Selected mineral and heavy metal concentrations in blood and tissues of vultures in different regions of South Africa

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Abstract

Concentrations of eight essential elements (Ca, Co, Cr, Cu, Fe, Mn, Ni and Zn) and three toxic metals (Al, Pb and Sr) were measured in various tissue samples from African whitebacked (*Pseudogyps africanus*), Cape griffon (*Gyps coprotheres*) and Lappetfaced (*Torgos tracheliotos*) vultures in different regions of South Africa. Blood samples from live African whitebacked vultures were taken from nestlings from two breeding populations, adults from a wildlife reserve and immature birds held in captivity. With the exception of Sr and Mn, concentrations of the majority of metals differed between two or more of the sampling localities and between captive and wild individuals. Birds from Moholoholo had the highest overall blood metal concentrations, while concentrations in birds from Dronfield were the lowest, as can be expected for nestlings and adults respectively. Fatty tissues and bones had the highest values of metal accumulation, especially Sr, and this is congruent with results from previous studies. It was concluded that most concentrations compared well with those reported for other avian species, but concentrations of Cr, Ni and Pb in the dead vultures were generally above values characteristic of heavy metal poisoning. The values reported for each of two wild populations of *P. africanus* nestlings and adults, and for two other vulture species could serve as base-line data for future comparative studies.

Keywords: Vultures, African whitebacked, *Pseudogyps africanus*, Cape griffon, *Gyps coprotheres*, Lappetfaced, *Torgos tracheliotos*, mineral, heavy metal
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Introduction

There has been increasing concern about the entry of potentially harmful substances into the food chain destined for human consumption (Mailman, 1980; Lacher & Goldstein, 1997) because heavy metals can be responsible for a variety of acute and chronic toxic effects in vertebrates (Parmegianni, 1983). The monitoring of such substances in air, water, soil, or in plants consumed by ruminants used for meat production is time consuming and expensive. Birds, especially vultures (by virtue of their position at the top of the food chain), may accumulate and concentrate heavy metals in their tissues and thus serve as more sensitive indicators of the level of environmental contamination (Guitart *et al*., 1994). It would be undesirable and impractical to kill adult vultures for this purpose, but nestlings represent ideal subjects for routine blood sampling, as they are commonly ringed for identification purposes at several sites in South Africa. There are no reference concentrations for metals in the blood of nestling vultures and it is also not known how these concentrations relate to concentrations in the blood and tissues of adult vultures. The aim of this experiment was to quantify concentrations of eight essential elements (Ca, Co, Cr, Cu, Fe, Mn, Ni and Zn) and three toxic metals (Al, Pb and Sr) in whole blood, brain, heart, kidney, liver, bone, body fat and muscle samples from African whitebacked (*Pseudogyps africanus*) nestlings and adults, Cape griffon (*Gyps coprotheres*) and Lappetfaced (*Torgos tracheliotos*) vultures in South Africa.

Material and Methods

Sixty specimens were collected over two years from free-living *P. africanus* individuals located in three regions in South Africa and from birds held in captivity. Twenty-two blood samples were obtained from African whitebacked vultures held in aviaries at the De Wildt Research and Breeding Station in the North-West Province (25º41´S, 27º56´E). The birds varied in age from immature to adult. Blood samples were also obtained from six free-living adults that were held at the Moholoholo Wildlife Rehabilitation Center (24º31´S, 30º49´E) for a brief period while recovering from the ingestion of poison. The actual breeding location of these vultures is unknown, but the Kruger National Park is probably within the foraging range of these birds.

Sample collection from nestlings took place at the Sandveld Nature Reserve, Free State Province (27º28´S, 25º38´E) and the Dronfield Ranch, Northern Cape Province (29º32´S, 24º41´E). Sandveld Nature Reserve is situated along the lower perimeters of the Bloemhof Dam, approximately 7km from Bloemhof. The Dronfield Estate is an estimated 10km from Kimberley. A blood sample of approximately 5ml was drawn via the brachial vein of the under-wing and immediately transferred into evacuated collection tubes (Van Wyk, 1992). Care was taken to keep the tubes perpendicular to prevent contact with the rubber tops to eliminate contamination. The test tubes were placed in crushed ice and stored at –20ºC upon arrival at the laboratory.

Eight dead vultures (five African whitebacked, one Lappetfaced and two Cape griffon vultures) were obtained from various regions of South Africa. Brain, pectoral muscle, body fat and a segment of femur were removed from each of the eight carcasses. With the exception of one Cape griffon vulture, which was at an advanced stage of decomposition, internal organs excised included heart, kidneys and liver. The skin, adipose tissue, excess muscle and sinews were completely cleaned from the femur to ensure that results measured would be representative of osseous tissue only. All samples were subsequently frozen and stored at –20ºC. It should be noted that data derived from the dead birds does not constitute a random sample.

Samples were thawed at room temperature, weighed, and then dried in an oven at 60ºC for a minimum of 48 hours, or until a constant dry mass was reached to enable measurement of moisture content. Metal concentrations were expressed on a dry mass basis (µg/g) to avoid errors in interpretation associated with varying degrees of moisture (Seymore *et al*., 1995). Glass containers used during the preparation of samples were soaked in a 2% Contrad solution (Merck) for 24 hours, rinsed in deionised water, acid washed in 1M HCl for a further 24 hours, and rinsed again in distilled water to remove traces of metals (Adendorff, 1993). TORT-2 (Lobster hepatopancreas reference material for trace metals; Industrial Analytical (Pty) Ltd, Kyalami, South Africa) was used as the certified reference material and represented a 95% confidence limit. A 1:2 solution of concentrated perchloric acid ($HClO_4$, 70%) and nitric acid (HNO_3, 55%) was added to each specimen to enable acid digestion, which was conducted at 200-250ºC until solutions appeared clear. Samples were allowed to cool, and then filtered through acid resistant filter paper (0.45µm). Filtrates were made up to 50ml with deionised water. Samples were placed in amber bottles without rubber tops, since these may be a source of Zn contamination. Metal concentrations were measured using atomic absorption spectrophotomery. Analytical standards were prepared from stock solutions to calibrate the apparatus (Adendorff, 1993; Seymore *et al*., 1995) and to serve as standard reference samples to verify the accuracy and repeatability of the analyses.

Data was log-transformed to satisfy the homogeneity of variance assumption of the analysis of variance procedure and analysed by one-way analysis using the Tukey studentised range test (Custer & Custer, 1995).

Results

Mineral concentrations of whole blood samples from live African whitebacked vulture specimens and differences ($P < 0.05$) between localities for each age group are presented in Table 1. All blood metal concentrations in *P. africanus* except that of Sr and Mn differed ($P \leq 0.05$) between two or more of the localities, and between free-living (Dronfield, Sandveld and Moholoholo) and captive (De Wildt) birds (Table 1). Concentrations of Cu, Fe, Ni and Pb differed ($P \leq 0.05$) between all four regions. Concentrations of seven of the 11 metals were higher in birds from Moholoholo than from the other three areas, and nestlings from Dronfield displayed the lowest levels for four metals (Fe, Mn, Pb and Zn). In general, the nestlings had lower Al, Ca, Co, Cr, Mn and Zn concentrations and higher Sr concentrations compared to the other age groups, whereas vultures held in captivity (the immature birds) had the lowest Ni concentration (Table 1).

Table 1 Mean (± s.d.) concentrations of minerals in blood samples from *P. africanus* (µg/g dry matter)

	Nestlings		Immature	Adult
	Dronfield	Sandveld	De Wildt	Moholoholo
	n = 28	*n = 4*	*n = 22*	*n = 6*
Moisture[*]	89.27 (±0.73)	88.92 (±0.47)	79.69 (±0.75)	78.59 (±0.91)
Al	37.46 (±1.13)[a]	12.52 (±1.00)	45.30 (±2.29)	46.74 (±4.02)
Ca	115.23 (±7.98)	113.87 (±7.03)	138.39 (±2.80)[b]	133.06 (±2.65)
Co	1.12 (±0.16)	1.04 (±0.11)	1.35 (±0.22)[b]	1.62 (±0.31)
Cr	12.64 (±1.52)	12.42 (±1.16)	14.66 (±1.10)[b]	17.77 (±0.67)
Cu	3.92 (±0.23)[a]	4.61 (±0.12)	3.61 (±0.17)[b]	8.36 (±0.23)
Fe	340.39 (±14.00)[a]	531.61 (±3.59)	460.29 (±8.45)[b]	820.92 (±2.27)
Mn	1.51 (±0.24)	1.77 (±0.06)	2.17 (±0.29)	2.21 (±0.52)
Ni	12.84 (±1.51)[a]	10.54 (±1.44)	7.63 (±0.14)[b]	12.38 (±1.45)
Pb	3.22 (±0.33)[a]	6.28 (±0.02)	5.71 (±0.19)[b]	7.81 (±0.99)
Sr	1.40 (±0.23)	1.34 (±0.20)	1.27 (±0.19)	1.21 (±0.08)
Zn	5.93 (±1.04)[a]	14.69 (±3.09)	19.93 (±3.44)	16.51 (±5.07)

[a,b]Means within rows for similar age groups (i.e., [a]between nestlings from Dronfeld and Sandveld, and [b]between immature and adult vultures) differ significantly ($P < 0.05$); [*]Moisture is expressed as a percentage.

Concentrations of minerals from eight dead vultures from three species are listed in Tables 2 and 3. The highest mean tissue concentrations for nine of the metals were for adipose (fat) tissue followed by bone (Table 2). The lowest concentrations for eight of the minerals were found in brain tissue, and metal concentrations were similar in heart, kidney and liver samples.

Table 2 Mean (±s.d.) concentrations of minerals in tissue samples from *P. africanus* (µg/g dry matter)

	Brain	Heart	Kidney	Liver	Bone	Fat	Muscle
	n = 3	*n = 5*	*N = 5*	*n = 5*	*n = 4*	*n = 5*	*n = 5*
Moisture[*]	80.03 (±1.32)	79.18 (±2.31)	74.19 (±3.18)	69.44 (±1.81)	33.67 (±11.05)	15.56 (±3.09)	73.77 (±2.45)
Al	19.32 (±2.47)	31.11 (±13.27)	38.76 (±9.13)	47.29 (±21.49)	141.92 (±25.61)	260.49 (±165.93)	30.69 (±10.87)
Ca	2646.37 (±62.34)	228.89 (±71.06)	395.55 (±161.35)	376.96 (±95.40)	161205.80 (±69242.60)	2897.83 (±605.79)	114.11 (±23.45)
Co	2.27 (±0.68)	2.21 (±0.22)	5.28 (±1.29)	4.80 (±1.86)	9.56 (±0.86)	20.15 (±3.82)	2.02 (±1.21)
Cr	6.90 (±0.83)	13.49 (±4.17)	18.39 (±4.19)	19.57 (±5.97)	32.68 (±6.42)	52.39 (±7.95)	13.56 (±0.68)
Cu	4.46 (±1.16)	11.70 (±2.23)	14.90 (±2.41)	31.85 (±9.05)	31.58 (±5.87)	113.97 (±24.81)	18.23 (±1.36)
Fe	128.02 (±27.18)	538.46 (±49.48)	384.38 (±104.16)	227.82 (±93.55)	378.90 (±116.39)	1304.40 (±106.89)	293.80 (±44.45)
Mn	0.78 (± 0.12)	3.38 (±0.73)	4.86 (±1.06)	11.59 (±4.00)	13.59 (±2.79)	17.61 (±6.54)	1.79 (±0.45)
Ni	2.90 (±1.45)	11.38 (±3.13)	8.10 (±2.55)	13.92 (±4.64)	25.19 (±3.05)	186.67 (±67.66)	10.75 (±4.37)
Pb	3.40 (±0.06)	9.75 (±2.21)	12.30 (±1.98)	14.81 (±5.39)	27.10 (±2.70)	45.56 (±22.49)	7.79 (±1.61)
Sr	1.45 (±0.23)	1.81 (±0.67)	2.33 (±2.07)	3.62 (±1.82)	226.21 (±56.25)	29.73 (±2.62)	1.11 (±0.40)
Zn	5.18 (±1.04)	18.68 (±3.85)	150.03 (±39.18)	32.21 (±22.83)	131.02 (±21.70)	334.90 (±51.92)	19.65 (±2.95)

[*]Moisture is expressed as a percentage.

Table 3 Heavy metal concentrations in one Lappetfaced (**Lf**) and two Cape Griffon (**CG**) vultures (µg/g dry matter)

	Moisture	Al	Ca	Co	Cr	Cu	Fe	Mn	Ni	Pb	Sr	Zn
Brain												
CG (n = 1)	81.96	16.86	2241.38	1.24	4.53	4.20	107.77	0.66	3.16	3.08	2.03	4.63
Kidney												
CG (n = 1)	70.74	55.19	309.10	7.71	31.69	12.41	491.27	6.99	14.85	17.93	3.87	198.35
Lf (n = 1)	79.08	37.25	165.22	3.17	20.47	10.27	430.80	5.09	11.81	7.84	1.58	91.68
Liver												
CG (n = 1)	73.58	48.08	448.72	2.31	18.79	22.69	232.05	11.15	12.82	21.54	1.25	72.44
Lf (n = 1)	81.92	32.19	271.53	3.22	13.52	9.59	347.15	3.68	7.83	9.86	1.51	22.70
Fat												
Lf (n = 1)	25.59	470.16	4108.87	18.39	69.44	115.20	1316.13	18.63	139.44	52.66	12.26	424.35
Muscle												
CG (n = 1)	68.36	30.75	99.90	2.20	18.41	14.18	313.36	2.93	11.40	8.76	1.60	19.92
Lf (n = 1)	72.31	30.05	118.27	2.63	12.96	10.58	274.62	2.42	9.23	6.61	1.03	13.38

Discussion

The collection of sample material from wild, adult vultures of any species is a task that poses a vast array of problems and difficulties. However, concentrations of heavy metals are frequently reported for adult birds, but less often for chicks or fledglings (Stewart *et al*., 1997). Mature birds have an extended time period for exposure and the potential to mobilize metals in their internal tissues from past exposure (Burger, 1993, 1994; Burger *et al*., 1994). In contrast, recent research has proposed that chicks are particularly useful indicators for both baseline pollution studies and monitoring programs. The collection of blood specimens from nestlings is a relatively uncomplicated procedure, and ringing operations conducted on an annual basis at breeding colonies represent opportunities for obtaining samples without excessive disturbance to the colonies in question. Nestlings concentrate heavy metals during a specific period of time (i.e. from hatching to leaving the nest) and from a local and definable foraging range (Stewart *et al*., 1997). This information could, therefore, be more valuable than that derived from measurements of adult tissue concentrations where it is rarely possible to evaluate the accumulation period or define the feeding area from which metals are accumulated (Stewart *et al*., 1997).

Pseudogyps africanus is not only the most common vulture in southern Africa, but is the only vulture species in South Africa that enjoys a relatively secure conservation status (Mundy, 1982; Anderson, 1995). The foraging range of this species overlaps that of other vulture species in many areas, and their feeding habits are similar to those of the Cape griffon vulture (Mundy *et al*., 1992). Colonies can be surveyed repeatedly because they display nest site fidelity and nest synchronously within a given region. African whitebacked vultures therefore represent potential biological monitors for ecosystems within their immediate breeding and foraging range.

There was substantial variation in blood Al concentrations between individual samples in African whitebacked vultures (Table 1). Values ranged from 11.2 (in nestlings from Sandveld) to 59.1 µg/g (in adults from Moholoholo), and the level in nestlings at Dronfield was almost three times higher ($P < 0.05$) than at Sandveld. This indicates that a local source of Al contamination may exist in close proximity to Dronfield Ranch. High concentraltions of Al were present in adipose and osseous tissues of African whitebacked vulture carcasses (Table 2), consistent with reports indicating that Al accumulates in osseous tissue (Fimreite *et al*., 1997). The Lappetfaced vulture had higher Al levels in the kidney (55.19 µg/g) than the African whitebacked (38.76, ± 9.13 µg/g) and the single Cape griffon vulture (37.25 µg/g). However, mean Al concentrations in kidney, liver, muscle and heart were similar to the overall mean concentration in blood (38.17 ± 5.67 µg/g), indicating that blood concentration could be a valuable indicator of levels in these tissues.

The adult birds from De Wildt (in captivity) had higher ($P < 0.05$) whole blood Ca concentrations than vultures from Moholoholo (Table 1). This is probably the result of different diets. On the other hand, blood concentrations of Co, Cr, Cu, Fe, Mn and Pb in African whitebacked vultures were higher ($P < 0.05$) at Moholoholo than at De Wildt (Table 1). A paper production plant is situated near the Kruger National Park and water-borne effluent from this plant may be circulating Co and some of the other minerals into the foraging range of the birds from Moholoholo. Mean concentrations of these minerals indicate that birds from Dronfield and Sandveld are subject to lower levels of exposure than individuals from Moholoholo. Airborne Co pollution could possibly explain the slightly higher Co concentrations in nestlings from Dronfield, as this colony is approximately 10km from the industrial city of Kimberley. Concentrations in blood could be valuable indicators of levels of these minerals because similar means (Tables 2 and 3) were obtained in brain, liver and/or muscle tissues (except for Fe, but including Pb, Sr and Zn). A detailed study of representative tissue samples might confirm this. The values for Fe are not likely to be of value as indicators of environmental emissions due to the substantial variation (Tables 1 to 3).

The mean Cr concentration for all tissue samples analysed (18.87, ±12.4 µg/g) was higher than the upper limit for (supposedly polluted) birds in Mexico (Mora & Anderson, 1995). These researchers regarded concentrations of 6.5-17 µg/g to be below the threshold for biological effects. The tissue Cu concentrations measured in this study were also well below 500 µg/g, which is considered to be the level at which toxic effects are shown; a study of 19 pelagic seabirds concluded that Cu concentrations were highest in liver (5.93, ±0.81 µg/g wet weight), followed by muscle (5.05, ±0.63 µg/g wet weight) and kidney (4.71, ±1.06 µg/g wet weight) (Honda *et al*., 1990), which validates the order of distribution in vulture tissues.

Al, Mn, Sr and Zn were the only metals for which no significant differences ($P > 0.05$) were detected between wild and captive immature and adult *P. africanus*. In general, higher quantities of Mn were present in fat and bone of the vulture carcasses (Tables 2 and 3). This is consistent with the role of Mn in the mineralisation of vertebrate skeletal tissue (Seymore *et al*., 1995).

The pattern of accumulation of Ni in blood samples of African whitebacked vultures differed from that of the majority of metals analysed. The Ni concentration at Dronfield was higher (P < 0.05) than that at Sandveld, and also differed (P < 0.05) between the two adult populations (Table 1). Free-living individuals exhibited higher Ni levels (12.5 ± 1.51 µg/g) than birds held in captivity (7.63 ± 0.14 µg/g). Nickel, with the exception of Sr, is the only metal for which nestlings from Dronfield contained the highest contamination levels (Table 1). The bioaccumulation of Ni was in the heart, liver, muscle and kidney samples of the dead vultures, and means ranged between 9.94 and 11.38 µg/g for these tissues (Tables 2 and 3). The lowest concentration was present in the brain and in comparison to the other tissues, these values seem inconsequential. Concentrations of Ni were found to be much higher in the feathers of Black (*Anas rubripes*) and Mallard (*Anas platyrhynchos*) ducks (0.8-5.3 µg/g) in comparison to levels in control samples (Ranta *et al*., 1978). The levels of Ni in the feathers of Turkey vultures (*Cathartes aura*; 0.12-0.8 µg/g) and California condors (*Gymnogyps californianus*; 0.31-2.6 µg/g) (Wiemeyer *et al*., 1986) were well below the levels measured in the blood samples of African whitebacked vultures, indicating Ni poisoning in the vultures of the present study.

Lead levels in blood are the best indicators of recent exposure and the degree of Pb poisoning over short periods of time (Tirelli *et al*., 1996). Blood Pb concentrations remain elevated for as much as 45 days after Pb ingestion (Samuel *et al*., 1992). Mean levels of 3.97 (± 1.55) µg/g and 5.71 (± 0.19) µg/g were recorded in free-living and captive vultures, respectively. Blood concentrations in captive Mallard ducks have also been found to be higher than in free-living specimens (Longcore *et al*., 1974; Tirelli *et al*., 1996). However, controversy exists concerning the definition of toxicity levels of Pb for avian species (Tirelli *et al*., 1996). A blood concentration of 10 µg/g was proposed as a conservative threshold level indicating exposure to non-background quantities (Daury *et al*., 1993), and it has been suggested that birds with blood Pb levels higher than 4 µg/g, and possibly even with levels of 2.5-3 µg/g, have ingested Pb in one form or another (Pain, 1989). The mean for African whitebacked vulture blood samples in this study was 4.54 (± 1.47) µg/g. The chronic intake of oral doses of Pb results in high Pb concentrations in the skeleton, intermediate concentrations in liver and kidneys and the low concentrations in the heart, lungs, muscle and brain. Acute exposure (a rapid, large dose of lead), on the other hand, results in a high rate of deposition in the liver and kidneys (Longcore *et al*., 1974). The pattern displayed in the tissues of the dead specimens examined in this study is consistent with the pattern described above for chronic oral ingestion (Tables 2 and 3). The high concentrations in femurs are not necessarily indicative of acute intoxication as Pb in osseous tissues is also associated with chronic exposure (Longcore *et al*., 1974). The mean Pb concentration observed in this study is, however, similar to amounts of 40-98 µg/g recorded in Pb-poisoned avian specimens collected in the wild by the above-mentioned authors. It has been suggested that birds may survive with high blood Pb levels without apparent symptoms of poisoning due to the production of nuclear inclusion bodies (Tirelli *et al*., 1996). It is also possible that Pb can be bound by metallothionein-like proteins produced by red blood cells and sequestered in a non-bioavailable form, hence protecting an organism against Pb toxicity (Church *et al*., 1993). This is unlikely to apply to the elevated Pb levels measured in vulture tissues reported in the present study.

Strontium and Mn are the only metals for which no differences (P < 0.05) were detected between two or more of the populations of African whitebacked vultures and between free-living and captive individuals. The high Sr concentrations in the femurs of the vulture carcasses (Tables 2 and 3) suggest that this metal was primarily distributed to the osseous tissues. Sr retention can be of long duration because it interchanges with Ca (Seymore *et al.*, 1995). The lowest concentration of osseous Sr (125.54 µg/g) was measured in an immature African whitebacked vulture, which was roughly nine months old and appeared much younger than the other vultures analysed. The age difference between the dead birds may explain the variation in bone Sr levels observed.

The single Lappetfaced vulture had a Zn level of 424.35 µg/g (Table 3), which is higher than the Long and Morgan median effects range (Ross & DeLorenzo, 1997). The Zn concentrations measured in fat, kidney and bone in this study are higher than normal levels in birds which vary between 100 and 200 µg/g (Merian, 1991). The mean adipose Zn level in African whitebacked vultures (Table 2) was higher than the low effects range of 150 µg/g, but lower than the median effects range of 410 µg/g. These levels for dead birds are much higher than for the blood levels of the other vultures studied (Table 1). The highest blood Zn concentrations were detected in adult African whitebacked vultures from De Wildt (Table 1). The mean blood Zn concentrations in nestlings at Dronfield differed from those at Sandveld. Differences in Zn concentrations in birds have been attributed to differences in diet and bioavailability (Adendorff, 1993). The mean for the vulture tissues (47.22 ±43.75 µg/g) falls within the ranges reported for Great skuas (*Catharacta skua*; 25.2-496.6 µg/g) and Herring gulls (47.3-165.4 µg/g; Hutton, 1981), and exceeds mean concentrations ranging from 23.2-28.8 µg/g for a number of avian species from the (supposedly unpolluted) Mexicali valley in Mexico (Mora & Anderson, 1995). Similarities of observed Zn levels for duck species from five diverse populations suggested than Zn accumulation, and perhaps metabolism, is carefully controlled (Ranta *et al*., 1978). Consequently, as pointed out by the latter authors, the use of Zn as a biological index in wildlife is not extremely promising.

Conclusion

The results of this study quantified the concentrations of eight essential elements and three toxic metals in various tissues of *P. africanus* nestlings and adults, and in two other vulture species in South Africa. Levels of eight of the 11 (72.7%) elements measured in this study were within the range documented for species devoid of deleterious symptoms induced from heavy metal poisoning. However, certain individuals exhibited potentially toxic concentrations of Cr, Ni and Pb. The sources of the metals detected in this study should be identified, because clear differences were revealed between the groups sampled for the majority of metals analysed. Vultures could be utilized as bioindicators of pollution since it is conceivable that, by virtue of their position at the top of the food chain, they successfully accumulate heavy metals (as the results for bone and fat tissues indicated). Studies regarding accumulation rates should first be done before extrapolation of values for nestlings to adults is attempted.

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References

Adendorff, A., 1993. Die Voorkoms van Geselekteerde Metale in Organe en Weefsels van die Kolgans, *Alopochen aegyptiacus* en die Waterhoender, *Gallinula chloropus* in Myn-, Nywerheids- en Rioolbesoedelde Varswaterekosisteme aan die Witwatersrand. M.Sc. Dissertation, Rand Afrikaans University, Johannesburg, South Africa.

Anderson, M.D., 1995. Mortality of African whitebacked vultures in the North-West Province, South Africa. Vulture News 33, 10.

Burger, J., 1993. Metals in feathers of Brown noddy (*Anous stolidus*): Evidence for bioaccumulation or exposure levels. Environ. Monit. Assess. 24, 181.

Burger, J., 1994. Metals in avian feathers: Bioindicators of environmental pollution. Rev. Environ. Toxicol. 5, 197.

Burger, J., Horoszewski Lavery, M. & Gochfield, M., 1994. Temporal changes in lead levels in Common tern feathers in New York and relationship of field levels to adverse effects in the laboratory. Environ. Toxicol, Chem. 13, 581.

Church, H., Day, J.P., Braithwaite, R.A. & Brown, S.S., 1993. Binding of lead metallothionein-like protein in human erythrocytes. J. Inorg. Biochem. 49, 55.

Custer, T.W. & Custer, C.M., 1995. Transfer and accumulation of organochlorines from Black-crowned night-heron eggs to chicks. Environ. Contam. Toxicol. 14, 533.

Daury, R.W., Schwab, F.E. & Bateman, M.C., 1993. Blood lead concentration of waterfowl from unhunted and heavily hunted marshes of Nova Scotia and Prince Edward Islands, Canada. J. Wildl. Dis. 29, 577.

Fimreite, N., Hansen, O.Ø. & Pettersen, H.C., 1997. Aluminum concentrations in selected foods prepared in aluminum cookware, and its implications for human health. Bull. Environ. Contam. Toxicol. 58, 1.

Guitart, R., Torra, M., Cerradelo, S., Puig-Casado, P., Mateo, R. & To-Figueras, J., 1994. Pb, Cd, As, and Se concentrations in livers of dead wild birds from the Ebro Delta, Spain. Bull. Environ. Contam. Toxicol. 52, 523.

Honda, K., Marcovecchio, J.E., Kan, S., Tatsukawa, R. & Ogi, H., 1990. Metal concentrations in pelagic seabirds from the North Pacific Ocean. Arch. Environ. Contam. Toxicol. 19, 704.

Hutton, M., 1981. Accumulation of heavy metals and selenium in three seabird species from the United Kingdom. Environ. Pollut. 12, 129.

Lacher, T.E.Jr. & Goldstein, M.I., 1997. Tropical ecotoxicology: Status and needs. Environ. Toxicol. Chem. 16, 100.

Longcore, J.R., Locke, L.N., Bagley, G.E. & Andrews, R., 1974. Significance of lead residues in Mallard tissues, Spec Sci Rep - Wildlife No 182. Dept. Int. Fish. and Wildl. Serv., Washington, DC, US. pp. 1.

Mailman, R.B., 1980. Heavy metals. In: Guthrie, F.E., Perry, J.J., (Eds). Introduction to Environmental Toxicology. Elsevier, New York. pp. 43.

Merian, E., 1991. Metals and Their Compounds in the Environment. VCH Verlagsgesellschaft, Weinheim.

Mora, M.A. & Anderson, D.W., 1995. Selenium, boron and heavy metals in birds from the Mexicali Valley, Baja California, Mexico. Bull. Environ. Contam. Toxicol. 54, 198.

Mundy, P.J., 1982. The Comparative Biology of Southern African Vultures. D.Phil. Dissertation. University of Zimbabwe, Harare.

Mundy, P., Butchart, D., Ledger, J. & Piper, S., 1992. The Vultures of Africa. Russel Friedman Books CC, Randburg and Halfway House, SA.

Pain, D.J., 1989. Haematological parameters as predictors of blood lead and indicators of lead poisoning in the Black duck (*Anas rubripes*). Environ. Pollut. 60, 67.

Parmegianni, L., 1983. Encyclopedia of Occupational Health and Safety. Int. Labor. Org., Geneva, Switzerland.

Ranta, W.B., Tomassini, F.D. & Nieboer, E., 1978. Elevation of copper and nickel levels in primaries from Black and Mallard ducks collected in the Sudbury district, Ontario. Can. J. Zool. 56, 581.

Ross, P. & Delorenzo, M.E., 1997. Sediment contamination problems in the Caribbean Islands: Research and regulation. Environ. Contam. Toxicol. 16, 52.

Samuel, M.D., Bowers, E.F. & Franson, J.C., 1992. Lead exposure and recovery rates of Black ducks banded in Tennessee. J. Wildl. Dis. 28, 555.

Seymore, T., Du Preez, H.H. & Van Vuren, J.H.J., 1995. Manganese, lead and strontium bioaccumulation in the tissues of the yellowfish, *Barbus marequensis*, from the lower Olifants River, Eastern Transvaal. Water SA 21(2), 159.

Stewart, F.M., Monteiro, L.R. & Furness, R.W., 1997. Heavy metal concentrations in Cory's shearwater, *Calonectris diomedea*, fledglings from the Azores, Portugal. Bull. Environ. Contam. Toxicol. 58, 115.

Tirelli, E., Maestrini, N., Govoni, S., Catelli, E. & Serra, R., 1996. Lead contamination in the Mallard (*Anas platyrhynchos*) in Italy. Bull. Environ. Contam. Toxicol. 56, 729.

Van Wyk, E., 1992. A Biochemical Genetic Study of *Gyps coprotheres* with Notes on the Bioaccumulation of Pesticides in the Blood. M.Sc. Dissertation, Rand Afrikaans University, Johannesburg, South Africa.

Wiemeyer, S.N., Jurek, R.M. & Moore, J.F., 1986. Environmental contaminants in surrogates, foods, and feathers of California condors (*Gymnogyps californianus*). Environ. Monit. Assess. 6, 91.