SCIENCE & RESEARCH SERIES NO.71

FLUORIDE IN NEW ZEALAND BIRDS: A REVIEW

by

C.J.R. Robertson and J.W. Lock

Published by
Head Office,
Department of Conservation,
P 0 Box 10-420,
Wellington,
New Zealand

ISSN 0113-3713
ISBN 0-478-01611-5

Cataloguing-in-Publication data

Robertson, C. J. R. (Christopher John Rutherford), 1941-
Fluoride in New Zealand birds : a review / by C.J.R. Robertson and J.W. Lock. Wellington, N.Z. : Dept. of Conservation, 1994.
1 v. ; 30 cm. (Science & Research series, 0113-3713 ; no. 71)
Includes bibliographical references.
ISBN 0478016115
1. Birds--Research--New Zealand. 2. Fluoride. I. Lock, J. W. II. New Zealand. Dept. of Conservation. Science and Research Division. III Title. IV. Series (Science and research series ; no. 71)
598.20993 20
zbn94-059884

Keywords: fluoride, New Zealand birds, krill, *Diomedea epomophora sanfordi*, *Larus bulleri*, *Larus d. dominicanus*, *Larus novaehollandiae scopulinus*, *Sturnus vulgaris*, *Passer domesticus*, *Porphyrio p. melanotus*, Tiwai Point, Taiaroa Head

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C.J.R. ROBERTSON[1] & J.W. LOCK[2]

Science & Research Division, Department of Conservation, PO Box 10420, Wellington,

118 The Ridgeway, Mornington, Wellington

ABSTRACT

Fluoride is naturally present in the atmosphere, soils, water vegetation and animal tissues. There have been few studies of the effects of excessive levels of fluoride on birds, especially in the wild. A compilation of measurements of fluoride levels is given for 127 New Zealand bird taxa. These values demonstrate the extremely high natural levels of bone fluoride (6000-14000+ppm (μ/g) ash weight) which can be found, especially among NZ marine bird species. However these samples are uneven or sparse, and the birds of variable and generally unknown age. Accordingly the significance of other than gross difference in bone fluoride levels from these data will be hard to detect. There is some evidence to support the conclusion that fluoride levels in bone increases with age. Only one species, the House Sparrow, has been found close to an aluminium smelter with elevated levels of bone fluoride which are significantly different from other NZ locations. In the absence of a positive connection between bone fluoride levels and the significant impairment of breeding in overseas studies, there seems little reason to suspect any significant effects on birds in the environs of installations such as the Tiwai Point aluminium smelter. However, the absence of direct evidence does not mean that there is no possibility of there being an effect.

1 INTRODUCTION

Newman (1977) suggested that although much is known about the effects of fluoride on domestic animals, few studies have considered the effects on wildlife, and that studies involving birds are even rarer. The majority of studies published since that time have concentrated on the effects of fluoride contained in fumes, liquid effluent or particulate matter from industrial plants (including steel, brick and ceramic works, superphosphate and aluminium smelters), or have attempted to study effects through artificially adding supplements to the diet of captive birds. Sampling of fluoride levels in New Zealand birds was initially related to the environmental testing undertaken before the building of an aluminium smelter at Tiwai Point near Bluff at the southern end of the South Island of NZ (Stringer 1972; Stewart *et al.* 1974). These were some of the first studies of their type to be undertaken before the introduction of such an industrial plant into the tested environment.

Intermittent and small samples were taken of a range of bird species as part of the Tiwai Point smelter monitoring programmes until 1983. In the absence of any obviously significant effect these samples have not been continued since then. From 1975 to 1983, in association with other studies on heavy metals (Lock *et al.* 1992), JWL was also able to have fluoride levels tested in a wide range of New Zealand bird taxa. These samples were mostly from birds collected for, or deposited with, the National Museum of New Zealand with collection sites covering much of the New Zealand region.

This study was commissioned by the Southland Conservancy, of the Department of Conservation, reviews our knowledge of the effects of fluoride in birds and summarises the known test results for fluoride levels in a wide range of NZ taxa. We have been unable to find an equivalently wide compilation across an avian fauna elsewhere.

2 FLUORIDE ANALYSIS METHODS & DATA SOURCES

Unless otherwise stated, fluoride levels are expressed as ppm (μ/g) bone ash weight or mg F/kg dry grass throughout the New Zealand samples. Methods of extraction are as in Stewart *et al.* (1974) for bone and shell and Manley *et al.* (1975) for pasture.

Sample results for New Zealand birds have been obtained from JWL (unpubl.); the raw data used in Turner *et al.* (1978) from samples collected in 1973-74; raw data from September 1969 - September 1970 held in the files of NZAS; January 1975 - January 1976 data for Pukeko *Porphyrio p. melanotus* from the MAF Invermay Fluorine Laboratory; raw data from Stringer (1972); from CJRR (unpubl.) being bird samples collected in various parts of new Zealand including Bluff and Tiwai Point localities during 1982, along with samples of Northern Royal Albatross *Diomedea epomophora sanfordi* eggshell from Taiaroa Head, all tested by the MAF Invermay Fluorine Laboratory for the NZ Wildlife Service. During the period February 1982 to January 1983 (CJRR unpubl.) five plots were sampled regularly for vegetation (mainly introduced grasses) at the Taiaroa Head Nature Reserve, Dunedin (a maritime location), and tested at the MAF Invermay Fluorine Laboratory for the NZ Wildlife Service. The vegetation samples were taken from different sections of each metre square sample plot on each sample occasion. No part of the plot was sampled more than once during the 12 months.

Where there was any possibility that raw data of tested birds may have been accessed twice from different sources, the samples were compared and any duplicated test results removed. A consolidated summary is presented in Figure 1 and Appendix 1. Also in Appendix 1, summary data from Stewart *et al.* (1974) are presented separately as it was not possible to access their raw data separately for inclusion in the consolidated summary. Some of the material used in our summations was certainly used by Stewart *et al.* (1974).

Bird names for New Zealand fauna follow Turbott (1990).

3 SOURCES & LEVELS OF FLUORIDE

Fluoride is naturally present at variable levels in the atmosphere, water, vegetation, soils, and animal tissues. Exposure of living organisms to above normal concentrations of fluoride (often related to some human activity) may result in the alteration of the organism's biochemistry and bone morphology (Henny and Burke, 1990). This is especially so in humans, ungulates and mammals where too little or too much in the diet may be detrimental to health. Fish and other aquatic (especially marine species) can accumulate fluoride in their skin, skeleton or exoskeleton with Hodge and Smith (1965) calling "fluoride the prototype bone seeker".

The fluoride content of normal seawater averages 1.4 ppm in New Zealand waters (Robertson 1981). Manley *et al.* (1975) found seawater values a little lower in their study at Bluff, but similar to overseas values for an ocean estuary. Fresh water levels are generally low (< 0.5 ppm), except in mineral springs and thermal pools or lakes (Manley *et* al. 1975) where much higher levels may be achieved. Sea spray is a common mode for the transfer of fluoride to the land and vegetation.

Ingestion of vegetation by bird or invertebrate fauna is one source of fluoride uptake during feeding. Manley *et al.* (1975) noted that average pasture fluoride levels in New Zealand compared well with those in other parts of the world, but that higher levels had been caused periodically by topdressing with superphosphate. They reported from Allcroft *et al.* (1965) that there was a little evidence of seasonal variation, with lower levels in summer and higher in winter (but confined to one farm location). Monthly variations (highest in July and December) were found by Murray (1981) who suggested for a maritime site near Newcastle, Australia, that low levels could be influenced by high foliar growth or wind direction.

The data presented for vegetation sampled at Taiaroa Head in Figure 2 suggest (in contrast to Allcroft *et al.* 1965; Manley *et al.* 1975) a difference between summer and winter with highest levels being shown during summer. At Taiaroa Head, the highest levels coincided with the annual die-off of the oldest grass growth during the height of the summer and possibly reflect an accumulation of fluoride over a period of time, as samples came from the same area, but not the same plants over the period surveyed. No topdressing occurred in the vicinity during the trial period, but there is a significant level of aerosol deposition of fluoride through sea spray and associated high relative humidity at that location.

Soil invertebrates that ingest soils can be expected to reflect the levels found there naturally, plus any enhancements caused by fluoride deposition through sea spray, water or particulate matter. Soil samples taken at Taiaroa Head (composite yellow brown earth granular loan derived from loess overlying volcanic basalt) in February 1982 (n=5, range 213-440 ppm, mean 358 ppm) were at the higher end of those shown for a sample of NZ soils in Gemmell (1946). This probably reflects the close association of the area with maritime conditions. Murray (1981) demonstrated a substantial level of fluoride accumulation in insects, especially soil dwelling Isopoda, as evidence of some fluoride movement along the overall food chain. This would seem to be similar to that found in the marine environment for fish and krill (Nichol 1989).

Many factors can influence fluoride levels in animals, including the age of the animal, concentrations in food and water, the nature of the food and interactions with other elements (e.g. aluminium, cadmium and magnesium), which may affect excretion and deposition into bones and tissues. Accumulation in bone is rapid in the young, and grazing animals are regarded as being the most susceptible to fluoride damage. Merkley (1981) suggests that once in bird bone, fluoride levels remain relatively stable and unavailable even at times such as egg laying, when calcium (and fluoride) is more mobile.

Stringer (1972) and Stewart *et al.* (1974) suggested from their studies that bone fluoride levels were highest in those birds which live predominantly in the coastal, estuarine and marine habitats and fed on marine plants and animals.

Culik (1987a,b) showed for Adelie penguins *Pygoscelis adeliae* feeding predominantly on krill *Euphausia* sp. with high fluoride levels (Soevik & Braekkan 1979) that while the highest concentration in Adelie penguin soft tissue was in the salt glands (only developed in maritime birds), the greatest overall concentrations in bone demonstrated the high affinity of fluoride for bone. This concentration reached close to maximum levels in chicks within 2 weeks of hatching. Thereafter, the mean fluoride concentrations in the Adelie penguin did not rise significantly. Culik suggests that once equilibrium is reached, bone fluoride concentrations remain stable unless the daily fluoride dose changes.

This suggests that for bird species (especially maritime birds or those which become adapted to those conditions), where diet items such as krill or fish are naturally high in fluoride (Wright & Davison 1975; Culik 1987a,b), that bones, rather than continuing to accumulate fluoride in the skeleton (cf. heavy metals), instead act as a buffer for fluoride peaks. Once possible fluoride equilibrium is reached, Culik suggests that most additional fluoride taken up is excreted through the kidneys to cloacal discharge. Schneppenheim (1980, 1981) found that krill-consuming fish in the Antarctic have elevated fluoride values compared with fish from other waters. He went on to conclude however, that these seemingly high values did not affect either the fish or their warm blooded predators (penguins and seals), despite the high levels of fluoride in their bones, tissues and feathers.

The literature makes many suggestions of increased levels of fluoride in bone in relation to the age of the bird, although few quantify this. In wild birds, Stewart *et al.* (1974) and Kay et al (1975) have concluded that seed-eating birds (which are generally more short-lived) have lower bone fluoride concentrations than longer-lived more omnivorous species. Henny & Burke (1990) concluded from a study of known age and assessed age Night-herons *Nycticorax nycticorax,* that fluoride probably accumulated throughout life with the greatest levels of accumulation in the youngest birds. No sexual differences were detected.

A small sample of known age and sexed Starlings *Sturnus vulgaris* was contained within the New Zealand data (Figure 3). These data demonstrate some level of significant increase with age in females (Pearson Correlation 0.674 11df. $p \geq .02$). There is some difference in feeding patterns between sexes for this population at Belmont, Wellington (J.E.C. Flux, *pers. comm.)* with the females feeding extensively on the nearby beach at Petone during the breeding season. This may indicate a higher proportion of breeding female diet being made up of shell fragments (from shellfish) or possibly amphipods. Pattee *et al.* (1988) suggest that the variability implies different uptake, excretion and/or deposition rates among individual birds. They found a noteworthy incidence of females dumping fluoride into their eggshell, but still having higher bone fluoride levels than males. Bird & Massari (1983) found that in American Kestrels *Falco sparverius,* females generally accumulated more fluoride in their bones than males, and suggested that this may be a function of the continual build-up and break-down of the medullary bones during egg production.

An attempt (CJRR *unpubl.*) to determine whether eggshell samples from known age Northern Royal Albatrosses would indicate increased accumulation with age of the female bird was inconclusive (Figure 4, and see also series of data within Figure 4 shown in Figures 5 & 6). There is a clear lack of data in the older age classes. When the two oldest points are removed the regression is insignificant, but may possibly support the findings of Culik (1987a,b), that most fluoride accumulation in marine birds may occur when young, reaching a plateau as an adult. However, of some interest was the further examination of the Royal Albatross data for known age individuals depending on their present and previous breeding status when an egg was laid. The Royal Albatross is a biennially breeding species, if it is successful in raising and fledging a chick. Egg failure, or loss of the chick at under two months old, results in breeding again in the following season. The extended mean chick rearing period of 240 days means that parents have a greatly increased intake of food (and thus exposure to fluoride intake) during chick rearing.

Though the data are limited, in the majority of situations where an egg was laid following the rearing of a chick, the fluoride levels of the eggshell showed an increase (Figure 5). Conversely where an egg (or eggs) had been laid without a period of chick rearing occurring in between the previous laying, then there was generally a reduction in the fluoride content of the shell sample (Figure 6). These observations could support the possibility of variable levels of fluoride in an individual, and that there can be some movement of accumulated bone fluoride to eggshell.

Data on fluoride levels have been accumulated (Figure 1 & Appendix 1) for 127 of the 305 taxa of birds which are recorded as visiting or breeding in New Zealand. Those taxa recording the highest bone fluoride levels of 6000-14000+ppm (μ/g) ash weight, with two exceptions, come from true marine species such as albatrosses and petrels, as well as those others living coastally and overlapping the marine environment, such as terns and gulls. The two obvious exceptions among non-marine taxa both seem to have been influenced by human related factors.

All areas exposed to periodic aerial topdressing with superphosphate products and especially areas close to the processing plants that produce these products, can have some general or periodic elevation of soil and vegetation fluoride levels. A group of feral Rock Pigeon *Columba livia*, which were found dead of unknown causes in the Hamilton rail yards, had fluoride levels of 1600-8200 ppm in their bones (n=11, mean=2870). It is possible that such high levels were the result of ingestion of particulate phosphate fertiliser products during scavenging in the rail yards.

The other obvious exception was samples of House Sparrows *Passer domesticus*, including those from the immediate Tiwai Point smelter environs collected in 1982. No previous samples of this species had been collected before smelting operations started at this site. The 1982 sample had a range of 2430-7777 ppm (n=9, mean=4130) compared with other samples of this species from around New Zealand which had a range of 349-2500 ppm (n=9, mean =1301). This suggests a significant increase ($p = <.001$) in fluoride levels for birds living and feeding close to the Tiwai Point smelter. A study in Czechoslovakia (Macuch *et al.* 1969) of 'sparrows' showed a range of 1013-3527 ppm close to a smelter compared to 84-565 ppm elsewhere.

The only species where there is a good range of samples both before and after the Tiwai Point smelter commenced operating, is the Pukeko. Stewart *et al.* (1974) gives a range of 143-1400 ppm (n=16, mean=344) which compares well with samples from round the country which had a range of 76-2040 ppm (n=73, mean =512). A sample of Pukeko taken during 1975-76 as part of the monitoring programme at Tiwai Point, produced a range of 399-2480 ppm (n=11, mean=1127) with a statistically significant difference of p = <.01 when compared with the sample in Stewart *et al.* (1974). No Pukeko were sampled at Tiwai Point in 1982. As the age of individuals in the two samples was unknown, the difference may be an artifact of a larger number of birds in the later sample, or a reflection through the diet of the Pukeko, of increased fluoride levels in vegetation and invertebrates close to the site.

As a family, the NZ gulls exhibited the widest range of fluoride levels between species. These data provide an interesting comparison between food types. The highest levels are found in the Red-billed Gulls *Larus novaehollandiae scopulinus* (1008-12500 ppm, mean=4554), which are generally coastal and island breeders and feed predominantly on euphausiid crustacea and fish, especially in the breeding season, with some scavenging along beaches, plus insects and earthworms from farmland.

Black-billed Gulls *Larus bulleri* (1160-5800 ppm, mean=2333) are confined mainly to breeding on the inland reaches of braided rivers in the South Island where their diet is primarily fresh water and land invertebrates, and fish. Outside the breeding season they move to the coast and feed by scavenging on land, or at sea on fish and crustaceans such as *Munida*.

The Southern Black-backed Gull *Larus d. dominicanus* (66-4699 ppm, mean =1488) is found throughout the country from mountain to the coast. As an omnivorous scavenger at rubbish dumps, open farmland and the coast, its diet is more variable than those of the other two species, with less of the obviously primary sources of food-based fluoride. It should be noted however, that there may be some effect, particularly on this species, when they live in the vicinity of the Tiwai Point smelter. Birds sampled away from the smelter location or before the smelter was operating (n=46, 66-3050 ppm, mean=1269) had lower bone fluoride levels, than a sample taken near the smelter in 1982 (n=7, 302-4699 ppm, mean= 1921). There is still a possibility however, that their food sources could have been contaminated by the proximity of a superphosphate plant near the smelter and within the feeding range of local gulls.

Steel & Thomson (1984) show a similar inter species difference with predatory birds within the British Isles. There was some relationship within taxa, with diurnal raptors showing higher mean levels of fluoride than Owls. The highest levels were in those species who fed on birds, and the lowest levels for those that feed mostly on small mammals. This suggested that smaller birds may be greater accumulators of fluoride in a form accessible to the predator. Within the Owls, the two species with highest fluoride had a diet which included earthworms, but Steel & Thomson suggest that the fluoride could come from the soil in the earthworm gut. There was no clear relationship between bone consumption (from the prey) and fluoride burden in the host.

4 EFFECTS OF FLUORIDE ON WILD BIRDS

Henny and Burke (1990) suggest that virtually nothing is known about fluoride concentrations required to cause damage to wild avian species. Newman (1977) noted that House Martin *Delichon urbica* nesting densities were lower immediately adjacent to an aluminium smelter in Czechoslovakia in the areas of highest fluoride emissions. Though suggestive of the influence of fluoride other factors such as dust and noise could not be completely discounted as contributory factors.

The majority of the available studies seem to focus on supplementing the diet of birds in captivity with differing levels of fluoride in food or water. While Merkley and Sexton (1982) reported no negative effects when 100 ppm was added to the drinking water of domestic chickens, van Toledo and Combs (1984) found decreased food consumption and egg production along with changed shell characteristics at 900-1200 ppm additional fluoride.

A study by van Toledo (1978) noted that while fluoride levels in eggs of different species vary, (possibly in relation to varied nutrition) no conclusions were possible concerning the direct effects of contamination by fluoride on the population. He cautions however, that though health may not be directly affected, there was the possibility of a reduction in the number of exposed birds during the study. Pattee *et al.* (1988) and Hoffman *et al.* (1985) both suggest that fluoride ingestion may have had a detrimental effect on the reproductive success of Eastern Screech-owls *Otus asio*.

Fleming *et al.* (1987) noted that fledging weights were reduced in nestling Starlings fed daily oral doses of 23 mg F/kg of body weight. He concluded that while this level of exposure altered growth, the amounts of oral fluoride administered appeared to be more toxic than equivalent amounts of fluoride ingested in the normal diet. This, he suggested, could mean that his results overestimated the potential effect of fluoride on free-living birds within fluoride-contaminated environments.

5 CONCLUSIONS

All available sources (published and unpublished) of fluoride analyses of New Zealand birds have been investigated and compiled into the first comprehensive set of New Zealand baseline data. Where material is available, these baseline data have been compared measurements of fluoride concentrations from bird samples taken during the 1980's near the Tiwai Point aluminium smelter.

A review of the literature and the most recent overseas reviews suggests that any detrimental effects of fluoride on wild birds have not been clearly proven. While there is some limited evidence of reduced nesting density and range of species that live near older style aluminium plants in industrial areas of Europe, the evidence for the effects of fluoride as an implicating factor is not compelling.

It is clear that fluoride accumulates in bone. It can in the short term also become elevated in tissue, but may if this occurs be more easily excreted. The consumption of foods or ingestion of water high in fluoride or associated particulate matter seems to be the most important route for exposure of birds to fluoride. The literature records variable results for the accumulation of fluoride in bone related to age and sex, but there seems to be some evidence that concentrations increase with age in a greater number of species. Small amounts of data from two New Zealand species (using known aged animals) at sites well removed from the Tiwai Point smelter give further support to this view.

There is good circumstantial evidence to suggest that fluoride combined in bone or eggshell is relatively well bound and not likely to be easily available to affect other biological processes such as growth and reproduction. Thus, levels in bone are probably more a reflection of cumulative exposure. There is little available information on the availability or the effects of fluoride in soft tissues. Soft tissue levels may reflect current rather than cumulative exposure, and logically soft tissue levels are more likely to reflect residues which might be more biologically active.

There is no New Zealand evidence of significant reductions in bird numbers or distribution as a result of fluoride ingestion, and in fact many maritime species seem to have bone fluoride levels which would be considered extraordinarily high if found in land based species. There are clear indications from the New Zealand data to support suggestions of increasing concentrations of bone fluoride with age, with the main source of the fluoride being the primary food source, and possibly to a lesser extent, particulate matter present on vegetation. There is one specific example of House Sparrows from the Tiwai Point smelter location having fluoride levels significantly greater than those found in that species elsewhere in New Zealand, or for passerines in such a situation overseas.

Sampling of birds throughout New Zealand for the testing of fluoride levels has been uncoordinated, so the data are uneven or sparse, and the birds of variable and generally unknown age. Accordingly the significance of other than gross difference in bone fluoride levels from these data will be hard to detect. In the absence of a positive connection between bone fluoride levels and the significant impairment of breeding in overseas studies, there seems little reason to suspect any significant effects on birds in the environs of installations such as the Tiwai Point smelter. However, the absence of direct evidence does not mean that there is no possibility of there actually being an effect. Studies designed to address this specific question would be needed before a more definite confirmation could be made.

The presence or absence of any populations of endangered or threatened NZ endemic bird species from the Tiwai Point area or other present or proposed industrial sites elsewhere in the country is an important factor in determining the extent or intensity of any future monitoring and research requirements. The New Zealand data suggest that the sampling of species such as House Sparrows and Starlings, may be able provide a useful indicator of changing levels of additional fluoride entering the food chain within the close environs of industrial plants.

6 ACKNOWLEDGEMENTS

Our grateful thanks to the many staff, and especially D.A. White for analytical expertise and S.R.B. Solly, for support at Wallaceville Animal Research Centre, of the then Ministry of Agriculture and Fisheries for assistance to JWL and for providing the facilities for the testing of a wide range of bird samples; to J.C. Turner for supplying the raw data from Turner *et al.* (1978); to Sandy Bartle and Noel Hyde of the then National Museum, Wellington, who provided and prepared many of the bird carcasses for testing; to New Zealand Aluminium Smelters Limited and K.J. Duke for access to their site for sampling of species in 1982, and access to their library and records in 1993; to D.J. Stewart and the then Ministry of Agriculture and Fisheries, Invermay Fluorine Laboratory testing facilities, for analyses done for the NZ Wildlife Service in 1982-83; to The National Archives for access to various NZ Wildlife Service files; to J.E.C. Flux previously of Landcare Research Ltd. for his advice on the behaviour of Starlings in Belmont; to R.W. Furness, University of Glasgow, J.A. Cooke, University of Natal for advice on sources and W.J. Fleming, US Fish & Wildlife Service for access to an unpublished review. This report was commissioned by the Southland Conservancy of the Department of Conservation, and the manuscript has been critically reviewed by C.W. Pugsley, K.J. Duke, D.J. Stewart, D.G Newman and R.M. Sadleir.

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