g, 10 μg Ni/g, 46 μg Cu/g) and sacral vertebrae (1 μg Pb/g, 21 μg Ni/g, 19 μg Cu/g) of a single Reed Cormorant were recorded by Van Eeden (1990). Similar values were also observed for a single White-breasted Cormorant *P. carbo* collected from the same locality (Van Eeden, 1990). However, these values do not compare well with those found for the Reed Cormorant during this investigation, although this is most probably due to the fact that single specimens were analysed. However, Greichus et al. (1977) recorded dry mass concentrations of 0.6 μg Cd/g, 5 μg Cu/g and 2 μg Pb/g in three Reed Cormorant carcasses collected from the Hartbeespoort Dam. These values were considerably lower than the tissue metal levels found for the Reed Cormorant during this study (Tables 2 to 5), especially in the cases of lead and cadmium. This might be attributed to either dilution through mere body volume in contrast to tissues that are capable of sequestering metals in high concentrations from the body of the bird or to genuinely high concentrations encountered in their environment.

Various studies on the concentrations of a number of metals in a variety of bird species have suggested that the diets of birds were most probably the major source of these metals (Hulse et al., 1980; Cheney et al., 1981; Nicholson, 1981; Reid and Hacker, 1982; Lock et al., 1992). These authors also suggested that the specific dietary preferences among different bird species as well as among individuals of the same species could have a pronounced effect upon the concentrations of these metals in the birds' tissues. It would also appear that the effects of diet are greater than taxonomic differences in evaluating tissue metal burdens. Reed Cormorants might exhibit higher metal levels as a consequence of their specific diet rather than as a result of any intrinsic function of being a Reed Cormorant. The dietary preferences as well as the occurrence and concentrations of cadmium, copper, nickel and lead in some food items of each of the three bird species were determined (Van Eeden, 1994) and will be the subject of a future publication. These data may throw more light on the role of diet in the possible transfer of metals from the food to the birds concerned.

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