

# CHLORINATED HYDROCARBON RESIDUES IN PEREGRINES AND THEIR PREY SPECIES FROM NORTHERN CANADA

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This paper reports upon the levels of chlorinated hydrocarbon pesticide residues in Peregrine Falcons (*Falco peregrinus*), Peregrine eggs, and in the prey species of Peregrines from western Canada, and compares these findings with those from other regions, particularly Great Britain. Also included are data on the reproductive success of the pairs we encountered. This project was conceived when it became clear at the International Conference on the Biology of the Peregrine Falcon held at Madison, Wisconsin, in September 1965 that organochlorine residues are very possibly responsible for the drastic decline of Peregrines in Europe, Great Britain, and the United States. Several scholars in England (Cramp 1963; Ratcliffe 1963; Ratcliffe 1965; Jefferies and Prestt 1966) have attempted to correlate the reduction of the Peregrine with the presence of pesticide residues, but no work on the subject in North America has been published.

## METHODS

In June and July 1966 we traveled down the Peace River from the town of Peace River in central Alberta to the Slave River, and then down the latter to Great Slave Lake, and finally down the Mackenzie River to Inuvik, NWT, a total distance of about 1900 miles (3000 km), searching the riverbanks and cliffs for nesting Peregrines. We often examined both sides of the river with binoculars where likely situations for Peregrine nesting occurred, sometimes firing a rifle to flush suspected occupants. The adult females were trapped at some sites, and usually we took one egg from each nest for pesticide analysis.

It was possible to remove up to about a gram of subcutaneous fat from each captured female by making an incision 2 cm long just lateral to the dorsal midline at the base of tail. The fat was obtained by separating it from the skin and underlying muscle with a forceps and freeing it with a scissors. Finally the wound was closed with 8 to 10 interrupted collagen sutures, and sprayed with a colloidin wound dressing. All falcons were immediately released and showed normal behavior.

Specimens of various species that are potential Peregrine prey were collected, plucked, and then the whole bird was homogenized. A sample of the homogenate was then preserved in a preweighed vial with

10 cc of 10 per cent formalin so that the wet weight of the sample could be determined later in the laboratory. All collected samples were periodically shipped to the laboratory.

In Wisconsin in September and October 1966 Berger collected fat from five immature Peregrines caught on migration; liver, brain, and breast muscle were obtained from another immature male that died before release as a result of extensive lesions in the lungs. Also analyzed were brain and fat tissue as well as the homogenized remainders of two immature female Peregrines trapped in Wisconsin and Texas in 1965 and stored frozen soon after capture.

All samples collected were analyzed for DDT, DDE, TDE (DDD), dieldrin, and heptachlor epoxide by the Wisconsin Alumni Research Foundation, Madison, Wisconsin, using a Barber Colman Pesticide Analyzer with a  $\frac{1}{4}$ "  $\times$  4' pyrex column packed with a 5 per cent DC200 on Chromport XXX. Column temperature was 182°C, injector temperature was 235°C, and detector temperature was 240°C, with the nitrogen gas flow at 100 cm<sup>3</sup> per minute. Fat was extracted in a 1:3 mixture of diethyl ether and petroleum ether in a Soxhlet apparatus, and clean-up was performed in hexane with a florisil column.

## PESTICIDE RESIDUE LEVELS

*Peregrine tissues.* The average amounts of the various pesticide residues found in the subcutaneous adipose tissue of nesting adult female Peregrines in northern Canada and in the fat of migrating immature females from Wisconsin are given in table 1. In the fat from nine adult females DDT varied between 16.0 and 52.8 ppm; DDE, 200-369; TDE, 22.2-55.7; dieldrin, 1.4-6.3; and heptachlor epoxide, 1.9-7.4, with a range of 266 to 449 ppm total residues. In the five immature females DDT varied between 0.33 and 2.17 ppm; DDE, 7.2-20.6; TDE, < 0.01-1.84; dieldrin, < 0.01-0.33; and heptachlor epoxide was < 0.01 ppm in one bird. Total residues varied between 7.9 and 24.9. Since the fatness of the birds appeared to vary considerably, the amount of extractable fat was determined for eight of these samples. The amount of extractable fat in the tissue varied between 64.1 and 77.0 per cent of wet weight, with a mean of 72.6 per cent for eight samples; the values given here for adipose tissue (wet basis) can be

TABLE 1. Chlorinated hydrocarbon residues in Peregrine tissues and eggs and in some potential prey.

	N	Compounds in ppm, wet-weight basis: Means $\pm$ SE (95% confidence limits)					Mean total residues
		DDT	DDE	TDE	Dieldrin	Heptachlor epoxide	
Adipose tissue							
Breeding birds	9	37.3 $\pm$ 12.2 (27.9-46.7)	284 $\pm$ 62 (237-331)	39.5 $\pm$ 11.2 (31.0-48.0)	3.3 $\pm$ 1.3 (2.3-4.3)	4.4 $\pm$ 2.6 (2.4-6.4)	368.2
Migrant immatures	5	0.9 $\pm$ 0.7 (0.0-1.8)	14.0 $\pm$ 5.3 (7.5-20.5)	0.6 $\pm$ 0.7 (0.0-1.5)	0.2 $\pm$ 0.2 (0.0-0.4)	0.0	15.8
Eggs							
Viable	5	2.9 $\pm$ 2.5 (0.0-10.0)	17.8 $\pm$ 10.9 (4.4-31.2)	2.1 $\pm$ 1.1 (0.7-3.5)	0.8 $\pm$ 0.7 (0.0-1.7)	0.4 $\pm$ 0.3 (0.0-0.8)	24.0
Nonviable	2	2.5 $\pm$ 0.5 (0.0-6.9)	27.9 $\pm$ 19.5 (0.0-204.9)	2.9 $\pm$ 0.7 (0.0-9.0)	0.5 $\pm$ 0.1 (0.0-1.8)	0.8 $\pm$ 0.6 (0.0-5.9)	34.6
Embryo	1	1.6	8.0	1.6	0.2	0.4	11.8
Prey <sup>a</sup>	11	0.13 $\pm$ 0.18 (0.01-0.25)	0.66 $\pm$ 0.67 (0.21-1.11)	0.11 $\pm$ 0.16 (0.00-0.22)	0.01 $\pm$ 0.02 (0.00-0.02)	0.05 $\pm$ 0.04 (0.02-0.08)	0.96

<sup>a</sup> Mew Gull (*Larus canus*), (1); Arctic Tern (*Sterna paradisaea*), (2); Spotted Sandpiper (*Actitis macularia*), (2); Cliff Swallow (*Petrochelidon pyrrhonota*), (1); Brewer's Blackbird (*Euphagus cyanocephalus*), (1); Yellow-bellied Sapsucker (*Sphyrapicus varius*), (1); Townsend's Solitaire (*Myadestes townsendi*), (1); Bohemian Waxwing (*Bombycilla garrula*), (2).

converted to an estimate of residues on a dry fat basis by multiplying by a factor of 1.38.

In the two immature Peregrines collected in 1965, DDT was 1.03 and 0.0 ppm wet basis, DDE 24.6 and 7.68, and dieldrin 0.69 and 0.60 ppm in fat. DDT was not detected from brains, but DDE was 0.28 and 0.056 ppm on a wet basis, and dieldrin 0.63 and 0.043. Other organochlorine residues were not detected.

Eight Peregrine eggs were collected for analysis; these results also appear in table 1. The last egg in the table was broken in shipment, and only the very large embryo was analyzed. The ranges of residue levels in the seven unbroken eggs were: DDT, 0.9-7.2 ppm; DDE, 10.4-41.8; TDE, 0.9-3.4; dieldrin, 0.3-2.0; heptachlor epoxide, 0.2-1.2; the range of total residues among the seven eggs was 13.9-49.9 ppm.

At one nest site a day-old Peregrine chick died accidentally. The entire bird was homogenized and analyzed. The residue levels found in ppm (wet basis) were: DDT, 0.95; DDE, 21.7; TDE, 1.44; dieldrin, 0.32; and heptachlor epoxide, 0.14.

An immature male Peregrine trapped in Wisconsin on 29 September 1966 was analyzed for DDT, DDE, TDE, dieldrin, and heptachlor epoxide and contained less than 1.0 ppm of DDT and its metabolites in the brain, about 1.0 ppm of these residues in liver plus about 0.20 ppm dieldrin and heptachlor epoxide combined, and 1.6 ppm DDT and its metabolites plus 0.1 ppm dieldrin in muscle.

*Prey species.* Average pesticide residues found in 11 individuals of a variety of prey species of the Peregrine are shown in table 1. Among these, the Cliff Swallow, with residues

totaling 2.00 ppm (wet basis), and the two Spotted Sandpipers, with total residues averaging 2.38 ppm (wet basis), appear to have carried the highest residues. The ranges of the various residues in the 11 birds were: DDT, 0.00-0.63 ppm; DDE, 0.02-2.53; TDE, 0.00-0.57; dieldrin, 0.00-0.06; heptachlor epoxide, 0.01-0.13.

#### OBSERVATIONS ON PEREGRINE REPRODUCTION

Since only one visit was made to most of the nest sites, we have no information on the final outcome of the nesting attempts. Most of the sites were visited near the time of hatching, although four eggs in two clutches were in the first half of incubation. Two of the 15 sites were occupied by pairs without eggs or young, but one of these pairs was aggressive when we approached an empty ledge on the riverbank. Of the remaining 13 pairs, 7 had 4 eggs or young (or both), 1 had 3, 3 had 2, and 2 had 1. Of the 33 eggs seen, only 4 were considered to be not viable. At one site containing one egg, the male was absent during the two-hour visit, but at all other sites both adults were seen and appeared to behave normally.

In the 15 nests, viable eggs or young, or both, averaged 2.3 per pair, or 2.6 for the 13 pairs with eggs or young.

#### DISCUSSION

It is important to know the extent to which the prey birds that we collected might serve as a source of chlorinated hydrocarbon residues in Peregrines. Pesticide residues in the eight species of prey varied greatly, but in

all cases DDT and its metabolites formed the major part of the total (table 1). Total residues in the four cleanest birds were near 0.1 ppm in each case, but total residues in one of the Spotted Sandpipers were 3.04 ppm, and were 2.00 ppm in the Cliff Swallow. These levels were the highest that we found but are substantially below those found in certain birds from areas with perhaps atypically high organochlorine residues. Woodcocks from New Brunswick in the spring of 1963 contained heptachlor and DDT averaging a total of 12.6 ppm (Wright 1965). A sample of 91 passerine birds found dead in Virginia after the application of dieldrin to the habitat had total levels of DDT and its metabolites and heptachlor epoxide averaging 3.4 ppm, and dieldrin levels were much higher than those found in the present study (Stickel and Heath 1965:15). In comparison, we found (unpublished data) a mean of 0.1 ppm DDT and its metabolites in nine Starlings (*Sturnus vulgaris*) from Colorado, with a range of zero to 0.33 ppm.

When residue levels in ppm are converted to total weight per individual bird, an expression of the amount of residue that would be ingested by a Peregrine when eating that bird is obtained. Aside from the fact that the 11 specimens that we collected are probably not typical of a Peregrine diet, a gram of prey from our sample would contain 0.69  $\mu\text{g}$  of residues. Captive female Peregrines require about 100 g of food per day (Craighead and Craighead 1956); wild Peregrines probably would require about 150 g per day. On a diet represented by the specimens we collected, a Peregrine would ingest on the average 103.5  $\mu\text{g}$  of residues per day. Seven female Peregrines that we weighed averaged 1020 g, or about one kilogram. On this basis a Peregrine would increase its residue load by 0.10 ppm per day, assuming complete assimilation of the residues. Stickel *et al.* (1965) found that Woodcocks absorb only 20 per cent of the heptachlor they ingested. If this percentage is used as an approximation, Peregrines might increase their residue level by 0.02 ppm per day. At this rate an initially uncontaminated Peregrine would reach the mean total residue level of the prey sample (0.97 ppm) in about 50 days, assuming no loss of residues. However, residue loss is about 2.8 per cent per day in Woodcocks on a clean diet (Stickel *et al.* 1965), and DDT residues are lost from the fat of chickens at an average rate of about 0.6 per cent per day over a 154-day period (Wesley *et al.* 1966). With a loss of even 5 per cent per day, Peregrines appar-

ently could accumulate residue levels equivalent to the average of our prey sample in a little more than two months.

However, young Peregrines are not initially free from residues, but carry substantial amounts from the egg. The chick that we collected bore 24.07 ppm (wet weight) of DDT and its metabolites plus 0.32 and 0.14 ppm of dieldrin and heptachlor epoxide, respectively, while the mean for eggs was 25.6, 0.6, and 0.5 ppm (wet weight) for these materials. Cade *et al.* (1968) found roughly half these latter levels in two eggs from the Yukon River in Alaska in 1966, and the residues in two chicks that they collected were roughly three fourths of those in the chick that we collected.

Nesting adult Peregrines in western Canada carry far higher residue levels in their fat than do immature migrants. The nine adults bore on the average about 23 times as much residue as the five three-month-old immatures captured in Wisconsin in 1966, and about 20 times the levels found in fat from two immatures collected in 1965. In Alaska Cade *et al.* (1968) found that adult fat has residues about 15 times greater than fat from large downy young. However, levels in fat from young Alaskan Peregrines yet to leave the nest average nearly three times more than our samples from migrant immatures trapped in Wisconsin. All these data suggest (1) that the high levels in adults compared with immatures are accumulated after the young move southward for winter where the birds may be exposed to prey bearing residue levels higher than their northern counterparts, (2) that there appear to be regional differences in the residue levels in Peregrines in the north, and (3) that it is likely that samples drawn from adults and immatures migrating in the United States are from different populations exposed to prey populations with different levels of contamination. More banding of northern Peregrines is needed to verify the third possibility.

Since organochlorine residues are fat-soluble, levels in adipose tissue taken by biopsy are much higher than those found in other tissues. One of our immature Peregrines collected in 1965 had 94 times the total residue in its adipose tissue compared with its brain, while the other had 28 times as much in fat. Two Prairie Falcons (unpublished data) had 106 and 121 times more residue in adipose tissue compared with brain, while Cade *et al.* (1968) found this ratio to average about 114 in four adult Peregrines from Alaska. In view of the variability of these ratios, only tentative statements can be made. But it would appear

that the nine Peregrines on the Mackenzie system bearing a mean of 368 ppm of residues in adipose tissue could be expected to have brain levels well below 10 ppm; and the migrating immatures, with a mean of 15.5 ppm, below 1.0 ppm.

If these extrapolations are correct, the Peregrines that we sampled had levels of residues in the brain well below those found in Peregrines thought to have died from acute organochlorine poisoning in Britain. Jeffries and Prestt (1966) found 51.9 ppm total residues in the brain of a British Peregrine thought to have died from pesticide poisoning, and Ratcliffe (1965) cited 51.2 ppm total residues in the brain of an adult male Peregrine found dead on a nest ledge in the Bristol Channel; in both of these cases, as in our samples, DDE made up the bulk of the residue. These levels from stricken birds are about 525, 91, and 57 times brain levels that we found in three immature migrant Peregrines presumably dying from unrelated causes, and about 10 times those Cade *et al.* (1968) found in the brains of four nesting Alaskan adults.

The immature Peregrine that we collected in 1966, which died from lesions in the lungs, bore 1.07 ppm (wet basis) total residues in its liver. Three adult Peregrines supposed to have died from acute pesticide poisoning had 77, 76, and 55 times more residue in their livers (Jeffries and Prestt 1966).

In four instances we were able to compare the level of each residue in fat from females with its level in their whole eggs in an attempt to establish an index between these values. The means for each of the various compounds (wet basis) in whole eggs varied between 4.5 and 15.1 per cent of those in the adipose tissue of falcons that laid them, with the mean of total residues in eggs being 5.5 per cent of the mean of total residues in female tissue. In another instance a whole nearly hatched embryo bore 4.4 per cent of the total residues found in the fat of the female that laid the egg.

Residue levels in seven whole eggs taken on the Mackenzie system varied from 13.9 to 49.9 ppm total residues, with a mean of 27.1. Cade *et al.* (1968) found that the levels of residues in two eggs from the Yukon River in 1966 were lower than ours. Our eggs averaged about five times the total chlorinated hydrocarbon residues found in a Peregrine egg in Great Britain in 1961 (Moore and Ratcliffe 1962). Ratcliffe (1965) found total residue levels varying between 2.9 and 36.1 ppm in 15 eggs, with a mean of 13.8, or about half that of our samples. While these means repre-

sent samples that vary widely in regard to pesticide levels, it seems clear that, in general, Peregrine eggs from western Canada bear substantially higher residues than eggs from Great Britain where Peregrines are having great difficulty reproducing.

All of 21 Osprey eggs from Connecticut in 1963 and 1964 and 41 from Maryland contained levels of DDT and its metabolites below the range of our Peregrine eggs (Stickel and Heath 1965:5). However, Genelly and Rudd (1956) reported that DDT levels as high as 150 ppm caused no reduction in pheasant egg hatchability.

We found no indication that the Peregrines of the Mackenzie system were failing reproductively. The 15 pairs that we observed averaged 2.27 viable eggs or young, compared with about 3.09 viable eggs or young in 11 nest sites seen near the time of hatching along the Yukon River in 1966 (Cade *et al.* 1968). At 13 sites on the Mackenzie system Peregrines averaged at least 3.0 eggs per pair. In comparison, Cade (1960) shows a mean clutch size of 2.9 for northern Alaska and 3.1 for other arctic sites, mainly in Canada. Hickey (1942) gives 3.0 as the mean clutch size for the Arctic. In 1964 in the central highlands of Scotland 15 pairs of Peregrines fledged a mean of 2.3 young per pair, with only one unsuccessful nest (Ratcliffe, unpublished data). In this remote area, the only place in Britain where the species appears to be doing well, reproductive performance is evidently better than along the Mackenzie.

Even though the Peregrines seen in this study seemed to be reproducing and behaving normally, and despite the indication that residues in adults and immatures are apparently below lethal levels, we believe that this species should have close surveillance and a continued assessment of residue levels in their tissues. The remarkable and disturbing ease with which these birds accumulate residues from nearly trace amounts in prey and then pass these materials to their young, coupled with the possibility of subtle sublethal effects of organochlorine residues on falcon reproduction, gives us scant reason for complacency.

#### SUMMARY

Peregrine Falcon (*Falco peregrinus*) adipose tissue, eggs, and prey species collected along the Peace, Slave, and Mackenzie rivers in Canada were analyzed for organochlorine residues by electron capture gas chromatography. Residues of DDT, DDE, TDE, dieldrin, and heptachlor epoxide in the fat of nine nesting adult female Peregrines averaged 37.3, 284,

39.5, 3.3, and 4.4 ppm (wet basis), respectively, but immature Peregrines caught in migration in September 1966 in Wisconsin have only 0.9, 14.0, 0.6, 0.2, and 0.0 ppm (wet basis) of these same materials. Total residues in 11 birds that are potential Peregrine prey averaged about 1.0 ppm (wet basis) in the whole body, but one bird had about 3.0 ppm. Total residues in seven whole Peregrine eggs averaged 27.1 ppm, about twice that found in Peregrine eggs in Britain. A seemingly normal average of 2.3 viable eggs or young, or both, was found near the time of hatching in the 15 sites that we observed. All these data suggest that adult Peregrines in northern Canada carry high levels of organochlorine resi-

dues acquired over a period of many months, that their eggs bear about twice the levels found in eggs from the stricken British Peregrine population, and that even with these precariously high levels the Canadian Peregrines appear to be reproducing normally.

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