Cadmium in the Environment and Its Impact on Birds

Pamela M. Whitehead
Philip E. Whitehead

Canadian Wildlife Service
Pacific and Yukon Region

1980

Table of Contents

Abstract

This review examines environmental cadmium emphasizing levels in food items of birds. The toxic effects of cadmium in experimental birds are summarized. Tissue levels in birds fed cadmium are compared to levels found in free-ranging birds.*

The mechanisms by which birds detoxify ingested cadmium and the distribution of the metal in avian tissues and eggs are discussed.

* All values are expressed in dry weight unless otherwise noted.

Summary and Conclusions

Cadmium is a toxic trace metal found throughout the environment. Although some plants and invertebrates eaten by birds can accumulate high levels of cadmium, most evidence indicates that it is not concentrated in marine or terrestrial food chains. However, cadmium is ubiquitous and has a long biological half-life so it is important to examine its chronic effects on the physiology of birds.

Birds exposed to high dietary levels of cadmium (> 700 ppm) show many acute effects: atrophied and discolored organs, flacid gut musculature, testicular necrosis, etc. There is evidence that low dietary levels can adversely affect reproduction and cause tissue damage. The severity of these effects is determined by several factors: dietary level of cadmium and other minerals, age, duration of exposure, etc. Values for all these factors usually are not determined in field studies. Consequently, the impact of cadmium cannot usually be predicted, from cadmium tissue levels alone.

White et al. (1978) determined that dietary cadmium levels up to 200 ppm, for as long as three months, had no histological, physiological, or reproductive effects on mallards. Cadmium levels in the tissues of these ducks (kidney - 194 ppm) were higher than levels found in most free-ranging birds (Appendices 1 and 2). Hull et al. (1977) reported even higher levels in free-ranging fulmar (kidney - 240 ppm) that were healthy and reproductively active.

Apparently birds can adjust to cadmium in their environment by binding it in a nontoxic form. Time is needed to induce the binding mechanism (metallothionein). Thus, chronic exposure might result in high tissue levels of cadmium, with most being bound to metalliothionien and detoxified. Alternatively, short term exposure might produce low tissue levels, but the cadmium might be bound to enzymes and exerting toxic effects. Consequently, the level of cadmium in avian tissue is not an especially good indicator of adverse physiological effects of the metal.

Cadmium levels are highest in the kidney and liver with very little transferred into eggs, even at high dietary levels. Consequently, the development and hatchability of chicks should be unaffected by the body burden of adult birds.

In the Fraser estuary, cadmium levels (water, sediment and invertebrates) are generally low. However, there are few data on levels in specific avian food species in this area.

Although there may be sites in British Columbia and the Yukon where cadmium levels are high (sewage outfalls, lead, and zinc mines, battery smelters, etc.), the probability of a significant number of birds being effected by acute exposure, is remote.

Introduction

Cadmium is a non-essential trace metal with known toxic effects. It is distributed throughout the environment in air, water, and soil from both natural sources and manufactured products.

Studies have shown that appreciable levels of cadmium can occur in the diets of many species of birds (Bull et al. 1977, Martin and Coughtrey 1975). It is the purpose of this report to summarize the effects of cadmium on birds, relating levels in the food chain to accumulation in tissue and possible effects of any particular body burden.

Sources of Cadmium

Cadmium is a relatively rare element closely related to zinc and found in nature wherever zinc occurs.

Mining and agricultural activities, industrial, and sewage effluents as well as natural weathering of rocks all release cadmium to the biosphere, especially that of the coastal marine environment.

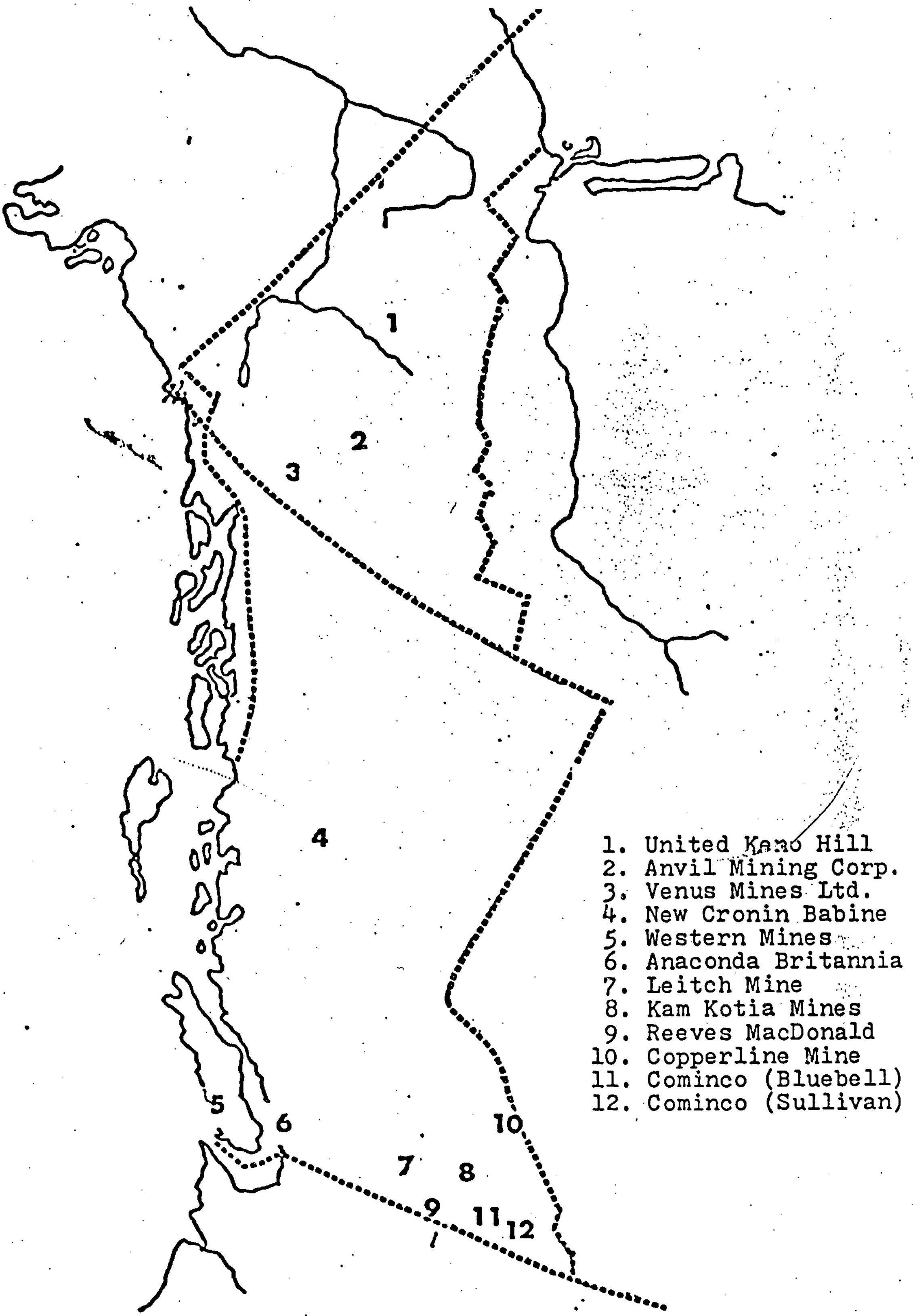
Cadmium is used in metallurgical and electroplating processes, in the manufacture of battery cells, as a constituent of paint pigments, and as a stabilizer in the manufacture of some plastics. Cadmium from these sources is often released into the environment in waste water effluent.

Significant volatilization of cadmium occurs during smelting of raw base metal ores, particularly lead and zinc, in the reclamation of iron and steel, and in incineration of waste products (Lymburner 1974). These atmospheric emissions settle back into soil, rivers, or oceans. The primary production sources of cadmium in British Columbia and the Yukon are shown in Figure 1.

Other important but less obvious sources of cadmium pollution are sewage sludge, fertilizers, rubber tires, and motor oil. The extent of environmental contamination is related to the intensity of use or production of these cadmium containing materials.

Figure 1

Primary production sources of cadmium in British Columbia and the Yukon (Lymburner, 1974)



Marine Water and Sediment

The concentration of cadmium in the oceans averages about 0.15 ppb (0.05-0.2 ppb) (Page and Bingham 1973). Upwelling currents can cause high cadmium levels in some areas. As these currents also bring nutrients to the surface they are often important feeding sites for sea birds (Bull et al. 1974).

Fleischer et al. (1974) noted that higher levels of cadmium in sea water than those generally found, would be expected from the cumulative natural input. The low levels found suggest that cadmium is being continuously deposited on the ocean bottom.

Cadmium levels in marine sediments from the Atlantic and Pacific oceans range from 0.1 to 1.0 ppm with some marine phosphate deposits having levels of cadmium in the range of 50-170 ppm (Caro 1964, cited by Page and Bingham [1974]). It is from these mineral deposits that many of the superphosphate fertilizers are produced that cause high cadmium levels in agricultural soils.

Fresh Water

The concentration of cadmium in fresh water is usually less than 1.0 ppb (Fleischer et al. 1974). In rivers and lakes polluted by cadmium, the metal is often undetectable in the water phase, while large concentrations may be found in suspended particles and bottom sediments. This is especially true at neutral or alkaline pH, or where high levels of organic material are present (Yamagata and Shigematsu 1970, cited in Friberg et al. [1974]).

Fraser River Estuary

The highest concentrations of cadmium in the lower Fraser River are found in mixed system wastewaters, particularly those receiving inputs from electroplaters (Table 1). The Lulu Island sewage treatment plant, where some of the highest levels of cadmium occur (mean 25 ppb, range 4-45 ppb), receives 40% of its total wastewater from one electroplating firm. In residential wastewater, cadmium is usually not detectable (Koch et al. 1977). Cadmium levels in the sediments from the Brunette River watershed ranged from 0-2.8 ppm with a mean of 0.28 ppm (Hall et al. 1976). These values are low in comparison to heavily industrialized systems such as the Illinois River (mean 2.0 ppm, range 0.2-12.1) (cited in Hall et al. 1976), and more closely resemble levels found in an unpolluted estuarine system - mean 1.0 ppm; range 0.17-1.2 (Taylor 1976) and non-industrial systems such a Rideau River (mean 0.46, range 0.15-1.0) (Hall et al. 1976). At Iona sewage treatment plant sediment values averaged less than 0.6 ppm (Greater Vancouver Sewerage and Drainage District 1974). Similar values at Iona were found by McGreer (1979).

Table 1. Cadmium levels in mixed-system wastewaters near Vancouver, B.C. (Koch et al. 1977).

Location	Cd (ppb)		
	Mean	Median	Range
UBC (North and South sewer)	-	< 1	< 1-7
English Bay	3	6	2-19
Iona Island S.T.P.	-	3	< 1-17
Burnaby Central	-	2	< 1-7
Burnaby South Slope	-	1	< 1-3
Lulu Island S.T.P.	25	29	< 4-45

Soils

The concentration of cadmium in uncontaminated soils is low, averaging 0.4 ppm with considerable variability due to the type of soil (Doyle 1977). For example, soils from sedentary rock contain higher levels of cadmium than those from igneous or metamorphic rocks. In clay and alkaline soils cadmium is absorbed and therefore less available while in acidic and sandy soils it is more mobile (Hiatt and Huff 1975).

Due to the acidic nature of soils in the lower mainland of B.C. cadmium will likely be readily available for uptake into plants and terrestrial invertebrates.

The extent of cadmium contamination of soils in the lower Fraser Valley was evaluated by John et al. (1972). Cadmium levels in surface samples of agricultural soils averaged 0.88 ± 0.79 ppm (range n.d. - 4.67 ppm) while levels were as high as 95 ppm in surface samples near a battery smelter in Richmond (mean 48.96 ppm, range 7.92-95.40 ppm). Soil profile samples taken near the smelter indicated that cadmium accumulated in the surface layer with little downward movement. This study also found agricultural soils collected from five sites near Vancouver contained substantially higher levels of cadmium (mean 1.92 ppm) than found in soils from rural areas (mean 0.69 ppm). This increased contamination may be attributed to the greater proximity of the sites to industrial and metropolitan pollution.

A similar study in England compared a woodland ecosystem to an industrial site and found levels of cadmium comparable to the previous study - industrial topsoil averaged 42 ppm compared with 2 ppm from the unpolluted site. In clay soil the industrial site had cadmium levels of 14 ppm while similar soil from the control area had no detectable level of the metal (Martin and Coughtrey 1975).

Plants

The cadmium content of most plants is similar to levels in soil or water (Friberg et al. 1971). However, some field crops and aquatic plants are capable of absorbing and accumulating substantial levels. The concentration of cadmium in plants depends on a number of factors:

- the species of plant
- the concentration of cadmium in soil or water
- the pH of medium
- the type of soil

Apparently, there is no mechanism for eliminating cadmium once it is incorporated into plant tissue (Fleischer et al. 1974). Thus, high levels of cadmium could be ingested by birds if contaminated plants constituted a major source of their food.

Field Crops

Williams and David (1973) found plants could accumulate 0.4 to 7% of the cadmium available in the soil. Sludge and superphosphate fertilizers can contribute to high cadmium levels in soil and, consequently, in plants. Corn grown in sewage-sludge amended soil contained cadmium levels 10 times higher than control plants, and increasing sludge application rates resulted in a linear increase in cadmium levels in corn (Hinesly et al. 1976). A comparison of cadmium uptake in oats grown on contaminated soil with those grown on relatively uncontaminated soil showed strong evidence of cadmium bioaccumulation in the roots (Table 2).

Table 2. Cadmium uptake in corn (from John et al. 1972).

	Cadmium Content (ppm)	
Material	Control	Contaminated Soil
Soil	1.3	46.4
Oat roots	-	205.1
Oat shoots	0.6	16.8

John et al. (1972) found, after 3 weeks growing in soil containing 100 ppm cadmium, levels of 387 ppm in radish roots and 138 ppm in lettuce tops. Values for control plants grown in soil containing 0.67 ppm cadmium were 7.4 ppm in radish roots and 2.3 ppm in lettuce tops. Potatoes, occasionally a food source of ducks wintering on the lower mainland, do not appear to accumulate cadmium to any extent. Potatoes growing in soil containing 20-36 ppm had levels averaging 0.36 ppm (Cannon 1970, cited in Page and Bingham [1973]).

Aquatic Plants

Some aquatic plants have the capacity to concentrate heavy metals from their environment, thus acting as natural depolluting agents.

Scirpus americanus, a major food source of snow geese and, to a lesser extent, of mallards, pintails, and green-winged teal can magnify the concentration of cadmium in water up to 35 times in stems and as high as 500 times in rhizomes. Levels of cadmium as high as 238.7 ppm were found in rhizomes after 72 h in water, containing 0.4 ppm cadmium (Charbonneau and Tremblay 1972). The aquatic plant Najas guadulepensis Spreng, growing in water containing levels of cadmium ranging from 0.005 ppm to 0.83 ppm deposited between 7.1 and 5429 ppm (ash wt) after 21 days exposure (Cearley and Coleman 1973). Valiela and Banus (1974) found that the marsh grass Spartina alteriflora is also able to incorporate cadmium from sediment into tops and shoots. Seaweed (Fucus sp.), considered a good indicator of heavy metal pollution, was sampled at Iona Sewage Treatment Plant (outfall side). Cadmium levels ranged from 3.0 to 6.7 ppm. These are low when compared with cadmium concentrations in seaweed from other estuaries, Bristol (13.8 ppm) and Severn (15-220 ppm) (Greater Vancouver Sewerage and Drainage District 1974).

Fish and Invertebrates

Invertebrates are known to concentrate heavy metals relative to environmental concentrations and could be a major source of cadmium contamination in avian food chains (Valiela and Banus 1974, Darracott and Watling 1974, Spehar et al. 1978).

Concentration factors as high as 10^5 have been reported in free ranging molluscs (Fleischer et al. 1974). Spehar et al. (1978) investigating bioaccumulation of cadmium in stoneflies (*Pteronarcys dorsata*), caddisflies (*Hydropsyche bettoni*), and snails (*Physa integra*) found residue levels 600 to 30,000 times greater than cadmium concentrations in the water after 28 d exposure (Table 3).

Table 3. Comparison of cadmium concentration in invertebrates to that of aquatic environment (from Spehar et al. 1978).

	Cadmium Content (ppm)	
Water	0.003	0.035
Snail (*Physa integra*)	40.0	200.0
Caddisfly (Hydropsyche *bettini*)	90.0	300.0

As well, this study found that some aquatic invertebrates such as stoneflies are relatively insensitive to cadmium even after

28 d exposures.

Bull and Murton (1977) proposed the sea skate (*Halobates micans*) as a possible worldwide indicator of cadmium contamination. The mean concentration in 111 samples was 22.7 ppm ranging from 0 to 309 ppm.

Fraser River Estuary

In the Fraser estuary, cadmium concentrations in the water are extremely low and this is reflected in low levels in marine organisms.

In over 300 specimens of 14 species of fish from the lower Fraser, cadmium was detected in only one fish, a white sturgeon (*Acipenser transmontanus*) (0.38 ppm wet wt) (Northcote et al. 1975).

Bawden et al. (1973) in a baseline study of Roberts and Sturgeon banks found cadmium was less than 2 ppm in samples of all major faunal species except one oyster (*Crassostrea gigas*) from Sturgeon Bank (12 ppm) and in two shrimp *Callianassa californiensis*), sampled from Roberts Bank (7.4 ppm) and Sturgeon Bank (3.7 ppm).

At the Iona Sewage Outfall the levels of cadmium in oysters (*Crassostrea gigas*) exceeded the limit set for human consumption (0.5 ppm wet wt) and there was evidence of cadmium accumulation in crabs and oysters (Fraser River Estuary Study 1978). Studies by the Greater Vancouver Sewerage and Drainage District (1974) found mean values of cadmium of 19 ppm in oysters from this area from the North end of the Iona Jetty with maximum values of 26.7 ppm in oysters from the outfall side.

Average cadmium levels of 1.7 ppm occurred in sea cucumber (*Molpadia intermedia*) found in the Point Grey dumpsite in the Strait of Georgia. There appears to be no indication of elevated cadmium levels in this area (Thompson and Paton 1978).

Ingestion of Cadmium by Birds

Birds occupy a sensitive position as top consumers in many food chains. An understanding of the mechanisms of absorption, tissue distribution, and elimination of cadmium would allow predictions of the concentration or dilution of this element in the avian system.

Absorption

The duodenum appears to be an important regulator of cadmium uptake in birds. At low to moderate levels of exposure the duodenum actively binds ingested cadmium, thus preventing its accumulation in tissue and subsequent damage (Jacobs et al. 1978, Koo et al. 1978, and Sell 1975). The levels of cadmium in the duodenum of Japanese quail (Coturnix coturnix japonica) were as high as 16 times greater than dietary levels of cadmium (Jacobs et al. 1978).

The portion of gut distal to the duodenum, the jejunum, also appears to concentrate cadmium, although to a lesser degree than the duodenum (Jacobs et al. 1978).

Most cadmium ingested by birds is eventually excreted, for example, hens excreted 70-80% of a single oral dose of cadmium during the first 24 h and 90-93% by 96 h (Sell 1975).

Cadmium 109 began appearing in droppings of sparrows (Spizella passerina) 8 h after feeding and after 192 h, 77% of the tagged metal had been eliminated (Anderson and Van Hook 1973).

Only a small percentage of the cadmium ingested by birds is found in tissues other than the duodenum. Sparrows retained 8% of dietary cadmium after 20 days (Anderson and Van Hook 1973); quail, 2.97% (Jacobs and Fox 1972); and hens, 2.36% (Sell 1975).

These figures are comparable to those found for mammals, with 1-8% of cadmium being incorporated into tissue other than gut (Friberg et al. 1971, Doyle et al. 1974).

Cadmium retention may vary depending on exposure time. Hens maintained on a diet of 60 ppm cadmium for 20 d retained a significantly higher percentage of total cadmium intake (3.65%) than hens fed a single oral dose (2.36%) (Sell 1975).

It is well documented that the kidney and liver retain the highest percentage of cadmium in the tissues. Anderson and Van Hook (1973) found 84% of the cadmium in the tissue of sparrows (excluding duodenum) was concentrated in kidney and liver. Similar results were found for chickens and mallards (Anas platyrhynchos) (White and Finley 1977, Jacobs et al. 1978, Dyer et al. 1974) with concentrations in the kidney approximately twice that of the liver. Cadmium residues in other tissues are low relative to kidney and liver (Dyer et al. 1974). White and Finley (1978) found low cadmium levels in blood, brain, muscle, and gonad tissue of mallards.

Moderate excesses of essential elements also appear to decrease absorbtion and retention of low dietary levels of cadmium in all tissues except the duodenum. Birds fed minerals at levels twice that in basal diets retained 25% less cadmium in liver, kidneys, and whole body (Jacobs et al. 1978). The tissue most affected by mineral supplements was the jejunum-cloacal section of the gut where levels of cadmium were reduced by a factor of 4 times. Jacobs et al. (1973) suggest that at low level exposure cadmium may be effectively bound in the duodenum, but transported to other tissue from the jejunum.

The exact mechanism by which cadmium is transported through the intestinal mucosa is unknown. Although some researchers suggest that it may involve mechanisms similar to copper and iron transport (Fleischer et al. 1974).

Nordbert (1972) found cadmium was distributed to organs minutes after a single injection where it was bound to a protein of low molecular weight (10,000) called metallothionein.

This protein contains 24 cysteine sulfhydryl groups on each molecule (Margoshes and Vallee 1957). Metalliothionein acts by binding heavy metals (one metal ion to three sulfhydryl groups) and preventing them from binding to sulfhydryl groups on enzymes (Brown 1978).

Metallothionein complexes are usually stored solubilized in liver and kidney cytoplasm. Cadmium not bound to metallothionein may be bound to high molecular weight proteins such as enzymes, which are rendered nonfunctional causing pathological changes. Thus, metallothionein can be considered as a storage site of cadmium in a non-toxic state (Friedberg 1974).

Piscator (1964, cited in Brown [1978]) proposed metallothionein is synthesized in liver tissue where it is bound to heavy metals and transported to the kidney, and stored in the cortex. A small amount of the body burden of cadmium may be excreted, particularly if renal-turbular damage has occurred

(Piscator 1964; Nordberg 1972, cited in Brown [1978]). A number of researchers have studied this Cd-binding protein in birds (Freeland and Cousins 1973, Nishiura et al. 1976, Sunda et al. 1974, Hill 1974).

If birds are chronically exposed to cadmium, newly synthesized Cd-Bp will increase in the cells until progressive accumulation of cadmium exceeds the binding capacity of metallothionein, with the resulting "spillover" to high molecular weight proteins. This "spillover" depends on the level of metallothionein in tissue and whether synthesis of new binding protein can keep pace with metal inflow.

Thus, the actual level of cadmium in avian tissue is less important in determining toxicity than the ratio of metallothionein - Cd complex to cadmium bound to high molecular weight proteins (enzymes).

Chronic exposure might result in high tissue levels of cadmium, all bound to metallothionein and hence detoxified, while shorter periods of exposure could result in lower tissue levels of cadmium, but with a large proportion of the cadmium being bound to enzymes with resulting toxic effects (Brown 1978). Bull and Murton (1977) found extremely high levels of cadmium in apparently healthy and reproductively active seabirds (Appendix 1). They suggested these birds have evolved mechanisms to cope in an environment containing cadmium.

Nishimura et al. (1976) found large differences in cadmium retention between rats and quails maintained on diets containing identical cadmium levels. It is well established that tissue levels as well as nutritional requirements for metals in the zinc group are higher in quail than rats. Possibly the difference in tissue uptake depends on a greater number of Cd-binding sites being available in quail tissue (Nishimura et al. 1976). This suggests that the capacity of tissue to bind cadmium and the number of cadmium binding sites may vary considerably between individuals and between species.

Brown (1978) found good indications in the wildlife community at Iona Island that the ratio of metallothionein-bound cadmium to cadmium bound to proteins of high molecular weight increased both with increased exposure to cadmium and with increasing trophic level. Brown found mussels (*Mytilus edulis*) from a relatively unpolluted area had a lower metallothionein bound metal to enzyme bound metal ratio (approx. 0.37) than mussels from more polluted sites (approx. 0.48). On a higher trophic level, greater scaup (*Aythya herodias*) had the highest metal loading ratio (0.70) (Brown et al. 1977).

Absorbtion and Distribution in Eggs

A number of studies have reported the absorbtion and tissue distribution of cadmium fed to laying birds and the extent of transfer of dietary cadmium into eggs (White and Finley 1978, Vogt et al. 1977, Koo et al. 1978, Dyer and Born 1974, Sell 1974).

The data show that very little cadmium is transferred into eggs of chickens or ducks even when high levels of this element are added to the diet.

White and Finley (1978) found very low levels of cadmium in mallard eggs (Table 4).

Table 4. Cadmium uptake in mallard eggs (White and Finley 1978).

	Cadmium Concentration (ppm)			
Diet	Control	2	20	200
Eggs	< 0.007	< 0.007	0.01	0.04

Similar results for mallards and chickens on diets of 600 ppm cadmium were found by Hennig et al. (1971) and Sell (1975). Dyer and Born (1974) injected trace amounts of 109-Cd into leghorn chickens and found the average egg contained about 0.1% of the whole body cadmium level with about 80% of the total egg residue in the yolk, 15% in the white, and 5% in the shell.

In a 309 day laying test hens were maintained on diets containing 5 and 10 ppm cadmium. Control eggs had levels of 0.005 ppm cadmium in whites and 0.02 ppm in yolks. The 5 ppm diet had no effect on cadmium contents while the 10 ppm diet increased the cadmium content in yolks from 0.02 to 0.1 ppm (Vogt et al. 1977).

A survey of heavy metal concentrations in seabirds of North America and Antarctic found cadmium levels of 0.1 ppm in both pelican (*Pelecanus occidentalis*) and Antarctic tern (*Sterna vittata*) eggs and 0.2 ppm in common tern (*Sterna hirundo*) eggs. However, the authors noted that the levels were close to the limit of detection and should be interpreted with caution (Anderlini et al. 1972).

In summary, these studies indicate there is a poor correlation between dietary cadmium and cadmium levels in eggs.

Biological Half-life

An important aspect of cadmium metabolism is the biological half-time. Studies on mammals indicate a very long half-life; 500 days in dogs and 200-300 days in rats. However, experiments have shown highly variable values depending on dose, route of intake, and single or repeated exposure. Values for half-life can also be misleading if renal tubule damage has occurred as a result of continuous exposure to cadmium (Friberg et al. 1971).

Anderson and Van Hook (1973) studied the uptake and biological turnover of 109-cadmium in chipping sparrows. The half-life in the gut of these birds was 0.5 d while 99 d were required for elimination of one half the tissue burden of cadmium. The long term presence of this metal in the liver and kidney could increase the potential for toxic effects. However, this long half-life is probably a result of the metal being selectively bound to metallothionein and thus detoxified.

<u>Biomagnification</u>

Although cadmium is accumulated in some avian food species it is not appreciably biomagnified in birds. Fleischer et al. (1974) noted cadmium levels in plankton-eating petrels (liver - 20 ppm) are no higher than levels found in zooplankton (13 ppm). He also reported that levels in the livers and kidneys of fish-eating birds are only about 10 times those of fish from the same area. Consequently, he concluded that cadmium is not concentrated in marine food chains.

Similar orders of magnitude were found by Martin and Coughtrey (1975) in a comparison of cadmium concentrations in three trophic levels in close proximity to a lead-zinc smelter (Table 5).

Table 5. Cadmium concentrations in three trophic levels (Martin and Coughtrey 1975).

	Range of Cd Concentration (ppm)
Producers - plants	6 - 25
Herbivores - woodlice, slugs, snails	29 - 171
Carnivores - thrush (kidney)	387
- sparrowhawk (kidney)	66

Hineley et al. (1976) showed the increasingly higher cadmium levels in soil resulted in a linear increase in cadmium concentration in corn. However when this corn was fed to pheasants the increased cadmium levels in the diet did not result in a linear response in the tissues. However, there are few studies where cadmium residue levels have been determined in successive species in a food chain and, in particular, there are few data pertaining to cadmium residues in the avian food chain.

Toxic Effects

The toxic effects of cadmium have been attributed to the interference of this non-essential metal with biologically important metals in metalloenzymes (Brown 1978). These enzymes are rendered nonfunctional by conformational changes brought about by binding metals such as cadmium with properties different than the required metals such as zinc or copper. As a result, substrate molecules may no longer fit binding sites on the enzyme (Friedberg 1974, cited in Brown [1978]).

Effects on Body Weight and Food Consumption

One of the effects found in birds maintained on a diet containing cadmium is a decrease in food intake and subsequent weight loss, although some studies have reported otherwise.

Hennig et al. (1968) reported the food intake of laying hens was reduced by 50% after 3 d on a diet containing 200 ppm cadmium and, in a later study (Hennig 1971), confirmed the finding with mallard ducks. Sell (1975) reported similar results for hens maintained on 60 ppm Cd after 6 d.

However, White and Finley (1977) reported dietary cadmium (2, 20, 200 ppm) did not cause significant body weight loss or decreased food consumption in adult mallard ducks in 30 day trials.

Sturkie (1973) also reported no significant weight loss in adult chickens injected daily with 2 mg/kg cadmium for 22 d.

Effects on Egg Production

Low, chronic dietary levels of cadmium (< 100 ppm) appear to have little or no effect on egg production or egg fertility. Slight reduction in egg production was shown in laying hens at dietary cadmium levels of 60 ppm (Sell 1975) while Hennig et al. (1968) found a cessation of egg production in hens maintained at 200 ppm. Similar results were found in mallard ducks (Hennig et al. 1971).

White and Finley (1977) found egg production in mallards suppressed at 200 ppm but no effect from dietary levels of 2 and 20 ppm.

Vogt et al. (1977) noted cadmium fed to hens at 5 and 10 ppm did not affect laying performance, however dietary levels of 10 ppm resulted in decreased egg shell stability.

Although dietary cadmium (100 to 200 ppm) was shown to affect egg production in mallards, no measureable effect on fertility of eggs was found (Hennig et al. 1971, cited in Sell 1976).

Effects on Iron Metabolism

Anemia is common in animals exposed to cadmium. Freeland and Cousins (1973) produced anemia in young chicks with dietary cadmium of 75 ppm for 17 d. Similar results were found in young quail (Jacobs et al. 1972). In contrast White and Finley (1977) fed adult mallards cadmium up to 200 ppm without significant reduction of hematocrits or hemoglobin thus suggesting that anemia may be an age-related phenomenon.

Effects on Tissues

Intestine

Cadmium can result in damage to intestinal tissue. However, the effects appear to be age related and are reduced in adult birds and over time. Lesions were produced in the small intestine of quail maintained on a diet of 75 ppm for 4 weeks (Richardson and Fox 1974). Day old quail fed 1 ppm cadmium for 2 d showed degeneration of absorptive cells at villous tips. Quail fed the same dietary levels for a longer period (14 d) appeared to adapt and only half the birds showed any adverse histological effects. Longer intervals (28 and 49 d) further reduced any effects (Mason et al. 1977).

Kidney

The most common toxic effect of chronic cadmium poisoning in man and experimental animals is renal turbular dysfunction. Adverse changes in tubular function cause increased excretion of low molecular weight globins and an increase in urinary cadmium excretion.

White et al. (1978) found that considerable accumulation of dietary cadmium in adult mallard kidneys over an extended period is necessary to produce kidney damage. Diets of 2 and 20 ppm did not cause any appreciable renal damage, while 200 ppm caused slight to severe cellular degeneration and increased kidney weights after 60 and 90 d.

Similar results were found in quail and chicks (Richardson et al. 1974, Pritzl et al. 1974).

Testes

Cadmium can cause acute testicular necrosis in mammals and similar effects have been found in birds.

Richardson et al. (1974) induced testicular hypoplasia feeding young quail dietary cadmium (75 ppm) during the first 4 wk after hatching. Spermatogenic cells failed to mature at 4 wk of age but normal maturation occurred after 6 wk.

Ovaries

Few reports are concerned with the effects of cadmium on the female reproductive organs in either mammals or birds. One avian study using female koel (Eudynamys scolopacca) and a single injection of cadmium (0.15 mg/kg) found a significant decrease in weight of ovaries and oviduct as well as cellular destruction. This study reported a significant reduction of epinephrine in adrenal tissue which may have suppressed gonadal activity (Sarkar et al. 1975).

References

Anderlini, V.C., P.G. Connors, R.W. Risebrough, and J.H. Martin. 1972. Concentrations of heavy metals in some Antarctic and North American sea birds. Pp. 49-62 in B.C. Parker, ed. Proc. symp. conserv. probl. Antarctica. Virginia Polytechnic Inst. and State Univ.

Anderson, S.H. and R.I. Van Hook, Jr. 1973. Uptake and biological turnover of cadmium-109 in chipping sparrows Spizella-passerina. Environ. Phys. and Biochem. 3(5): 243-247.

Badsha, K.S. and M. Sainsbury. 1977. Uptake of zinc, lead, and cadmium by young whiting in the Severin estuary. Marine Pollution Bulletin 8(7): 164-166.

Baker, F.D., C.F. Tumasonis, W.B. Stone, and B. Bush. 1976. Levels of PCB and trace metals in waterfowl in New York state. N.Y. Fish and Game Journal 23(1): 82-90.

Banus, M.D., I. Valiela, and J.M. Teal. 1975. Lead, zinc, and cadmium budgets in experimentally enriched salt marsh ecosystem. Estuarine and Coastal Marine Science 3(4): 421-430.

Bawden, C.A., W.A. Heath, and A.B. Norton. 1973. A preliminary baseline study of Roberts and Sturgeon banks. Westwater Research Centre tech. report no. 1. Univ. of B.C., Vancouver, B.C. 54 pp.

Benedict, A.H., K.J. Hall, and F.A. Koch. 1973. A preliminary water quality survey of the lower Fraser River system. Westwater Research Centre tech. report no. 2. Univ. of B.C., Vancouver, B.C. 50 pp.

Birge, W.J. and O.W. Roberts. 1976. Toxicity of metals to chick embryos. Bull. of Environ. Contam. Toxicol. 16(3): 319-324.

Boyle, E.A., F. Sclater, and J.M. Edmond. 1976. On the marine geochemistry of cadmium. Nature 263: 42-44.

Brown, D.A., C.A. Bawden, and K.W. Chatel. 1977. The wildlife community of Iona Island jetty, Vancouver, B.C. and heavy metal pollution effects. Environmental Conservation 4(3): 213-216.

Brown, D.A. 1978. Toxicology of trace metals: metallothionein production and carcinogenesis. Ph.D. thesis, Univ. of B.C. 271 pp.

Bull, K.R., R.K. Morton, D. Osborn, P. Ward, and L. Cheng. 1977. High levels of cadmium in Atlantic sea birds and sea skaters. Nature 269(5628): 507-509.

Burch, G.E. and J.J. Walsh. 1959. The excretion and biological decay rates of $Cd^{115}M$ with a consideration of space, mass, and distribution in dogs. J. Lab. Clin. Med. 54(66): ??

Cannon, L. 1970. Trace element excesses and deficiencies in some geochemical provinces of the United States. P. 21 in D.D. Hemphill, ed. Proc. Univ. of Missouri, 3rd ann. conf. on trace substances in environ. health. Univ. of Missouri, Columbia, Mo.

Caro, J.H. 1964. Superphosphate: its history, chemistry, and manufacture. U.S. Dept. of Agricul. and Tenn. Valley Auth. U.S. Printing Office, Washington, D.C. P. 273.

Cearley, J.E. and R.L. Coleman. 1973. Cadmium toxicity and accumulation in southern Naiad. Bull. of Environ. Contam. and Toxicol. 9(2): 100-101.

Charbonneau, M. and J.-L. Tremblay. 1972. Etude du role de Scirpus americanus pers. dans la depollution des eaux contaminees par les metaux lourds. Le Naturaliste Canadien 99: 523-532.

Darracott, A. and H. Watling. 1975. The use of mollusks to monitor cadmium levels in estuaries and coastal marine environments. Trans. of the Royal Soc. of South Africa 41(4): 325-338.

Doyle, J.J. 1977. Effects of low levels of dietary cadmium in animals. A review. J. of Environ. Qual. 6(2): 111-116.

Dyer, R.D. and G.S. Born. 1974. The distribution of intra-peritoneally injected cadmium - ^{115}M in chickens 7(2): 119-124.

Fleischer, M., A.F. Sarofim, D.W. Fassett, P. Hammond, H.T. Shacklette, I.C.T. Nisbet, and S. Epstein. 1974. Environmental impact of cadmium: A review by the panel on hazardous trace substances. Environ. Health Perspec. 7: 253-323.

Freeland, J.H. and R.J. Cousins. 1973. Effect of dietary cadmium on anemia iron absorbtion and cadmium binding protein in the chick. Nutrition Reports International 8(5): 337-347.

Friberg, L., M. Piscator, G. Nordberg, and T. Kjellstrom. 1973. Cadmium in the environment, II. U.S. Environmental Protection Agency, Raleigh, N.C. publ. no. EPA-R2-73-190. 169 pp.

Friedberg, F. 1974. Effects of metals binding on protein structure. Quart. Rev. Biophys. 7: 1-33.

Fullmar, C.S., T. Gru, and R.H. Wasserman. 1978. Effect of cadmium administration on intestinal calcium absorption and vitamin D dependent calcium binding protein. Fed. Proc., Fed. Amer. Soc. Exper. Bio. 37(3): 408.

Gardiner, J. 1974. The chemistry of cadmium in natural water - I. A study of cadmium complex formation using the cadmium specific - ion electrode. Water Research 8: 23-30.

Greater Vancouver Sewerage and Drainage District . 1974. Environmental studies at Iona Island. B.C. Research Dept. no. 2 prep. 162 pp.

Haghiri, I. 1973. Cadmium uptake by plants. J. Envir. Qual. 2(1): 93-96.

Hall, K.J., I. Yesaki, and J. Chan. 1976. Trace metals and chlorinated hydrocarbons in the sediments of a metropolitan watershed. Westwater Research Centre tech. report no. 10. Univ. of B.C., Vancouver, B.C. 74 pp.

Hardisty, M.W. and R.J. Huggins. 1974. Ecological implications of heavy metal in fish from the Severn estuary. Marine Pollution Bulletin 5(1): 12-18.

Hennig, A., G. Hartmann, K. Gruhn, and M. Ande. 1968. Kontrazeptive wirkung von cadmium bei legehennen. Die naturwissen - schaften. 55: 551-552.

Hennig, A., K. Georgi, and H. Jeroch. 1971. Fur kontrazeptiven wirkung des kadmiums. Arch. Exp. Vet. Med. 25: 793-798.

Hiatt, V. and J.E. Hoff. 1975. The environmental impact of cadmium: an overview. Intern. J. Environ. Studies 7: 277-285.

Hill, C.H. 1974. The induction of chick mucosal cytosol binding proteins for cadmium and zinc by diets containing these elements. Fed. Proc., Fed. Amer. Soc. Exper. Bio. 33(3 pt.1): 699.

Hinesly, T.D., E.L. Ziegler, and J.J. Tyler. 1976. Selected chemical elements in tissues of pheasants fed corn grain from sewage sludge amended soil. Agro-ecosystems 3(1): 11-26.

Hoffman, R.D. and R.D. Curnow. 1973. Toxic heavy metals in Lake Erie herons. Proc. Confer. on Great Lakes research 16: 50-53.

Huckabee, J.W. and B.C. Blaylock. 1974. Microcosm studies on the transfer of mercury, cadmium, and selenium from terrestrial to aquatic ecosystems. Trace Substances in Environmental Health 8: 219-228.

Jacobs, R.M., A.O. Lee Jones, M.R.S. Fox, and B.E. Fry, Jr. 1978. Retention of dietary cadmium and the ameliorative effect of zinc, copper, and manganese in Japanese quail. Journal of Nutrition 108(1): 22-32.

John, M.K., H.H. Chuah, and C.J. VanLaerhoven. 1972. Cadmium contamination of soil and its uptake by oats. Envir. Sci. and Tech. 6(6): 555-557.

Kirpatrick, D.C. and D.E. Coffin. 1975. Trace metal content of chicken eggs. Journal of the Sci. of Food and Agric. 26(1): 99-103.

Koch, F.A., K.J. Hall, and I. Yesaka. 1977. Toxic substances in the wastewaters from a metropolitan area. Westwater Research Centre tech. report no. 12. Univ. of B.C., Vancouver, B.C. 107 pp.

Koo, S.I., C.S. Fulmar, and R.H. Wasserman. 1978. Intestinal absorbtion and retention of cadmium-109. Effects of calcium vitamin D-3 status and other variables. Fed. Proc., Fed. Amer. Soc. Exper. Bio. 37(3): 405.

Lu, P.Y., R.L. Metcalf, R. Forman, R. Vogel, and J. Hassett. 1975. Model ecosystem studies of lead and cadmium and of urban sewage sludge containing these elements. J. Envir. Qual. 4(4): 505-509.

Lymburner, D.B. 1974. Environmental contaminants inventory study no. 2. The production, use, and distribution of cadmium in Canada. Canada Centre for Inland Waters, Inland waters Directorate report series no. 39. Burlington, Ontario. 71 pp.

McGreer, E.R. 1979. Studies of the bivalve, Macoma balthica (L.) on a mudflat receiving sewage effluent and on an unpolluted mudflat, Fraser River estuary, British Columbia. M.Sc. thesis, Univ. of B.C. 99 pp.

Martin, M.H. and P.J. Coughtrey. 1975. Preliminary observations on the levels of cadmium in a contaminated environment. Chemosphere 4(3): 155-160.

Martin, W.E. and P.R. Nickerson. 1973. Mercury, lead, cadmium, and arsenic residues in starlings, 1971. Pest. Monit. J. 7(1): 67-72.

Mason, K.E., M.E. Richardson, and M.R.S. Fox. 1977. Enteropathy caused by 1 or 10 parts-per-million dietary cadmium. Fed Proc., Fed. Amer. Soc. Exp. Bio. 36(3): 1152.

Murton, R.K., D. Osborn, and P. Ward. 1978. Are heavy metals pollutants in Atlantic sea birds. Ibis 120(1): 106-107.

Nishimura, M., H. Tanaka, and N. Urakawa. 1976. Cadmium binding protein in tissues of male rats and Japanese quail. Jap. Jour. Vet. Sci. 38(6): 619-628.

Nordberg, G.F. 1972. Cadmium metabolism and toxicity. Environ. Physiol. Biochem. 2: 7-36.

Northcote, T.G., N.T. Johnston, and K. Tsumura. 1975. Trace metal concentrations in lower Fraser River fishes. Westwater Research Centre tech. report no. 7. Univ. of B.C., Vancouver, B.C. 41 pp.

Ottaway, J.M. and W.C. Campbell. 1976. Determination of cadmium in the livers and kidneys of puffins by carbon furnace atomic absorption spectrometry. Inter. Jour. Envir. Analyt. Chem. 4(3): 233-239.

Page, A.L. and F.T. Bingham. 1973. Cadmium residues in the environment. Pesticide Reviews 48: 1-43.

Parslow, J.L.F., D.J. Jefferies, and M.C. French. 1972. Ingested pollutants in puffins and their eggs. Bird Study 19: 18-33.

Parsons, T.R., C.A. Bawden, and W.A. Heath. 1973. Preliminary survey of mercury and other metals contained in animals from the Fraser River mud-flats. J. Fish. Res. Board Canada 30: 1014-1016.

Piscator, M. 1964. On cadmium in normal human kidneys together with a report on the isolation of metallothionein from livers of cadmium-exposed rabbits. N. Hyg. Tidskr. 45: 76-82.

Pritzl, M.C., Y.H. Lie, E.W. Kienholz, and C.E. Whiteman. 1974. The effect of dietary cadmium on development of young chickens. Poultry Science 53(6): 2026-2029.

Richardson, M.E. and M.R.S. Fox. 1974. Dietary cadmium and enteropathy in the Japanese quail: histochemical and ultra structural studies. Laboratory Investigation 31(6): 722-731.

Rubin, A.J. 1974. Aqueous environmental chemistry of metals. ??

Sarkar, A.K., S.K. Moitra, and T. Midya. 1976. Histological, histochemical, and biochemical effects of cadmium chloride in female koel _Eudynamys-scolopacea_. Acta Histochemca 57(2): 205-211.

Sell, J.L. 1975. Cadmium and the laying hen, apparent absorption, tissue distribution, and virtual absence of transfer into eggs. Poultry Science 54(5): 1674-1678.

Shippee, R.L., P.E. Stake, K.L. Hermayer, and R.J. Wood. 1977. Tissue zinc, cadmium, and copper content and zinc to copper ratios of hens fed graded levels of zinc and cadmium. Fed. Proc., Fed. Amer. Soc. Exp. Bio. 36(3): 1176.

Spehar, R.L., R.L. Anderson, and J.T. Fiandt. 1978. Toxicity and bio-accumulation of cadmium and lead in aquatic invertebrates. Environmental Pollution 15(3): 195-208.

Sturkie, P.D. 1973. Effects of cadmium on electro-cardiogram, blood pressure, and hematocrit of chickens. Avian Disease 17: 106-110.

Suda, T., N. Horivchi, N. Otaki, S. Sasaki, and M. Kimura. 1974. Mechanisms of biological prevention of cadmium poisoning. Journal of Dental Research 53(5 pt. 1): 1092.

Taylor, D. 1976. Distribution of heavy metals in the sediment of an unpolluted estuarine environment. Science of the Total Environment 6(3): 259-264.

Thompson, J.A.J. and D.W. Paton. 1978. Heavy metals in benthic organisms from Point Grey dumpsite - Vancouver, B.C. A preliminary report. Pacific Marine Science report 78-11. Unpubl. manus.

Torwer, J.C., S.R.B. Solly, J.C.M. Mol-Krijnen, and V. Shanks. 1978. Organochlorine and heavy metal levels in some birds from New Zealand estuaries. N.Z. Jour. of Science 21: 99-102.

Valiela, I. and M.D. Banus. 1974. Response of salt marsh bivalves to enrichment with metal containing sewage sludge and retention of lead, zinc, and cadmium by marsh sediments. Environmental Pollution 7(2): 149-158.

Vogt, H., K. Nezel, and S. Matthes. 1977. Effect of various lead and cadmium levels in broilers and laying rations on the performance of the birds and on the residues in tissues and eggs. Nutrition and metabolism 21(suppl. 1): 203-204.

White, D.H. and T.E. Kaiser. 1976. Residues of organochlorines and heavy metals in ruddy ducks from the Delaware River 1973. Pesticide Monitoring Journal 9(4): 155-156.

White, D.H., M.T. Finley, and J.F. Ferrell. 1978. Histopathologic effects of dietary cadmium on kidneys and testes of mallard ducks. J. of Toxicology and Environmental Health 4: 551-558.

White, D.H. and M.T. Finley. 1978. Uptake and retention of dietary cadmium in mallard ducks. Environmental Research 17: 53-59.

Williams, C.H. and D.J. David. 1973. The effect of superphosphates on the cadmium content of soils and plants. Aust. J. Soil. Res. 11: 43.

Yamagata, N. and Shigematsu, I. 1970. Cadmium pollution in perspective. Bull. Inst. Public Health (Tokyo) 19(1): ?.

APPENDIX 1.0

Cadmium Levels (ppm, dry wt) -- Free Ranging Birds

Species	No.	Liver		Kidney		Ref.[1]
		Mean	Range	Mean	Range	
Fulmar	4	29.0	9.1-50.1	125.9	46.7-24.0	1
(Fulmarus glacialis)	1	159				2
Manx Shearwater	4	24.0	14.6-39.9	136.0	67.0-231	1
(Puffinus puffinus)	1	23.8				
Leach's Petrel (Oceanodroma leucorhoa)	3	33.0	20.6-57.0	92.2	68.5-128	1
Ashy Petrel (Oceanodroma homochroa)	10	53.2	32.7-73.7			4
Wilson's Petrel	10	20.3	14.5-26.1			4
(Oceanites oceanicus)	10	20.7	15.6-25.6			4
Snow Petrel (Pagodroma miua)	10	27.7	15.5-39.9			4
Storm Petrel (Hydrobates pelagicus)	4	17.7	9.2-26.5	39.4	30.2-52.9	1
Great Blue Heron (Ardea herodias)	1	7.07	(muscle) (nestling)			13+
Canada Geese (Branta canadensis)	9	N.D.				6+
Mallard	6	N.D.				6+
(Anas platrhynchos)	40*	0.436	.379-.493	1.954	1.922-1.986	11+
Black duck (Anas rubripes)	7	N.D.				6+
Canvasback (Aythya valisineria)	5		N.D.-4			6+
Greater Scaup (Aythya marila nearctica)	7		N.D.-7.14			6+

APPENDIX 1.0 Continued ... (2)

Species	No.	Liver Mean	Liver Range	Kidney Mean	Kidney Range	Ref.[1]
Bufflehead (Bucephala albeola)	4		N.D.			6+
White-winged scoter (Melanitta deglandi)	4		N.D.-7.14			6+
Scoter (Melanitta	1	23				12
Ruddy Duck (Oxyura jamaicensis)	8	2.18	1.46-5.71			7+
Sparrowhawk (Accipiter nisus)	2			32.8	3.7-61.9	5
Ruffed Grouse (Bonasa umbellus)	1	7.29		184		8+
S. Is. Pied Oyster - catcher (Haematopus ostralegus finschi)	16	0.69		3.70		10+
Pied Stilt (Himan topus leucocephalus)	23	0.46		3.69		10+
Herring Gull (Larus argentatus)	1	12.0				2
Black-backed Gull (Larus dominicanus)	34	2.18		11.82		10+
Red-billed Gull (Larus novae hollandiae scopulinus)	29	1.02		8.37		11+
Puffin (Fratercula arctica)	3	20.8	14.1-29.4	103.0	75.1-125	1
	5	17.0	12-17	79.0	33-96	3
	8	8.7	2.9-22.3			2
Robin (Turdus migratorius)	1	1.94		7.55		8+
Thrush (Turdus philomelos)	1			387		5

APPENDIX 1.0 Continued ... (3)

Species	No.	Liver		Kidney		Ref.[1]
		Mean	Range	Mean	Range	
Starling (*Sturnus vulgaris*)	1	2.04		3.57		8+
	51	0.20	0.179-0.7	(whole body)		9+
Pureko (*Porphyrio porphyrio melanotus*)	27	0.28		0.66		10+

[1] References:

1. Bull et al. 1977
2. Parslow et al. 1972
3. Ottaway and Campbell 1976
4. Anderlini et al. 1972
5. Martin and Coughtrey 1975
6. Baker et al. 1976
7. White and Kaiser 1976
8. Fleischer et al. 1974
9. White et al. 1977
10. Turner et al. 1977
11. White and Fincey 1978
12. Canadian Wildlife Service
13. Hoffman and Curnow 1973
14. Hinesly et al. 1976
15. Anderson and Van Hook 1973
16. Jacobs et al. 1977
17. Pritzl et al. 1974

\+ Original data expressed as wet weight - assumed 72% moisture.

* Experimental controls.

APPENDIX 2.0

Levels of Cadmium in Kidney and Liver of Captive Birds

Maintained on Dietary Cadmium

Species (No.)	Dietary Level ppm	Time	Kidney	Liver	Ref.[1]
Mallard (40)	2	30 d	5.50		11
(*Anas platyrhynchos*)	2	90 d	16.50		11
	20	30 d	47.82		11
	20	90 d	194.04		11
	200	30 d	314.29		11
	200	90 d	275.79		11
Pheasants (45)	0.17	99 d	5.57	1.24	14
(*Phasianus colchicus*)	0.33	99 d	8.66	1.72	14
	0.59	99 d	9.41	1.99	14
Chipping Sparrows (6) (*Spizella passerina*)	0.30	21 d	0.054	0.025	15+
Japanese Quail (20)	.007	14 d	10.04	4.54	16+
(0-14 d old)	" (and mineral suppl.)	14 d	6.39	3.46	
(*Coturnix coturnix japonica*)	0.518	14 d	76.79	33.46	
	" (and mineral suppl.)	14 d	47.86	21.57	
	3.64	14 d	528.6	244.8	
	" (and mineral suppl.)		389.3	211.78	
Leghorn chickens (48) (2 weeks old)	700	20 d	325	350	17

[1] See [1] of Appendix 1.0.

\+ Original data expressed as wet weight - assumed 72% moisture.