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FLUORIDE IN NEW ZEALAND BIRDS: A REVIEW

by

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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.

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FIGURE 1. Recorded ranges of bone fluoride (μ/g) ash weight for individual or grouped New Zealand bird taxa.

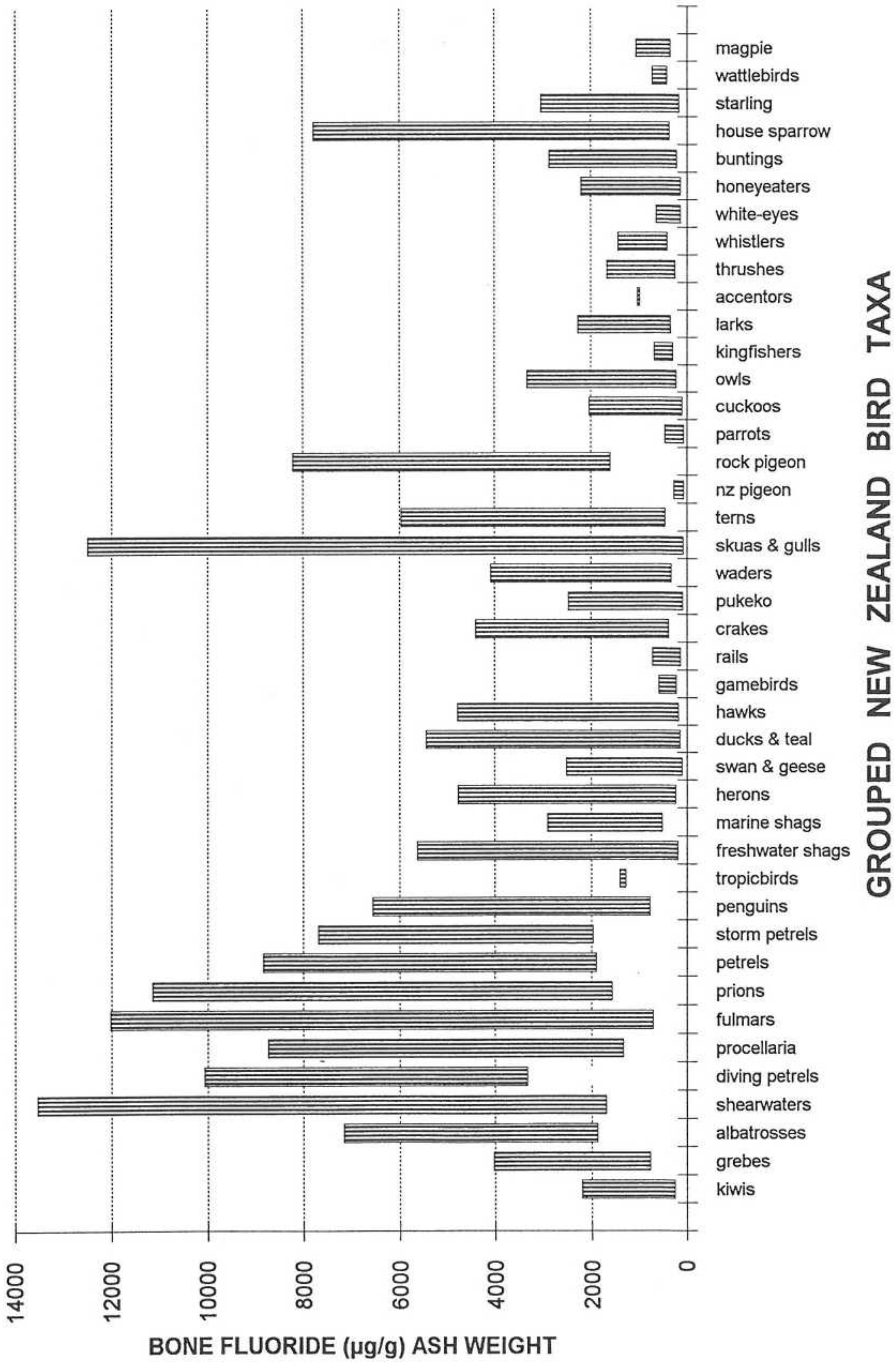


FIGURE 2. Fluoride levels in vegetation (mg F/kg dry grass) from five plots (Samples A-E) sampled periodically at Taiaroa Head Nature Reserve, 1982-1983.

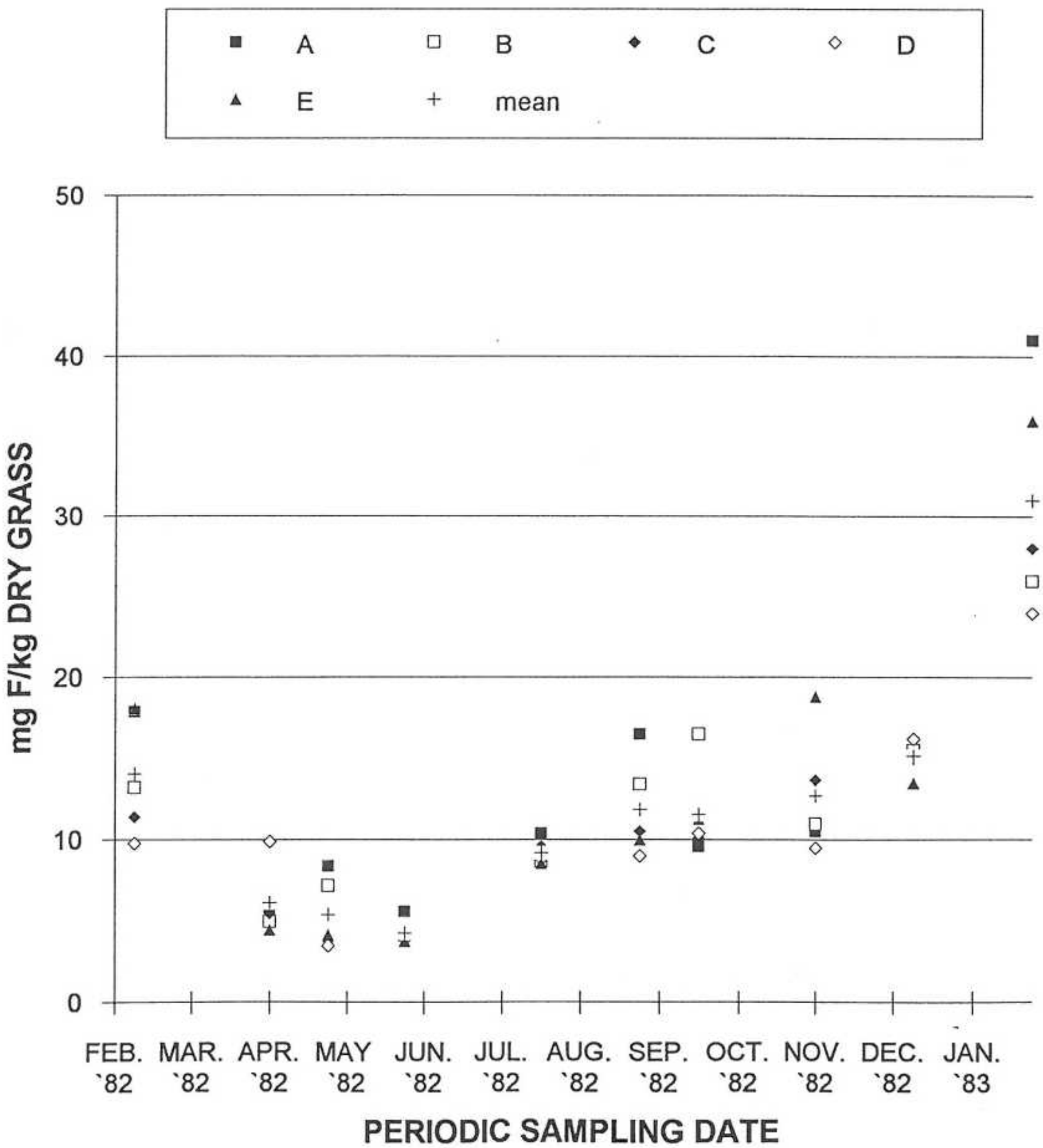


FIGURE 3. Distribution of bone fluoride levels in Starlings of known age from Belmont, New Zealand.

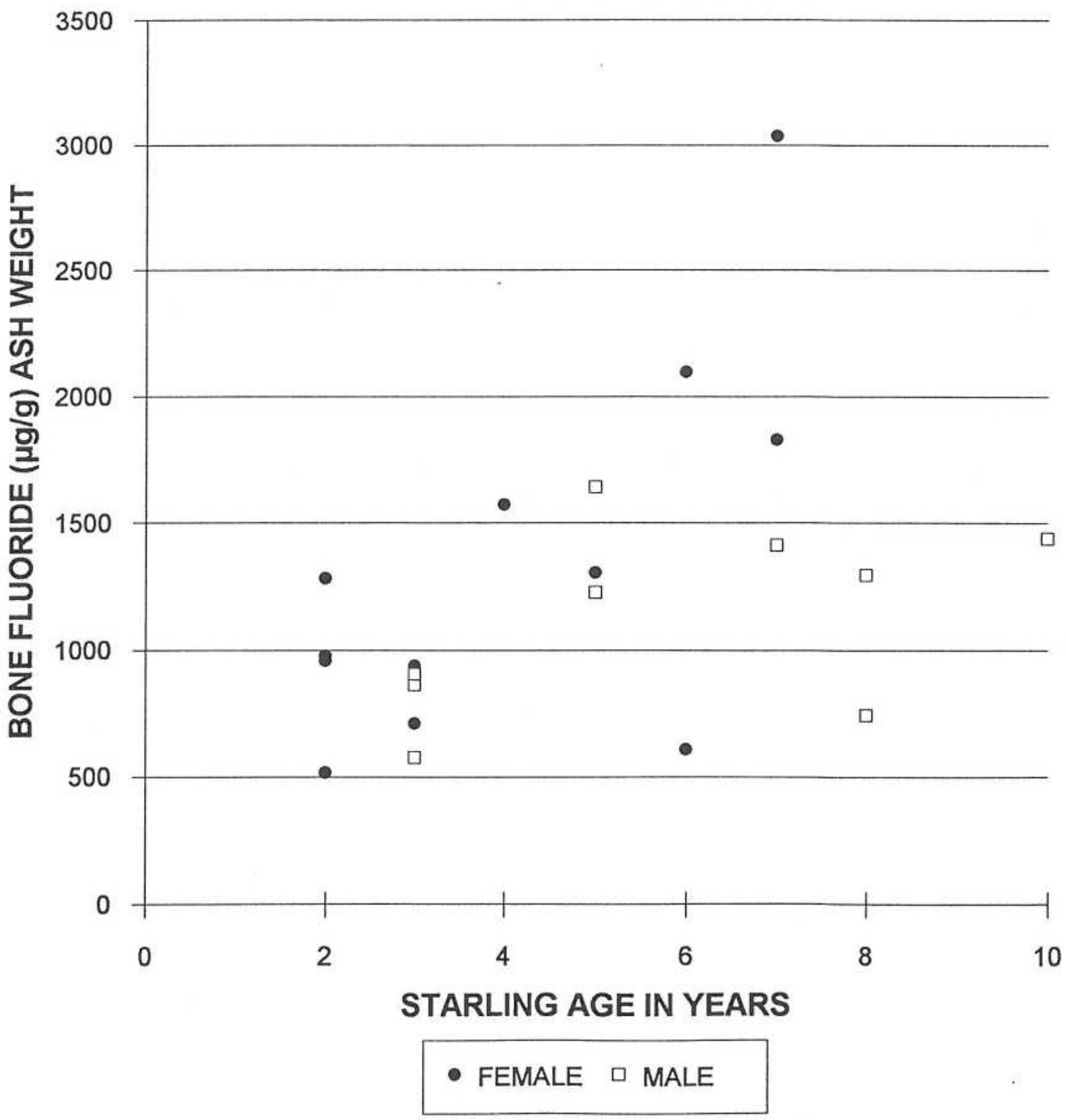


FIGURE 4. Distribution of fluoride levels in eggshell laid by Northern Royal Albatross females of known age at Taiaroa Head, New Zealand.

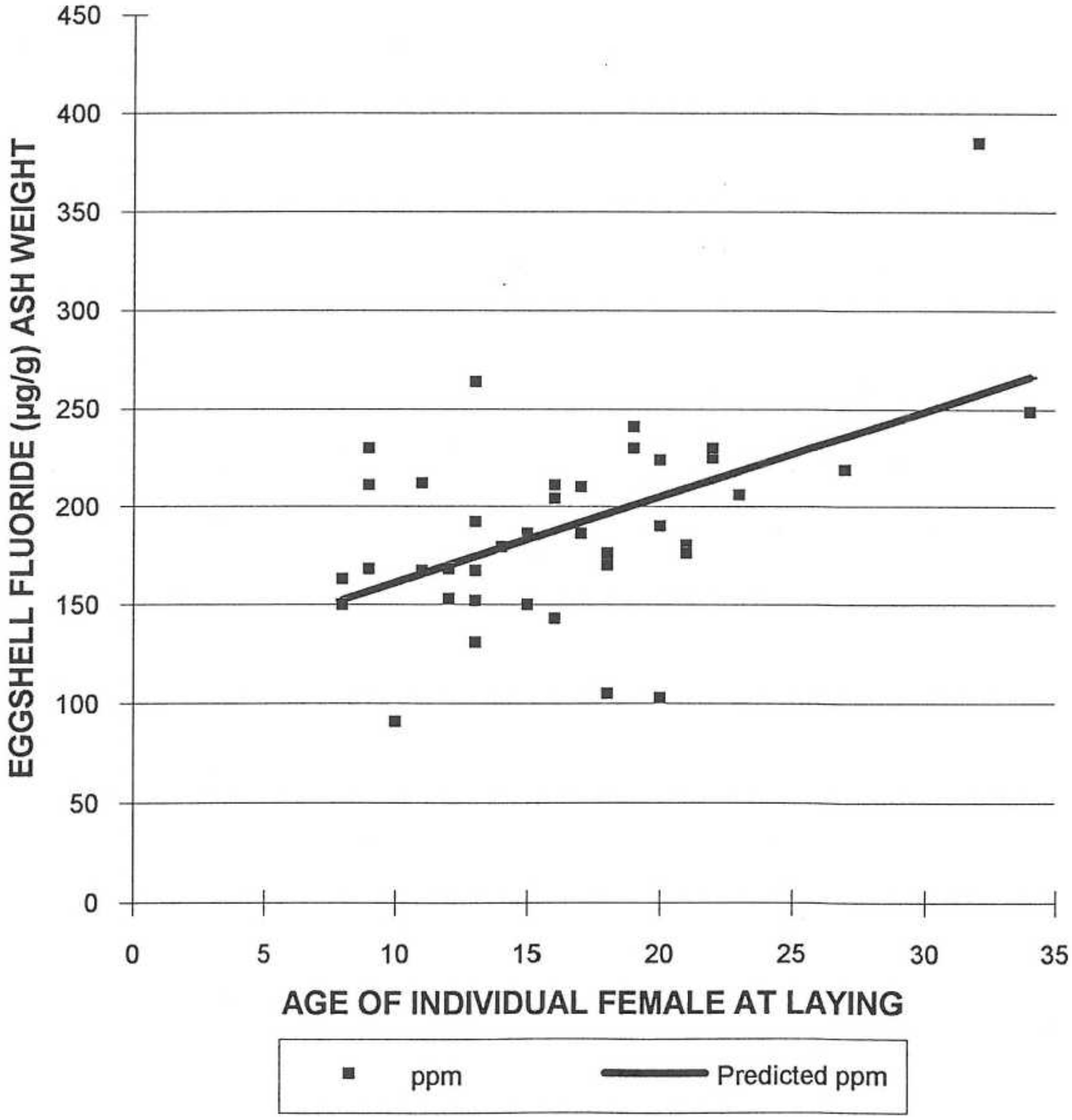


FIGURE 5. Changes in fluoride levels in eggshell between layings, for eggs laid following the successful fledging of a chick by nine known age Northern Royal Albatross females at Taiaroa Head, New Zealand.

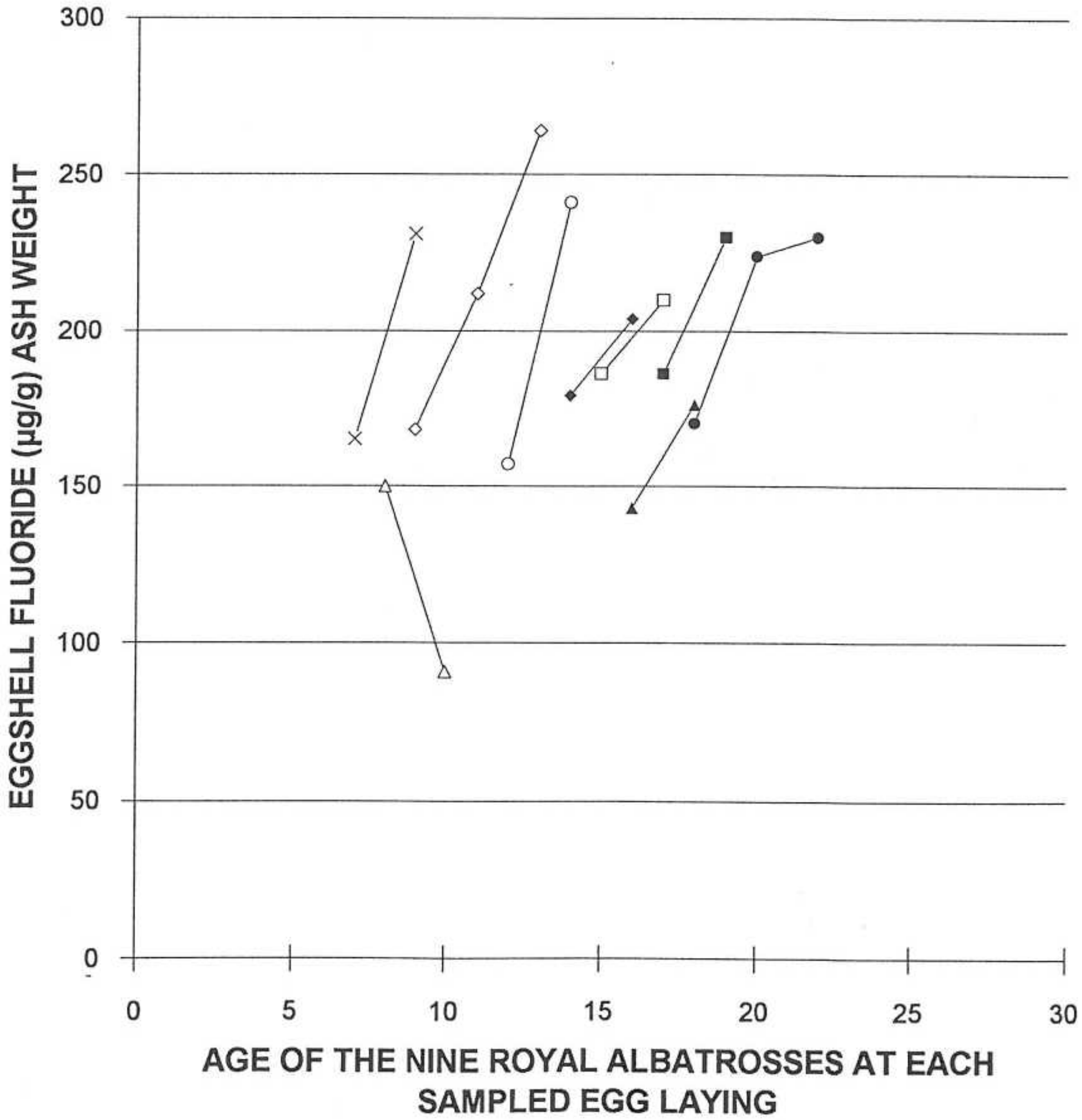
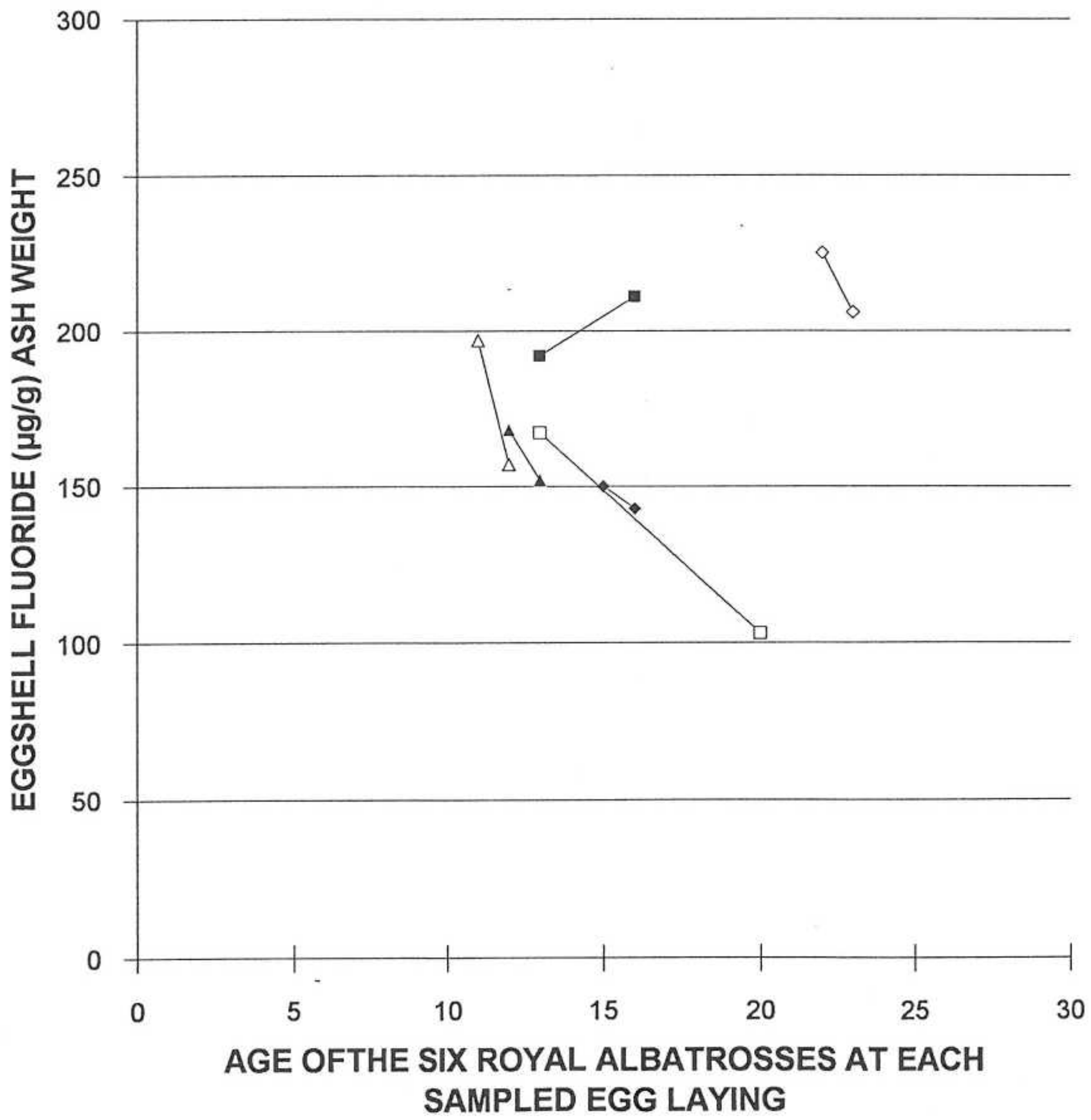


FIGURE 6. Changes in fluoride levels in eggshell between layings, for eggs laid after a period without chick rearing by six known age Northern Royal Albatross females at Taiaroa Head, New Zealand.



APPENDIX ONE. Known bone fluoride levels (μg/g) ash weight for New Zealand birds.
Ad = Adult; Imm = Immature; Unk = Unknown; Comb = Combined; SD = Standard deviation

	n =	Age	Range Min	Max=	Mean	SD
North Island Brown Kiwi	37	Ad	250	2204	1001	555
Apteryx australis mantelli	4	Imm	394	578	497	92
	41	Comb	250	2204	952	549
South Island Brown Kiwi	1	Ad	278	278	278	
A. a. australis						
Great Spotted Kiwi	2	Ad	551	672	612	86
A. haastii						
Australasian Crested Grebe	1	Ad	1576	1576	1576	
Podiceps cristatus australis						
New Zealand Dabchick	4	Ad	331	4024	2168	1885
Poliocephalus rufopectus						
Wandering Albatross	4	Ad	2891	6183	4819	1539
Diomedea exulans						
Southern Royal Albatross	2	Ad	7065	7091	7078	18
D. epomophora epomophora						
Black-browed Mollymawk	1	Imm	2706	2706	2706	
D. melanophrys melanophrys						
New Zealand Black-browed Mollymawk	2	Ad	2754	3274	3014	368
D. m. impavida	2	Imm	2556	3187	2872	446
	4	Comb	2556	3274	2943	344
New Zealand White-capped (Shy) Mollymawk	1	Imm	2713	2713	2713	
D. cauta steadi						
Salvin's Mollymawk	7	Ad	3386	6308	5072	1118
D. c. *salvini*	2	Imm	1866	3500	2683	1155
	9	Comb	1866	6308	4541	1488
Grey-headed Mollymawk	3	Ad	3810	4462	4102	331
D. chrysostoma	3	Imm	3060	4573	3675	795
	1	Unk	2341	2341	2341	
	7	Comb	2341	4573	3667	797
Northern Buller's Mollymawk	3	Imm	3867	5811	4629	1038
D. bulled platei						
Light-mantled Sooty Albatross	2	Ad	3640	7161	5401	2490
Phoebetria palpebrata	2	Imm	2553	3908	3231	958
	4	Comb	2553	7161	4316	1985
Flesh-footed Shearwater	2	Imm	1724	2623	2174	636
Puffinus cameipes						

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Ad = Adult; Imm = Immature; Unk = Unknown; Comb = Combined; SD = Standard deviation

	n =	Age	Range Min	Range Max	Mean	SD
Sooty Shearwater (Muttonbird) *P. griseus*	4	Imm	1684	6307	4166	2152
Short-tailed Shearwater (Tasmanian Muttonbird)	2	Ad	13500	13542	13521	30
P. tenuirostris	2	Unk	5921	8906	7414	2111
	4	Comb	5921	13542	10467	3731
Fluttering Shearwater *P. gavia*	2	Unk	6027	6034	6031	5
Hutton's Shearwater	1	Ad	6181	6181	6181	
P. huttoni	1	Imm	4329	4329	4329	
	2	Comb	4329	6181	5255	1310
North Island Little Shearwater	1	Ad	5349	5349	5349	
P. assimilis haurakensis	1	Imm	1712	1712	1712	
	2	Comb	1712	5349	3531	2572
Common Diving Petrel	1	Ad	8178	8178	8178	
Pelecanoides u. urinatrix	2	Unk	3333	5840	4587	1773
	3	Comb	3333	8178	5784	2423
Subantarctic Diving Petrel *P. u. exsul*	4	Ad	4645	10065	7856	2328
South Georgian Diving Petrel *P. georgicus*	2	Ad	8540	8913	8727	264
Grey Petrel *Procellaria cinerea*	1	Ad	8736	8736	8736	
Westland Petrel	3	Ad	3438	6611	5265	1640
P. westlandica	4	Imm	1327	1723	1571	176
	7	Comb	1327	6611	3154	2194
White-chinned Petrel (Shoemaker) *P. a. aequinoctialis*	2	Ad	2992	5428	4210	1723
Kerguelen Petrel	2	Imm	7094	7595	7345	354
Lugensa brevirostris	1	Unk	5333	5333	5333	
	3	Comb	5333	7595	6674	1188
Cape Pigeon	2	Ad	6055	10473	8264	3124
Daption c. capense	1	Imm	6651	6651	6651	
	3	Comb	6055	10473	7726	2397
Snares Cape Pigeon *D. c. australe*	1	Ad	10861	10861	10861	

APPENDIX ONE. Known bone fluoride levels (µg/g) ash weight for New Zealand birds.
Ad = Adult; Imm = Immature; Unk = Unknown; Comb = Combined; SD = Standard deviation

	n =	Age	Range Min	Range Max	Mean	SD
Antarctic Petrel	1	Ad	12025	12025	12025	
Thalassoica antarctica	4	Imm	7212	9474	7989	1018
	5	Comb	7212	12025	8796	2009
Antarctic Fulmar	7	Imm	4355	8871	7151	1800
Fulmarus glacialoides	2	Unk	7470	7576	7523	75
	9	Comb	4355	8871	7234	1568
Southern Giant Petrel	4	Imm	894	6970	3598	2934
Macronectes giganteus						
Northern Giant Petrel	3	Ad	1300	6053	3986	2436
M. halli	2	Imm	711	3596	2154	2040
	5	Comb	711	6053	3253	2240
Fairy Prion	6	Ad	3105	11154	7732	2647
Pachyptila turtur	2	Imm	6328	9638	7983	2341
	6	Unk	2090	9142	4665	2645
	14	Comb	2090	11154	6453	2898
Fulmar Prion	6	Ad	7394	10000	8985	908
P. crassirostris crassirostris	1	Imm	3077	3077	3077	
	7	Comb	3077	10000	8141	2382
Antarctic Prion	1	Unk	4312	4312	4312	
P. desolata banksi						
Broad-billed Prion	2	Unk	1596	7564	4580	4220
P. vittata						
Blue Petrel	2	Ad	4835	8602	6719	2664
Halobaena caerulea	2	Imm	6667	8602	7635	1368
	4	Comb	4835	8602	7177	1808
Pycroft's Petrel	1	Ad	7678	7678	7678	
Pterodroma pycrofti						
Cook's Petrel	2	Ad	7255	7403	7329	105
P. cookii	2	Imm	1885	2600	2243	506
	4	Comb	1885	7403	4786	2952
Black-winged Petrel	1	Ad	8841	8841	8841	
P. nigripennis						
Chatham Petrel	1	Ad	7667	7667	7667	
P. axillaris						
Mottled Petrel	1	Ad	8261	8261	8261	
P. inexpectata	1	Imm	6176	6176	6176	
	2	Comb	6176	8261	7219	1474

APPENDIX ONE. Known bone fluoride levels (µg/g) ash weight for New Zealand birds.

Ad = Adult; Imm = Immature; Unk = Unknown; Comb = Combined: SD = Standard deviation

	n =	Age	Range Min	Range Max	Mean	SD
Grey-faced Petrel *P. macroptera gouldi*	3	Ad	5714	7143	6581	762
White-headed Petrel *P. lessonii*	3	Ad	3981	8194	6447	2197
	1	Unk	6250	6250	6250	
	4	Comb	3981	8194	6398	1796
Grey-backed Storm Petrel *Oceanites nereis*	3	Ad	1955	6722	4499	2400
	1	Unk	4713	4713	4713	
	4	Comb	1955	6722	4553	1962
New Zealand White-faced Storm Petrel *Pelagodroma marina maoriana*	2	Unk	4118	6901	5510	1968
Black-bellied Storm Petrel *Fregetta tropica*	1	Unk	7692	7692	7692	
Yellow-eyed Penguin *Megadyptes antipodes*	2	Imm	1690	4534	3112	2011
Blue Penguin *Eudyptula minor*	12	Ad	1290	4630	3269	945
	2	Imm	775	4192	2484	2416
	2	Unk	2816	3281	3049	329
	16	Comb	775	4630	3144	1060
Eastern Rockhopper Penguin *Eudyptes cchrysocome filholi*	4	Ad	3419	6383	5074	1246
Fiordland Crested Penguin *E. pachyrhynchus*	2	Ad	2824	4037	3431	858
Erect-crested Penguin E. sclated	4	Ad	2038	6571	4838	2032
	1	Imm	1831	1831	1831	
	5	Comb	1831	6571	4237	2215
Red-tailed Tropic Bird *Phaethon rubricauda*	1	Ad	1274	1274	1274	
White-tailed Tropicbird *P. lepturus dorotheae*	1	Imm	1411	1411	1411	
Australasian Gannet *Morus serrator*	1	Ad	6094	6094	6094	
Black Shag (Black Cormorant) *Phalacrocorax carbo novaehollandiae*	7	Imm	184	3913	2057	1322
	1	Unk	3974	3974	3974	
	8	Comb	184	3974	2297	1399

APPENDIX ONE. Known bone fluoride levels (µg/g) ash weight for New Zealand birds.
Ad = Adult; Imm = Immature; Unk = Unknown; Comb = Combined; SD = Standard deviation

	n =	Age	Range Min	Range Max	Mean	SD
Little Shag (Little Pied Cormorant)	1	Ad	5635	5635	5635	
P. melanoleucos brevirostris	4	Unk	1800	4115	2984	1020
	5	Comb	1800	5635	3514	1478
Stewart Island Shag	4	Ad	1575	3049	2411	622
Leucocarbo chalconotus	2	Imm	1089	1362	1226	193
	6	Comb	1089	3049	2016	784
Bounty Island Shag	11	Ad	2131	3951	2907	529
L. ranfurlyi						
Spotted Shag	4	Ad	1997	2459	2285	215
Stictocarbo p. punctatus	10	Imm	509	1779	1170	459
	14	Comb	509	2459	1489	655
White-faced Heron	1	Imm	976	976	976	
Ardea n. novaehollandiae	3	Unk	618	4767	2435	2122
	4	Comb	618	4767	2070	1880
	3	*Stewart et. al.*	*1006*	*3264*	*2208*	*1135*
Cattle Egret	4	Imm	227	678	436	204
Bubulcus ibis coromandus						
Australasian Bittern	2	Unk	484	3557	2021	2173
Botaurus poiciloptilus						
Black Swan	3	Unk	88	478	230	216
Cygnus atratus						
Canada Goose	2	Ad	1995	2520	2258	371
Branta canadensis maxima	2	Unk	2020	2060	2040	28
	4	Comb	1995	2520	2149	249
Paradise Shelduck	1	Ad	915	915	915	
Tadorna variegata	1	Unk	794	794	794	
	2	Comb	794	915	855	86
Mallard	5	Ad	669	1059	923	149
Anas p. platyrhynchos	5	Imm	329	1100	551	313
	12	Unk	235	1942	648	464
	22	Comb	235	1942	688	393
	11	*Stewart et. al.*	*430*	*5440*	*1902*	*1375*
Grey Duck	7	Imm	368	1295	681	412
A. s. superciliosa						
Grey Teal	2	Imm	610	646	628	25
A. gracilis	6	Unk	784	1667	1278	306
	8	Comb	610	1667	1116	397

APPENDIX ONE. Known bone fluoride levels (µg/g) ash weight for New Zealand birds.
Ad = Adult; Imm = Immature; Unk = Unknown; Comb = Combined; SD = Standard deviation

	n =	Age	Range Min	Range Max	Mean	SD
Brown Teal	1	Imm	1106	1106	1106	
A. aucklandica chlorotis	1	Unk	134	134	134	
	2	Comb	134	1106	620	687
New Zealand Shoveler	1	Ad	4062	4062	4062	
A. rhynchotis variegata	3	Imm	470	753	634	147
	4	Comb	470	4062	1491	1718
New Zealand Scaup	7	Unk	199	4576	2129	1491
A. novaeseelandiae						
Australasian Harrier	10	Ad	166	2917	1118	778
Circus approximans	13	Unk	222	1087	708	257
	23	Comb	166	2917	886	572
	14	*Stewart et. al.*	*379*	*4775*	*1445*	1099
New Zealand Falcon	1	Ad	2285	2285	2285	
Falco novaeseelandiae	1	Imm	1398	1398	1398	
	2	Comb	1398	2285	1842	627
Chukor	2	Ad	333	580	457	175
Alectoris chukar						
Pheasant	1	Unk	213	213	213	
Phasianus colchicus						
Banded Rail	2	Ad	408	461	435	37
Rallus philippensis assimilis						
North Island Weka	2	Ad	131	726	429	421
Gallirallus australis greyi						
Western Weka	1	Ad	245	245	245	
G. a. australis	2	Unk	120	193	157	52
	3	Comb	120	245	186	63
Spotless Crake	1	Ad	372	372	372	
Porzana tabuensis plumbea	1	Unk	476	476	476	
	2	Comb	372	476	424	74
Marsh Crake	2	Ad	3462	4394	3928	659
P. pusilla affinnis	2	Unk	1315	1417	1366	72
	4	Comb	1315	4394	2647	1528
Pukeko (Swamphen)	7	Ad	76	405	235	135
Porphyrio p. melanotus	3	Imm	173	315	222	81
	37	Unk	183	2040	598	347
	47	Comb	76	2040	520	346
	16	*Stewart et. al.*	*143*	*1400*	*489*	*344*

APPENDIX ONE. Known bone fluoride levels (µg/g) ash weight for New Zealand birds.
Ad = Adult; Imm = Immature; Unk = Unknown; Comb = Combined; SD = Standard deviation

	n =	Age	Range Min	Range Max	Mean	SD
South Island Pied Oystercatcher	14	Unk	774	2910	1773	602
Haematopus ostralegus finschi	*14*	*Stewart et. al.*	*393*	*1965*	*1243*	508
Australasian Pied Stilt	5	Ad	1321	4053	2435	1204
Himantopus himantopus leucocephalus	1	Imm	318	318	318	
	25	Unk	360	4080	1563	924
	31	Comb	318	4080	1663	1022
Banded Dotterel	1	Ad	1948	1948	1948	
Charadrius *b. bicinctus*	1	Unk	2696	2696	2696	
	2	Comb	1948	2696	2322	529
Shore Plover	1	Imm	800	800	800	
Thinornis novaeseelandiae						
Spur-winged Plover	3	Ad	559	970	705	230
Vanellus miles novaehollandiae	1	Imm	402	402	402	
	4	Comb	402	970	629	241
Chatham Island Snipe	1	Ad	1599	1599	1599	
Coenocorypha pusila						
Eastern Bar-tailed Godwit	1	mm	1190	1190	1190	
Limosa lapponica baueri	1	Unk	439	439	439	
	2	Comb	439	1190	815	531
Arctic Skua	1	Imm	2500	2500	2500	
Stercoradus parasiticus						
Southern Black-backed Gull	13	Ad	124	4699	1228	1158
Larus d. dominicanus	7	Imm	66	2846	963	963
	33	Unk	678	3050	1489	577
	53	Comb	66	4699	1355	811
	16	*Stewart et. al.*	*754*	*3140*	*1907*	*729*
Red-billed Gull	3	Ad	2055	3837	2722	972
L. novaehollandiae scopulinus	3	Imm	1055	4855	2346	2173
	35	Unk	1008	12500	5305	3046
	41	Comb	1008	12500	4899	3026
	16	*Stewart et. al.*	*1058*	*8050*	*4003*	*2122*
Black-billed Gull	7	Unk	1160	5800	2333	1648
L. bulleri						
White-fronted Tern	4	Ad	1359	2702	2028	595
Sterna striata	1	Imm	435	435	435	
	5	Comb	435	2702	1709	879

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Ad = Adult; Imm = Immature; Unk = Unknown; Comb = Combined; SD = Standard deviation

	n =	Age	Range Min	Max	Mean	SD
Arctic Tern	1	mm	5970	5970	5970	
S. paradisaea						
New Zealand Pigeon	2	Imm	53	85	69	23
Hemiphaga n. novaeseelandiae	8	Unk	60	276	151	90
	10	Comb	53	276	135	87
Rock Pigeon	11	Ad	1584	8209	2879	1830
Columba livia						
North Island Kaka	1	Imm	376	376	376	
Nestor meridionafs septentrionafs						
Eastern Rosella	1	Ad	104	104	104	
Platycercus eximius	1	Unk	59	59	59	
	2	Comb	59	104	82	32
Red-crowned Parakeet	1	Ad	456	456	456	
Cyanoramphus n. novaezelandiae						
Yellow-crowned Parakeet	1	Imm	110	110	110	
C. a. auriceps	1	Unk	76	76	76	
	2	Comb	76	110	93	24
Shining Cuckoo	4	Unk	86	507	276	198
Chrysococcyx l. lucidus						
Long-tailed Cuckoo	1	Ad	36	36	36	
Eudynamys taitensis	1	Imm	2032	2032	2032	
	2	Unk	204	1050	627	598
	4	Comb	36	2032	831	916
Morepork	14	Unk	210	3333	945	942
Ninox n. *novaeseelandiae*						
New Zealand Kingfisher	1	Imm	375	375	375	
Halcyon sancta vagans	2	Unk	283	675	479	277
	3	Comb	283	675	444	205
Skylark	2	Unk	328	2267	1298	1371
Alauda arvensis	2	Comb	328	2267	1298	1371
Hedge Sparrow						
Prunella modularis	*1*	*Stewart et. al.*	*1021*	*1021*	*1021*	
Blackbird	4	Ad	236	1659	775	650
Turdus merula						

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Ad = Adult; Imm = Immature; Unk = Unknown; Comb = Combined; SD = Standard deviation

	n =	Age	Range Min	Max	Mean	SD
Song Thrush	1	Ad	1189	1189	1189	
T. philomelos	1	Unk	331	331	331	
	2	Comb	331	1189	760	607
Whitehead	4	Unk	396	1428	723	476
Mohoua albicilla						
Brown Creeper	1	Unk	670	670	670	
M. novaeseelandiae						
Grey Warbler	1	Unk	2212	2212	2212	
Gerygone igata						
North Island Fantail	1	Unk	1831	1831	1831	
Rhipidura fuliginosa placabilis						
Silvereye	4	Unk	123	638	327	222
Zosterops l. lateralis						
Poor Knights Bellbird	10	Ad	302	2202	818	542
Anthornis melanura oneho						
Bellbird	1	Ad	178	178	178	
A. m. melanura						
Tui	2	Ad	422	495	459	52
Prosthemadera n. novaeseelandiae	2	Unk	121	139	130	13
	4	Comb	121	495	294	192
Yellowhammer	7	Ad	632	1979	1161	452
Emberiza citrinella	4	Unk	283	868	573	273
	11	Comb	283	1979	947	482
Chaffinch	2	Ad	384	401	393	12
Fringilla coelebs	1	Unk	654	654	654	
	3	Comb	384	654	480	151
Greenfinch	2	Ad	682	1312	997	445
Carduefs chloris	5	Unk	466	2870	1284	986
	7	Comb	466	2870	1202	837
Goldfinch	1	Ad	1885	1885	1885	
C. carduefs	2	Unk	201	438	320	168
	3	Comb	201	1885	841	912
House Sparrow	7	Ad	349	2500	1391	916
Passer domesticus	11	Unk	774	7777	3559	1968
	18	Comb	349	7777	2716	1938

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Ad = Adult; Imm = Immature; Unk = Unknown; Comb = Combined; SD = Standard deviation

	n =	Age	Range Min	Max	Mean	SD
Starling *Sturnus vulgaris*	28	Ad	518	3036	1169	560
	1	Imm	698	698	698	
	14	Unk	632	1204	912	178
	43	Comb	518	3036	1075	479
	14	*Stewart et. al.*	*157*	*1390*	*703*	*355*
North Island Kokako *Callaeas cinerea wilsoni*	2	Ad	396	704	550	218
Australian Magpie *Gymnorhina tibicen*	5	Unk	325	1042	629	322
Rook *Corvus frugilegus*	1	Imm	927	927	927	