ORGANOCHLORINE RESIDUES IN NEW ZEALAND BIRDS OF PREY

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SUMMARY: The effects of organochlorines on raptors are reviewed. Pectoral muscle samples from 13 New Zealand falcons, 3 Australasian harriers, 7 little owls, 7 moreporks, 1 long-tailed cuckoo and 1 New Zealand pigeon were analysed for organochlorine pesticide and polychlorinated biphenyls. Five juvenile falcons contained a mean level of 2.6 mg total DDT/kg wet weight in their muscle, six adult falcons had an equivalent value of 11.7 mg/kg. Total DDT levels in harrier muscles ranged from 2.0-64.9 mg/kg. Levels in other species examined were probably too low to have detectable biological effects. Changes in New Zealand falcon eggshell thickness since 1948 were measured. There was no correlation between eggshell thinning and residue levels in two eggs and two young chicks. The shell-thinning of 0-13.3% found probably had little effect on breeding success as the most affected pairs were at the margins of the falcon's range.

INTRODUCTION

Organochlorines have long been implicated in the decline of carnivorous birds. These birds are the first to be affected because organochlorines used against insect pests become concentrated as they move up the food chain (Fimreite *et al.,* 1970; Lincer, 1975). Although geographical correlations have been found between pesticide usage and reproductive failures of raptors (Cramp *et al.,* 1962) organochlorines can also reach remote areas by wind-blown atmospheric dust (Risebrough *et al.,* 1968; Lincer *et al.,* 1970). Organochlorines vary widely in their toxicity, aldrin, dieldrin and endrin being about 100 times more toxic to quail than DDT or its breakdown product, DDE (De Witt, 1956). Dieldrin is 35-70 times more toxic to peregrines *(Falco peregrinus)* than DDE (Jeffries and Prestt, 1966) and embryos are more susceptible than adults (PeakalI, 1976a).

Organochlorines differ in their effects on animals. Polychlorinated biphenyls (PCBs) cause little shell thinning (Peakall, 1971) but delay breeding and may reduce parental attentiveness (Peakall and Peakall, 1973). DDT can cause shell thinning, delayed ovulation and death (Peakall, 1970a; Jeffries, 1973) as well as failure to produce repeat clutches (Cade *et al.,* 1967; Peakall, 1970b). Lincer (1975) and Peakall (1976b) have summarised studies showing a logarithmic relationship between shell-thinning and DDE in falcons.

Once absorbed, chemicals may be present at different concentrations in different tissues. Peakall (1976a) considered that for each unit of DDE in peregrine eggs there were about 0.15-0.4 in the brain, 1-2 in the muscles and 16-40 in the fat. Stress factors, such as parasites, moult, breeding or migration may cause fat reserves to be mobilised, releasing fat-soluble organochlorines to the other tissues in which they may then reach lethal levels (Ratcliffe, 1965b; Findlay and De Freitas, 1971; Henny.et *al.,* 1976). Once in the body, DDE may persist for a long time (Peakall *et al.,* 1975a), thus older birds generally show higher levels than juveniles (Cramp and Olney, 1967; Cade *et al.,* 1967; and this study).

DDT was used extensively in New Zealand between 1950 and 1970. Since then its use has been restricted to market gardens, orchards and other places where farm animals are not generally grazed. The most important studies on pesticides in terrestrial birds in New Zealand are those of Collett and Harrison (1968), who worked on organochlorines in a Christchurch orchard, and Harrison (1970), Lock and Solly (1916) and Solly and Shanks (1976) who made a general survey of pesticide levels in New Zealand birds and mammals.

This study was undertaken as part of a wider study of the biology of the New Zealand falcon *(Falco novaeseelandiae)* (Fox, 1977c). Because birds of prey are at the top of food chains they are especially susceptible to the effects of pesticides and are useful indicators of persistent pollutant levels in the ecosystem. Young (1969) has shown how relatively small changes in productivity or mortality

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could alter populations, and Peterson (1969) has warned that organochlorine levels in harriers, as well as in falcons and accipiters, need monitoring. Although the Australasian harrier *(Circus approximans gouldi)* is common in New Zealand, surprisingly little has been recorded on its productivity, mortality or on the age structure of its population.

METHODS

Sampling and storage

Specimens of 13 New Zealand falcons, 3 Australasian harriers, 7 little owls *(Athene noctua),* 7 moreporks *(Ninox novaeseelandiae),* 1 long-tailed cuckoo *(Eudynamis taitensis)* and 1 New Zealand pigeon *(Hemiphaga novaeseelandiae)* were obtained from private individuals, from taxidermists, and from the National Museum and the Canterbury Museum. but mostly during field work between 1971-1976 (see Tables 1-3). Causes of death, where known, are shown in the tables. Whole animals and tissues were stored deep-frozen in sealed polythene bags. Pectoral muscles and egg contents were sent by air to Wallaceville Animal Research Centre for analysis.

Analysis

The method of analysis used was that of Lock and Solly (1976). The limit of detection of DDE, DDT, HCB (hexachlorobenzene), lindane, PCB and TDE was 0.01 mg/kg. All references to DDE, TDE and DDT are to the pp'-isomers. Total DDT refers to the sum of the individual residues of DDE, TDE and DDT present in the sample. Workers on pesticides and environmental pollutants have expressed pesticide levels as mg/kg of fresh or wet weight of tissue, or as mg/kg dry weight, or as mg/kg lipid weight. These figures are thus not directly comparable. Residues referred to in this study have been quoted as, or converted into, levels per wet (fresh) weight of tissue. The tissue analysed was pectoral muscle in all samples except eggs. Egg analyses were performed on the homogenised contents of eaoh egg. Two eggs were addled and one contained a fully-formed dead chick.

Eggshell measurements

Eggshell thickness was measured in two ways. An index of thickness was obtained by weighing and measuring whole eggshells and calculating the Ratcliffe Index (RI), where RI = Weight (mg) $\div$ (Length (mm) x Breadth (mm)) (Ratcliffe, 1970).

Thirty-two eggs in the Canterbury Museum collection taken before 1948 were weighed and measured to establish a mean RI and range of RI's of normal pre-pesticide era eggs for comparison. Where shell fragments were available, direct measurements of shell thickness were made with a micrometer adapted to measure concave surfaces (Lewin, 1970).

Shell fragments from nine New Zealand falcon eggs (including two captive bred) and six whole eggshells (including one captive bred) were obtained from eight localities in northeastern South Island. Thickness was measured at 10 random places on the shell after all shell membranes had been removed. Ratcliffe Indices were calculated for whole shells, and where shell fragments were also available from the same clutch the results were correlated.

RESULTS

Analyses (in mg residue/kg wet weight of tissue) are shown in Tables 1 and 2. The last two specimens were picked up dead in two of the falcon study areas.

New Zealand falcon egg sample results are shown in Table 3 and shell thickness in Table 4.

Territory serial numbers refer to documented falcon pairs (Fox, 1977c). Where the RI was determined, the mean index of the six post-1962 eggs (Table 4, Nos. 3, 4, 8, 9, 10, 13), including an egg from captive birds, was 5.6% below the mean pre-1948 level. This was statistically significant ($P < 0.05$, Students t-test). Five eggs from pairs which had access to prey from cultivated ground (Table 4, Nos. 2, 3, 4, 6, 7) showed a mean decrease in thickness of 8.5% compared with the mean pre-1948 value, which is altered to 8.4 % if the egg from the captive birds is excluded. Both figures indicate significant thinning compared with pre-1948 eggshells ($P < 0.001$ and $P < 0.01$, respectively, Students t-test). The maximum thinning was 13.3 % in a North Canterbury egg (No.6) from a pair with a history of egg breakage. However, the total DDT level in this egg was only 1.50 mg/kg wet weight and in the four eggs in which shell thickness and DDT levels were both measured, there was no noticeable correlation between the two parameters. An egg (No. 13) from the Leatham River area, a rather remote part of inland Marlborough, contained only 0.86 mg total DDT/kg wet weight and was of 'normal' (pre-1948) shell thickness.

DISCUSSION

Could the pesticide levels found in muscle samples have proved lethal to the birds concerned? De Witt and Buckley (1962) found experimentally that bald eagles *(Haliaetus leucocephalus)* died in tremors when levels in excess of 43 mg DDT/kg wet weight were present in their livers. Porter and Weimeyer

TABLE 1. *Organochlorine residues (mg/kg wet weight pectoral muscle) in 13 New Zealand falcons and 3 Australasian harriers.*

Species	Specimen No.	Wt. (g)	Cause of death and condition	Age	Sex	Date	Location	DDE	TDE	DDT	Total DDT	Lindane	HCB	PCB
New Zealand falcon	1*	244	Injured and died Fair condition	J	M	-.5.76	Hawkes Bay	1.87	0.04	0.08	1.99	N	N	0.17
Falco novaeseelandiae	2	255	Shot Good condition	J	M	-.5.75	Waikaremoana	3.47	N	N	3.47	N	N	0.15
	3	320	Shot Good condition	J	M	—	Kurow or Methven	3.30	0.07	T	3.37	T	0.94	0.13
	4	531	Shot Good condition	J	F	25.4.76	Avon Valley, Marlborough	1.99	0.02	0.01	2.02	N	N	N
	5	510	Shot Good condition	J	F	-.-.75	Reefton	0.67	0.44	N	0.71	N	N	N
	6	630	Shot Good condition	J	F	26.4.64	Arthurs Pass	3.29	N	N	3.29	N	0.01	N
			Mean value for 5 juveniles					2.54	0.03	N	2.57	N	0.19	0.06
	7	270	Hit by car Good condition	A	M	9.6.75	Glenfalls, Ahimanawa	8.04	0.04	0.06	8.14	N	0.01	0.13
	8	250	Slight dehydrated condition	A	M	-.5.71	Rakaia Gorge, S. Canterbury	13.24	0.10	0.05	13.39	N	0.02	0.10
	9*	470	Injured and died Good condition	A	F	-.8.75	S. Hawkes Bay	2.32	0.02	0.07	2.41	N	0.02	0.21
	10	482	Injured and died Fair condition	A	F	20.7.76	Waihopai Valley, Marlborough	3.79	N	N	3.79	T	N	0.11
	11	533	Shot	A	F	—	Kurow or Methven	26.67	N	N	26.67	N	0.08	0.25
	12	531	Died in convulsions Good condition	A	F	23.7.74	Mt Lawry, N. Canterbury	16.69	N	N	16.69	0.01	N	0.16
	13	570	Shot	A	F	25.4.77	Upper Awatere R., Marlborough	1.76	N	N	1.76	N	N	N
			Mean values for 6 adults					11.70	0.03	0.02	11.74	N	0.02	0.12
			Mean values for 11 New Zealand falcons					7.54	0.03	0.01	7.58	N	0.10	0.10
Australasian harrier	14	855	Shot Good condition	J	F	-.8.75	North Canterbury	1.57	0.36	0.06	1.99	N	0.01	N
Circus	15	—	Hit by car	A	F	25.4.76	Ashburton	64.83	0.08	N	64.91	N	N	0.40
approximans	16	696	Found dead Good condition	A	M	14.6.77	Loburn, N. Canterbury	38.86	5.45	2.86	47.17	T	T	N

* Excluded from calculations—birds kept in captivity over one month before death.

NOTE: J = Juvenile; A = Adult; M = Male; F = Female; N = Nil; T = Trace.

TABLE 2. *Organochlorine residues (mg/kg wet weight pectoral muscle) in 7 little owls, 7 moreporks, 1 long-tailed cuckoo and 1 New Zealand pigeon.*

Species	Specimen No.	Wt. (g)	Cause of death and condition	Date	Location	DDE	TDE	DDT	Total DDT	Lindane	HCB	PCB
Little owl *Athene noctua*	17	155	Hit by car Good condition	26.3.75	West Melton, Canterbury	1.55	0.01	T	1.56	N	N	N
	18	197	Hit by car Good condition	–.8.76	Rangiora, Canterbury	0.47	N	N	0.47	N	N	N
	19	223	Hit by car Good condition	23.12.71	Christchurch	0.92	X	X	0.92	N	N	0.13
	20	230	Drowned Good condition	20.12.74	Loburn, N. Canterbury	3.88	N	N	3.88	N	N	N
	21	105	Hit by car	20.1.77	Loburn, N. Canterbury	1.03	0.02	0.01	1.06	N	N	N
	22	155	Hit by car	–.2.77	Loburn, N. Canterbury	9.60	N	N	9.60	N	N	N
	23	158	Hit by car	–.3.77	Loburn, N. Canterbury	0.94	N	N	0.94	N	N	N
			Mean values for Little owls			2.62	0.01	N	2.61	N	N	0.02
Morepork *Ninox novaeseelandiae*	24	210	Shot Good condition	3.4.72	Kaniere, West Coast	0.06	N	N	0.06	N	N	N
	25	207	Found dead Good condition	3.4.72	Kaniere, West Coast	1.11	0.11	N	1.22	N	T	N
	26	130	Injured and died Fair condition	16.3.76	Greymouth	0.29	N	N	0.29	N	T	N
	27	186	Hit by car Good condition	–.6.75	Lewis Pass	0.04	N	N	0.04	T	T	N
	28	203	Hit by car Good condition	13.9.72	Hokitika, West Coast	0.36	N	N	0.36	N	N	0.04
	29	152	Injured and died Thin condition	28.4.72	Greymouth	0.53	0.04	N	0.57	N	N	N
	30	156	Injured and died Fair condition	8.6.76	Eastbourne, Wellington	0.22	X	X	0.22	N	N	49.28
			Mean values for 7 moreporks			0.37	0.02	N	0.39	N	N	7.05
Long-tailed cuckoo *Eudynamis taitensis*	31	87	Found dying Thin condition	–.4.75	Hawarden	0.45	N	N	0.45	N	N	N
N.Z. pigeon *Hemiphaga novaeseelandiae*	32	585	Found dead, unmarked, with several others Good condition	–.9.75	Avondale, Waihopai Valley, Marlborough	0.01	N	N	0.01	N	N	N

NOTE: N = Nil; X = Not measured; T = Trace.

TABLE 3. *Organochlorine residues (mg/kg wet weight) in New Zealand falcon eggs and chicks.*

Specimen	DDE	TDE	DDT	Total DDT	Lindane	HCB	PCB
Addled eggs (A2), Leatham, Marl. 12 Dec. 1976	0.86	N	N	0.86	N	T	N
Addled egg (C10l), Hawarden, N. Canterbury, 20 Dec. 1976	1.50	N	N	1.50	N	T	N
Captive-bred pipping chick 23 Dec. 1976	5.05	T	0.05	5.10	T	0.01	0.01
Captive-bred 9 day old chick Jan. 1977	4.40	0.09	0.03	4.61	N	T	N

NOTE: N = Not detected; T = Trace.

TABLE 4. *Shell thickness and DDT residues in eggs of New Zealand falcons.*

	Source of eggs	Eggshell thickness (µm)	Ratcliffe Index	Total DDT (mg/kg) wet weight
1	32 pre-1948 eggs Canterbury Museum	-	1.671 EU (1.528-1.932)	presumed none
2	Hatched captive-bred egg 23 Dec. 1976	229.5 ED (207-254)	-	4.61*
3	Pipped captive-bred egg 23 Dec. 1976	232.8 ED (222-240)	1.528 ED	5.10
4	Territory C101 N. Canterbury 20 Dec. 1976	199.6 EN (190-218)	1.449 EN	1.50
5	Territory C104 N. Canterbury 22 Dec. 1975	168.0 EU (154-184)		
6	Territory C111 N. Canterbury 28 Nov. 1974	147.9 EN (129-175)		Bird No. 12, Table 1, is from this territory
7	Territory C111 N. Canterbury 8 Nov. 1974	180.5 EN (151-197)		Bird No. 12, Table 1, is from this territory
8	Territory A34 Medway R., Marl. Oct. 1963		1.526 EN	
9	Territory A34 Medway R., Marl. Oct. 1963		1.560 EN	
10	Territory A34 Medway R., Marl. Oct. 1963		1.510 EN	
11	Territory A39 Avon R. Marl. 9 Dec. 1976	229.2 ED (222-242)		Bird No.4, Table I, is from this territory
12	Territory A17 Waihopai R., Marl. 7 Dec. 1976	183.5 ED (172-193)		Bird No. 10, Table 1, is from this territory
13	Territory A2 Leatham R., Marl. 12 Dec. 1976	219.0 ED (214-230)	1.816 EN	0.86

NOTE: *This value from 9 day old chick; ED=Embryo developed; EN = Embryo not developed; EU = Embryo unknown; ( ) = Range; ----- = Not measured.

(1972) found experimentally that although 212-301 mg DDE/kg in the brains of American kestrels was lethal, only 24-78 mg DDE/kg in the whole carcase was necessary to cause death.

There is considerable specific and individual variability in the lethal levels of DDT and DDE, but in general, with mean values of 7.58 mg/kg for New Zealand falcons, most birds are probably not at risk. However, a falcon from South Canterbury (No. 11) containing 26.67 mg DDT/kg may have been at risk, especially as it had used up its fat reserves. No cause of death was found for the adult female falcon (No. 12) which died in convulsions and contained 16.69 mg DDT /kg, but a full pathological investigation was not made. Similarly, a harrier (No. 16) which contained 47.17 mg DDT/kg was not fully examined.

The levels of organochlorines found may have had some sub-lethal effects. Ratcliffe (1972) considered that sub-lethal levels of pesticides could cause poor co-ordination. Two of the falcons (No.4 and No. 10) were obtained with injuries which suggested mis-timed stoops (Fox, 1977b). Total DDT levels of up to 191 mg/kg wet weight found in harrier muscle in New Zealand (Lock and Solly, 1976) may have caused the harriers concerned to be more prone to being hit by cars when feeding on road kills.

At least nine pairs of falcons in North Canterbury and seven pairs in Marlborough at sites near cultivated country have shown impaired productivity. Some pairs laid 2-3 clutches in a year and in each case the eggs were broken or had disappeared. When nesting was successful the brood size was below average. These symptoms are similar to those observed in known pesticide-laden falcon populations. Although disturbance to breeding falcons by sheep mustering or tussock-burning has occurred in some areas it does not account for all failures to rear young.

Interpretation of measurements of eggshell thickness is complicated by variations in different parts of the shell, by individual variation (Klauss *et al.*, 1974) and by shell-thinning owing to embryonic development (Taylor, 1970), especially in the second half of incubation (Johnston and Comar, 1955). Kreitzer (1972) found a 7.3 % decrease in shell thickness of Japanese quail *(Coturnix japonica)* during incubation, but Berger *et al.* (1970) considered the change in falcon eggshells to be only slight and Ivens and Halliwell (1974) found no change at all. Thin-shelled eggs are more liable than normal eggs to break and to be ejected from the nest, causing a sample biased towards thick-shelled eggs to be collected. In general, if eggshells decrease in thickness by 20% they are unlikely to survive to the end of incubation (Peakall, 1970a). Thinning of 15-20% is likely to cause a decline in the population (Ratcliffe, 1967a, 1970; Cade and Fyfe, 1970; Fox, 1971; Cade *et al.,* 1971; Newton, 1973; Enderson and Craig, 1974; Lincer, 1975).

In this study, no correlation was observed between shell thickness and DDT content of eggs. The decrease in thickness observed in eggs taken since 1948, and the reduction in breeding success, although suggestive of a cause-and-effect relationship, cannot be definitely attributed to the presence of pesticides. However, Fyfe *et al.* (1969) considered that as little as 2 mg DDE/kg wet weight of prairie falcon *(Falco mexicanus)* eggs was sufficient to lower reproductive success and 12.5 mg/kg to cause reproductive failure. Studies by Berger *et al.* (1970), Cade *et al.* (1971), White *et al.* (1973) and Peakall *et al.* (1975b) support this contention.

The levels of total DDT in muscles of various prey species of the New Zealand falcon (Lock and Solly, 1976) were about 60% of the equivalent levels found in prey of the Irish peregrine by Norriss (1973), when the Irish peregrine population was showing signs of recovery after a drastic decrease probably caused by pesticides. Although environmental levels of some pesticides may be locally high in New Zealand, they are probably not high enough to affect the total population of falcons. The New Zealand falcon is a sedentary species, feeding largely on sedentary prey, and this behavioural characteristic has probably restricted pesticide levels in the falcon population as a whole (see Cade *et al.,* 1971; Lincer, 1975). Falcons in remote areas would rarely come into contact with pesticides.

Of the other raptors analysed, the harrier is in most danger of contamination by pesticides because it eats significant numbers of small birds (Redhead, 1968). Although this species has shown no sign of decrease in recent years, and although about 20 % of winter-trapped harriers were juvenile (indicating adequate productivity) (Fox, 1977a), a monitoring programme of biocide levels and nesting success would probably be of value. The little owl and the morepork feed mainly at lower trophic levels than the falcon (Marples, 1942; Cunningham, 1948; Lindsay and Ordish, 1964) and the low DDT levels detected are unlikely to have noticeable effects. One morepork (No. 30) had a high PCB content (49.28 mg/kg), possibly derived directly from industrial fumes (see Smith and Murphy, 1972) or from prey caught in an industrial area.

Although New Zealand mainland raptors do not appear to be in grave danger from pesticides, New Zealand falcons in the Auckland Islands might be severely affected. A falcon egg collected in 1973

(Bennington *et al.,* 1975) contained 68.0 mg DDT /kg and 88.0 mg PCB/kg lipid weight. Ratcliffe (1972) has shown that a high ratio of PCB: DDE is a feature of peregrine feeding on seabirds, in contrast to those breeding far inland. The Auckland Island falcons presumably have picked up these contaminants from the marine ecosystem (probably migratory seabirds) because the Auckland Islands are uninhabited and uncultivated, and there are no land masses nearby which could be sources of contamination. As there are probably only 6-20 pairs of falcons on the Auckland Islands the population could be in jeopardy.

CONCLUSION

The New Zealand falcon shows significant eggshell thinning in some geographical areas but there is insufficient evidence to implicate organochlorines in this effect. Immigration of falcons from the relatively uncontaminated main breeding areas is sufficient to compensate for lowered reproductive success of contaminated pairs. Despite possibly lethal levels in some harriers, the harrier population appears to be maintaining itself; more information is required on the breeding success of harriers in cultivated areas. Low organochlorine levels in the owls are probably a reflection of the owls' diets, as is the case with the other species.

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REFERENCES

BENNINGTON, S. L.; CONNORS. P. G.; CONNORS. C. W.; RISEBROUGH, R. W. 1975. Patterns of chlorinated hydrocarbon contamination in New Zealand sub-antarctic and coastal marine birds. *Environmental Pollution* 8: 135-147.

BERGER, D. D.; ANDERSON, D. W.; WEAVER, J. D.; RISEBROUGH, R. W. 1970. Shell thinning in eggs of Ungava Peregrines. *Canadian Field-Naturalist* 84 (3): 265-267.

CADE, T. J.; WHITE, C. M.; HAUGH, J. R. 1967. Peregrines and pesticides in Alaska. *Raptor Research News* 1(2): 23-38.

CADE, T. J.; FYFE, R. 1970. North American Peregrine Survey, 1970. *Canadian Field-Naturalist* 84: 231-245.

CADE, T. J.; LINCER, J. L.; WHITE, C. M.; ROSENEAU, D. G.; SWARTZ, L. G. 1971. DDE residues and eggshell changes in Alaskan falcons and hawks. *Science* 172: 955-957.

COLLETT, J. N.; HARRISON, D. L. 1968. Some observations on the effects of using organochlorine sprays in an orchard. *New Zealand Journal of Science* 11: 371-379.

CRAMP, S.; CONDER, P. J.; ASH, J. S. 1962. *Deaths of birds and mammals from toxic chemicals. January-June* 1961. Royal Society for the Protection of Birds, The Lodge, Sandy, Bedfordshire, England.

CRAMP, S.; OLNEY, P. J. S. 1967. *The sixth report of the joint committee of the British Trust for Ornithology and the Royal Society for the Protection of Birds on Toxic Chemicals.* The Royal Society for the Protection of Birds, The Lodge, Sandy, Bedfordshire, England.

CUNNINGHAM, J. M. 1948. Food of a Morepork. *Notornis* 3(1): 22-24.

DEWITT, J. B. 1956. Chronic toxicity to quails and pheasants of some chlorinated insecticides. *Agri cultural Foods and Chemicals* 4(10): 863-866.

DEWITT, J. B.; BUCKLEY, J. L. 1962. Studies on pesticide -eagle relationships. *Audubon Field Notes* 16(6): 541.

ENDERSON, J. H.; CRAIG. J. 1974. Status of the Peregrine Falcon in the Rocky Mountains in 1973. *Auk* 91: 727-736.

FIMREITE, N.; FYFE, R. W.; KEITH, J. A. 1970. Mercury contamination of Canadian prairie seed-eaters and their avian predators. *Canadian Field-Naturalist* 84 (3): 269-276.

FINDLAY, G. M.; DE FREITAS, A. S. W. 1971. DDT movement from adipocyte to muscle cell during lipid utilization. *Nature (London)* 229(5279): 63-65.

FOX. G. A. 1971. Recent changes in the reproductive success of the pigeon hawk. *Journal of Wildlife Management* 35(1): 122-128.

FOX, N. C. 1977a. Some morphological data on the Australasian Harrier *(Circus approximans gouldi)* in New Zealand. *Notornis* 24: 9-19.

FOX, N. C. 1977b. New Zealand Falcons taking poultry. *Notornis* 24: 140.

FOX, N. C. 1977c (Unpublished). *The Biology of the New Zealand Falcon* (Falco novaeseelandiae *Gmelin* 1788). Unpublished Ph.D. Thesis, University of Canterbury, Christchurch, New Zealand. 421 pp.

FYFE, R. W.; CAMPBELL, J.; HAYSON, B.; HODSON, K. 1969. Regional population declines and organochlorine insecticides in Canadian Prairie Falcons. *Canadian Field-Naturalist* 83(3): 191-200.

HARRISON, D. L. 1970. Environmental residues under New Zealand conditions. *Proceedings of 23rd New Zealand Weed and Pest Control Conference:* 118 123.

HENNY, C. J.; BEAN, J. R.; FYFE, R. W. 1976. Elevated Heptachlor Epoxide and DDE Residues in a Merlin that died after migrating. *Canadian Field-Naturalist* 90: 361-363.

IVENS, G. K.; HALLIWELL, W. H. 1974. Comparative shell thickness in wild and captive Prairie Falcons. *Raptor Research* 8: 60-66.

JEFFRIES, D. J. 1973. The effects of organochlorine insecticides and their metabolites on breeding birds. *Journal of Reproduction and Fertility,* Supplement 19: 337-352.

JEFFRIES. D.J.; PRESTT, I. 1966. Post mortems of Peregrines and Lanners with particular reference to organochlorine residues. *British Birds* 59(2): 49-64.

JOHNSTON, P. M.; COMAR, C. L.; 1955. Distribution and contribution of calcium from the albumen, yolk and shell to the developing chick embryo. *American Journal of Physiology* 183: 365.

KLAUSS, E. E.; OHLENDORF, H. M.; HEATH, R. G. 1974. Avian eggshell thickness variability and sampling. *Wilson Bulletin* 86(2): 156-164.

KREITZER, J. F. 1972. The effect of embryonic development on the thickness of the eggshells of Cotumix Quail. *Poultry Science* 51(5): 1764-1765.

LEWIN, V. 1970. A simple device for measuring eggshell thickness. *Canadian Field-Naturalist* 84(3): 305.

LINCER, J. L. 1975. DDE-induced eggshell-thinning in the American Kestrel: A comparison of the field situation and laboratory results. *Journal of Applied Ecology* 12: 781-793.

LINCER, J. L.; CADE, T. J.; DEVINE, J. M. 1970. Organo chlorine residues in Alaskan peregrine falcons *(Falco peregrinus* Tunstall), Rough-legged hawks *(Buteo lagopus* Pontopiddan) and their prey. *Canadian Field-Naturalist* 84(3): 255-262.

LINDSAY, C. J.; ORDISH, R. G. 1964. The food of the Morepork. *Notornis* 11: 154-158.

LOCK, J. W.; SOLLY, S. R. B. 1976. Organochlorine residues in New Zealand birds and mammals. *New Zealand Journal of Science* 19: 43-51.

MARPLES, B. J. 1942. A study of the Little Owl *(Athene noctua)* in New Zealand. *Transactions of the Royal Society of New Zealand* 72: 237-252.

NEWTON, I. 1973. Success of Sparrowhawks in an area of pesticide usage. *Bird Study 20(1):* 1-8.

NORRISS. D. W. 1973 (Unpublished). *Organochlorine insecticides and the Peregrine Falcon* (Falco pere grinus) *in Ireland*. M.Sc. Thesis, University of Dublin, 116 pp.

PEAKALL, D. B. 1970a. Pesticides and the reproduction of birds. *Scientific American* 222: 73-78.

PEAKALL, D. B. 1970b. p,p'-DDT: Effect on calcium metabolism and concentration of Estradiol in the blood. *Science* 168: 592-594.

PEAKALL, D. B. 1971. Effect of polychlorinated biphenyls (PCB's) on the eggshells of Ring Doves. *Bulletin of Environmental Contamination and Toxicology* 6(2): 100-101.

PEAKALL, D. B. 1976a. The Peregrine Falcon *(Falco peregrinus)* and pesticides. *Canadian Field-Naturalist* 90: 301-307.

PEAKALL, D. B. 1976b. Physiological effects of chlorinated hydrocarbons on avian species. In: Hague, R. and Freed, V. H. (Editors) *Environmental Dynamics of Pesticides*. New York: Plenum Publishing Corporation.

PEAKALL, D. B.; PEAKALL, M. L. 1973. Effect of a poly chlorinated biphenyl on the reproduction of artificially and naturally incubated dove eggs. *Journal of Applied Ecology* 10: 863-868.

PEAKALL, D. B.; MILLER, D. S.; KINTER, W. B. 1975. Prolonged eggshell thinning caused by DDE in the duck. *Nature* 254(5499): 421.

PEAKALL, D. B.; CADE, T. J.; WHITE, C. M.; HAUGH, J. R. 1975. Organochlorine residues in Alaskan Peregrines. *Pesticides Monitoring Journal* 8(4): 255-260.

PETERSON, R. T. 1969. In: Hickey, J. J. (Editor) *Peregrine Falcon Populations*. p. 531. University of Wisconsin Press.

PORTER, R. D.; WIEMEYER, S. N. 1972. DDE at low dietary levels kills captive American Kestrels. *Bulletin of Environmental Contamination and Toxicology* 8(4): 193-199.

RATCLIFFE, D. A. 1965. The Peregrine situation in Great Britain 1963-4. *Bird Study* 12(2): 66-82.

RATCLIFFE, D. A. 1967. Decrease in eggshell weight in certain birds of prey. *Nature* 215(5097): 208-210.

RATCLIFFE, D. A. 1970. Changes attributable to pesticides in egg breakage frequency and eggshell thickness in some British birds. *Journal of Applied Ecology* 7: 76-115.

RATCLIFFE, D. A. 1972. The Peregrine population of Great Britain in 1971. *Bird Study* 19(3): 117-156.

REDHEAD, R. E. 1968 (Unpublished). *Food habits of the Australasian Harrier* (Circus approximans). M.Sc. Thesis, University of Otago.

RISEBROUGH. R. W.; REICH, P.; PEAKALL, D. B.; HERMAN, S. G.; KIRVEN, M. N. 1968. Polychlorinated biphenyls in the global ecosystem. *Nature* 220: 1098-1102.

SMITH, D. G.; MURPHY, J. R. 1972. Unusual causes of raptor mortality. *Raptor Research* 6(2): 4-5.

SOLLY, S. R. B.; SHANKS, V. 1976. Organochlorine residues in New Zealand birds and mammals. *New Zealand Journal of Science* 19: 53-55.

TAYLOR, T. G. 1970. How an eggshell is made. *Scientific American* 222(3): 88-95.

WHITE, C. M.; EMISON, W. B.; WILLIAMSON, F. S. L. 1973. DDE in a resident Aleutian Island peregrine population. *Condor* 75: 306-311.

YOUNG, H. F. 1969. In: Hickey, J. J. (Editor) *Peregrine Falcon Populations*. pp. 513-519. University of Wisconsin Press.