PEREGRINES AND PESTICIDES IN ALASKA

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Long esteemed for its functional beauty and prowess as a hunter, the Peregrine Falcon (*Falco peregrinus*) is the most wide-ranging predatory bird. Breeding populations still occur on every continent and on most of the larger islands of the world. These falcons are noted for their tenacity in holding to traditional nesting sites—usually cliffs—year after year, and their breeding populations have been characterized by a high degree of stability through time, even in the face of extensive human modification and disruption of their environment (Hickey 1942; Ferguson-Lees 1951; Cade 1960; Ratcliffe 1962). In Great Britain, where the species has been most thoroughly studied, until recently the breeding population of some 600 pairs appeared to have changed little since Elizabethan times, when these falcons were much in demand for the sport of falconry and many individuals were removed from the wild population each year.

Quite suddenly in recent years many of these once-vigorous breeding populations, particularly in north temperate regions of intensive human habitation, began to show peculiar reproductive failures, followed after a time by disappearance of the adults from their historic nesting sites. At the Peregrine Conference held by the University of Wisconsin in 1965, the full extent of this unprecedented population decline both in North America and in Western Europe was documented and evaluated by peregrine experts from several countries (Hickey *et al.*, in press).

The various regional reports given at this conference show that the species has experienced simultaneous, catastrophic population declines over much of North America and Europe. The Peregrine now appears to be extinct as a breeding bird in the eastern United States from the Mississippi Valley to the Atlantic Coast and from Alabama north at least to Nova Scotia, a region that previously contained about 300 nesting sites known to be more or less continually occupied by breeding pairs. (See Herbert and Herbert [1965] for details about one local population.) Peregrines have also virtually disappeared from an extensive breeding range in Ontario. Reductions have been reported in all regions west of the Mississippi River wherever recent studies have been carried out (Enderson 1965), and, in particular, numbers are greatly reduced all along the Pacific Coast, where Peregrines were until a few years ago fairly common breeders (see Bond 1946, for former abundance). In Europe, Peregrines have declined drastically not only in countries of high human population and intensive agriculture, such as Great Britain, Germany, and France, but also in the more remote regions of Sweden and Finland (Hickey *et al.*, in press).

The available evidence implicates the biological concentration of residues of the chlorinated hydrocarbons (pesticides) in the Peregrine's food chain as the cause of its widespread decline in North America, Europe, and Great Britain. The main points were brought out clearly at the Peregrine Conference. These are: (1) reproductive malfunctions and population decline show a temporal correspondence with the beginning of heavy industrial and agricultural uses of pesticides following World War II; (2) the geographic pattern of decline and disappearance corresponds closely with the geographic pattern of pesticide utilization—where pesticides have been heavily used, the Peregrines are gone; where these chemicals are little used, Peregrines still breed in their former numbers (local exceptions such as the Finnish population now nearly extirpated can be explained by heavy contamination of the falcons by pesticides on their wintering grounds); (3) peculiar reproductive abnormalities, such as egg-eating, appear in a stricken population first, persist for a number of years during which there is little or no reproduction, to be followed by disappearance of the adults from their long-established aeries; and (4) in the one region (England) where residue analyses of Peregrine carcasses and eggs have been made previously, high residue levels of chlorinated hydrocarbons were found (Ratcliffe 1965a, 1965b; Jefferies and Prestt 1966).

Alaska is the only state where breeding Peregrines are still common and apparently unaffected as yet by the decline that has taken hold of the continental population farther south. Since our earlier studies (Cade 1960; White, in press) provide a broadly based background of information about the population characteristics of Alaskan Peregrines, we felt that an intensive re-examination of a well-known local breeding population of far northern Peregrines might be valuable as a comparative basis for a further evaluation of the hypothesis that pesticides are responsible for the population decline. If the Alaskan Peregrines are approaching the critical, initial phase of decline, we thought it would be particularly important to obtain current information on reproductive and population characteristics that could be associated with pesticide residues in the prey and tissues of these falcons.

Our earlier studies had also shown that breeding populations convenient for study exist along most of the major rivers of Alaska, such as the Colville and the Yukon. We chose the latter for this investigation, because there had been some unverified reports that Peregrines are decreasing in this region.

MATERIALS AND METHODS

Four boat trips were made over the course of the study area from Circle, Alaska to Castle Rock, Y.T., a distance of about 172 river-miles, as measured on USGS maps with a scale of 1:63360. These trips were made between 10 June and 31 July 1966. The two earlier trips allowed us to gather information at a time when there were downy young or eggs in the Peregrine nests, and the two later trips were made at a time when there were advanced nestlings or fledglings present, so that a fair estimate of reproductive success was obtained.

Wherever possible, actual nesting sites (aeries) of the falcons were climbed to and examined at close hand. Of the 17 pairs of falcons observed, one pair occupied a cliff too remote from the river to examine, one aerie could not be reached, although it was observed to be active, and two pairs evidently had no nests; the other 13 nests were found and examined. The following data were obtained at all aeries visited: number of eggs or young; sex ratios of young; food items in and about the nest; distance of site above the river, above base of cliff, below brink of cliff, back from the water's edge; area of nesting ledge; and other miscellaneous physical data. All young suitably aged for banding were given FWS numbered leg-bands. Records were kept on the actions of the adults at their aeries and on the development of the young. Notes were also made on local ecological conditions that may affect hunting territories, prey selection, and nest-site selection.

All bird specimens for pesticide analysis were collected either with a .12 or .410 gauge shotgun or with a mist-net. Nestling falcons, however, were killed by suffocation.

Specimens were preserved in a 10 per cent formalin solution made up from well water obtained at Eagle, Alaska. This solution contained less that 0.001 ppm each of DDE, TDE (DDD), and DDT, and no dieldrin. Whole specimens of the smaller species were preserved, but larger species were cut up, and the brain, pectoral muscle, liver, and some abdominal fat were preserved in separate containers. Whole specimens were first weighed intact. They were then skinned, and bills, legs, and wings beyond the first joint out from the body were removed. The specimens were again weighed and placed in acetone-washed jars with formalin. Lids on the preserving jars were lined with aluminum foil, and the jars were sealed with wax to prevent leakage.

The specimens obtained for analysis of pesticide residues came from both resident and migrant populations, and the species sampled were chosen on the basis of known prey items as determined by the present and previous field studies in this area.

Samples for residue analysis were dried for 48 hours at 40° to 45°C, ground with sodium sulfate, extracted for 8 hours with a 1:3 mixture of ether and petroleum ether, and cleaned by passage through a florisil column. Reading was on a Jarrell-Ash 28-700 electron gas chromatograph with a column 0.64 cm by 1.2 m on 60/70 Chrompport XXX. Flow rate was 120 ml per min. Temperatures were: column, 180°C; injector, 240°C; and detector, 205°C. Laboratory preparation and chromatography were performed by the Wisconsin Alumni Research Foundation.

DISTRIBUTION AND DENSITY OF BREEDING PAIRS

Seventeen pairs of Peregrines were found along 172 miles of river. Table 1 shows the relative locations of the cliffs occupied by these pairs and compares the 1966 distribution with that found in 1951 (Cade 1960). The average linear distance between occupied cliffs in 1966 was 10.5 miles (range of 31 to 2 miles). In 1951 the average distance between 19 occupied cliffs was 9.3 miles (range of 31 to 2.75 miles). Traveling the same stretch of river in the latter part of the nestling period in 1899, L. B. Bishop and W. H. Osgood (1900) estimated about one pair every 10 miles, which is remarkably good agreement with our actual counts made 52 and 67 years later.

Thirteen cliffs are known to have been used both in 1951 and 1966, and the number could

TABLE 1. Occupancy of cliffs by Peregrines along the Upper Yukon River.

Cliff no.	Miles between cliffs	Occupancy 1951	Occupancy 1966
1	—	Single adult	Pair nesting
2	8.0	Pair nesting	
3	3.0	Pair nesting	(Possibly missed)
4	4.0		Pair nesting
5	3.0	Single adult	
6	3.0	Pair nesting	Pair nesting
7	3.0	Pair nesting	
8	1.25		
9	2.75		
10	3.5	(Possibly missed)	Pair nesting
11	3.25		
12	3.0	Pair nesting	
13	2.0		
14	3.0	Pair nesting	Pair nesting
15	10.25	Pair nesting ?[a]	Pair nesting
16	8.5	(Possibly missed)	Pair nesting
17	1.5		
18	2.25	Pair nesting ?	
19	9.5		
20	3.0		
21	4.0	Pair nesting ?	Pair, no nest
22	14.0		
23	3.0		
24	14.0	Pair nesting	Pair nesting
25	2.0		Pair nesting
26	4.0		
27	5.0		
28	11.5	Pair nesting ?	Pair nesting ?
29	3.5	Pair nesting ?	Pair, no nest
30	2.5		
31	4.0	Pair nesting ?	Pair nesting
32	9.5	Pair nesting ?	Pair nesting
33	2.75	Pair nesting ?	Pair nesting
34	4.5	Pair nesting ?	Pair nesting
35	6.0	Single adult	Pair nesting

[a] A question mark indicates that a pair was present but that the exact nesting site was not found because of the lateness of the season.

have been higher as some pairs may have been overlooked in both years. At least four specific cliffs have histories of occupancy exceeding 30 years, and two located between Eagle and Dawson have been occupied for more than 65 years.

These Yukon falcons conform to the classic picture of a breeding peregrine population: a static number of pairs, each associated with a specific and long-used aerie. Numbers have not decreased in recent years, and there is no reason to think that Peregrines were ever more common on the upper Yukon within historic times than they are at present.

It is instructive to compare the distribution of occupied cliffs listed in Table 1 with the total number of cliffs on this stretch of the Yukon. From our knowledge of the kinds of sites chosen for nesting by these Peregrines, we judge that there are at least 35 cliffs potentially available for nesting. The average distance between all cliffs is 4.9 miles (range of 14 to 1.25 miles). Obviously some factor other than available nesting habitat is limiting this breeding population. Since in six of the cases listed in table 1 the distance between adjacent pairs was not more than 3 miles, it seems unlikely that territorial aggression is a limiting factor, as suggested by Ratcliffe (1962) for the much denser British population prior to its decline.

The section of river between cliffs numbered 17 and 27 was especially sparsely occupied, with only three pairs in each year spread among 11 cliffs. It is unlikely that density of food species varies sufficiently along this stretch of river to produce the observed variability in the linear distribution of Peregrine aeries; but the variation in suitability of the surrounding terrain for hunting by Peregrines may be the factor. This aspect of Peregrine ecology needs more study than it has so far received.

REPRODUCTIVITY OF THE YUKON PEREGRINES

On the average, northern Peregrines lay about three eggs, and the number of young chicks ranges around 2.3 to 2.7 per aerie (Cade 1960). In 1966 the mean number of downy chicks or eggs, or both, for 11 productive pairs on the upper Yukon was 3.09, and the mean number of advanced young was 2.25 per aerie for 12 pairs, compared with only 1.67 young per successful pair in 1951. (The 1951 value is based on an assessment made at a somewhat later stage of the breeding period than was the case in 1966, and the two values are not strictly comparable.) The mean number of fledged or nearly fledged young per occupied cliff, including unsuccessful pairs, was 1.80, as compared with 1.05 in 1951, and 1.4 for 25 aeries along the Colville River in 1952 (Cade 1960). Thus, by all prior standards of comparison available on far northern populations, the reproductivity of the Yukon Peregrines in 1966 must be judged to lie on the high side of the overall average value of about one young fledged per occupied site.

The Yukon value for 1966 also compares well with other samples of productivity obtained from more southern populations before the present decline set in; but in evaluating these comparisons it must be kept in mind that the average number of eggs produced by these southern falcons was four rather than three. For instance, Hickey (1942) reported an average of 1.5 young raised for 19 occupied aeries around New York in 1939 and 0.7 young for the same 19 sites in 1940. The reproduc-

TABLE 2. The prey of Peregrines in the taiga zone of Alaska.

Species	Weight class in grams	1951[a] No.	1951[a] % total	1951[a] % weight	1966 No.	1966 % total	1966 % weight
Red-necked Grebe	500	1	0.44	1.44	1	0.30	1.10
Horned Grebe	250	–	–	–	3	0.91	1.87
Black Brant	1400	1	0.44	4.00	–	–	–
Pintail	900	5	2.21	12.78	3	0.91	5.93
Green-winged Teal	300	7	3.09	6.00	9	2.76	5.93
Blue-winged Teal	300	–	–	–	2	0.60	1.32
Unidentified teal	300	–	–	–	2	0.60	1.32
American Widgeon	550	–	–	–	2	0.60	2.41
Shoveler	550	2	0.88	3.14	5	1.53	6.04
Canvasback	1300	1	0.44	3.71	–	–	–
Scaup ducks	600	3	1.33	5.14	1	0.30	1.32
Harlequin Duck	600	1	0.44	1.71	–	–	–
White-winged Scoter	1250	–	–	–	1	0.30	2.75
Surf Scoter	900	1	0.44	2.57	2	0.60	3.95
Unidentified ducks	500[b]	4	1.76	5.72	17	5.19	18.68
Waterfowl subtotal	–	26	11.50	46.35	48	14.60	52.62
American Kestrel	110	–	–	–	1	0.30	0.24
Spruce Grouse	550	1	0.44	1.57	1	0.30	1.21
Ruffed Grouse	550	1	0.44	1.57	–	–	–
Common Snipe	100	20	8.84	7.72	20	6.07	4.39
Upland Plover	150	1	0.44	0.42	–	–	–
Spotted Sandpiper	40	23	10.17	2.63	10	3.03	0.88
Lesser Yellowlegs	80	6	2.65	1.37	26	7.93	4.57
Solitary Sandpiper	40	–	–	–	9	2.76	0.79
Pectoral Sandpiper	60	–	–	–	1	0.30	0.13
Semipalmated Sandpiper	30	2	0.88	0.17	–	–	–
Northern Phalarope	25	1	0.44	0.07	3	0.91	0.16
Unidentified shorebirds	50[b]	–	–	–	10	3.03	1.10
Shorebird subtotal	–	53	23.51	10.39	79	24.03	12.02
Mew Gull	500	11	4.86	15.73	3	0.91	3.30
Bonaparte's Gull	250	2	0.88	1.44	5	1.53	2.74
Sabine's Gull	250	–	–	–	1	0.30	0.55
Arctic Tern	110	–	–	–	1	0.30	0.24
Unidentified larids	250[b]	–	–	–	4	1.21	2.20
Hawk Owl	350	1	0.44	1.00	–	–	–
Boreal Owl	80	–	–	–	1	0.30	0.18
Yellow-shafted Flicker	90	13	5.75	3.34	11	3.35	2.18
Unidentified woodpeckers	60	–	–	–	2	0.60	0.26
Empidonax flycatchers	10	1	0.44	0.02	7	2.18	0.15
Olive-sided Flycatcher	30	1	0.44	0.06	–	–	–
Say's Phoebe	20	–	–	–	1	0.30	0.04
Bank Swallow	10	1	0.44	0.02	1	0.30	0.02
Cliff Swallow	15	–	–	–	1	0.30	0.03
Gray Jay	80	24	10.60	5.49	63	19.15	11.07
Black-capped Chickadee	10	1	0.44	0.02	–	–	–
Hudsonian Chickadee	10	1	0.44	0.02	–	–	–
American Robin	80	9	3.98	2.05	8	2.43	1.41
Varied Thrush	70	10	4.42	2.00	16	4.87	2.46
Hermit Thrush	30	–	–	–	1	0.30	0.07
Swainson's Thrush	30	–	–	–	3	0.91	0.20
Unidentified hylocichlids	30	13	5.75	1.11	10	3.03	0.66
Townsend's Solitaire	30	–	–	–	1	0.30	0.07
Bohemian Waxwing	60	3	1.33	0.51	9	2.76	1.19
Orange-crowned Warbler	10	1	0.44	0.02	1	0.30	0.02
Yellow Warbler	10	1	0.44	0.02	2	0.60	0.04
Unidentified warblers	10[b]	–	–	–	2	0.60	0.04
Rusty Blackbird	50	6	2.56	0.85	2	0.60	0.22
Redpoll	10	1	0.44	0.02	–	–	–
Pine Grosbeak	40	1	0.44	0.11	1	0.30	0.09
White-winged Crossbill	30	5	2.21	0.42	–	–	–
Slate-colored Junco	10	2	0.88	0.05	6	1.82	0.13
Fox Sparrow	35	11	4.86	1.10	6	1.82	0.47
White-crowned Sparrow	25	–	–	–	2	0.60	0.11
Piciform and Passerine Subtotal		118	52.60	19.51	176	54.42	22.45

TABLE 2. *Continued.*

Species	Weight class in grams	1951[a] No.	1951[a] % total	1951[a] % weight	1966 No.	1966 % total	1966 % weight
Dusky Shrew	5	5	2.21	0.07	–	–	–
Voles, spp.	30	6	2.26	0.51	2	0.60	0.13
Red-backed Vole	30	–	–	–	2	0.60	0.13
Arctic Ground Squirrel	400	–	–	–	1	0.30	0.88
Snowshoe Hare	500	2	0.88	2.86	1	0.30	1.10
Mammal subtotal		13	5.77	3.44	6	1.80	2.44
Grand Total		226	100.00	100.00	329	100.00	100.00

[a] Based on table 7 of Cade (1960).
[b] Approximate weight.

tivity of the Yukon Peregrines in 1966 also exceeds the two best years reported by Hagar (in press) for 14 Massachusetts aeries between 1935 and 1942.

FOOD OF THE YUKON PEREGRINES

Three hundred and twenty-nine items of prey representing 49 species of birds and 4 species of mammals were found around the aeries in 1966. The basic pattern of prey utilization in 1966 was the same as that in 1951, and a comparison of the data for the two years shows that these Peregrines sample widely from the available avifauna, although certain types of birds are more susceptible to capture than others (table 2). A few mammals are also taken. Waterfowl constitute about 50 per cent of the diet by weight; Pintails (*Anas acuta*), Green-winged Teal (*Anas carolinensis*), and Shovelers (*Spatula clypeata*) are the most frequently taken ducks. Shorebirds constitute 10 to 12 per cent of the food by weight; the Common Snipe (*Capella gallinago*), Spotted Sandpiper (*Actitis macularia*), and Lesser Yellowlegs (*Totanus flavipes*) are most often caught. Small gulls make up about 10 to 15 per cent. Small land birds (Piciformes and Passeriformes) constitute about 20 per cent; and among these, the Yellow-shafted Flicker (*Colaptes auratus*), Gray Jay (*Perisoreus griseus*), American Robin (*Turdus migratorius*), Varied Thrush (*Ixoreus naevius*), and various hylocichlid thrushes are hardest hit. Small mammals make up only 2 to 3 per cent of the food.

The Peregrine is a top predator in its ecosystem, feeding on primary, secondary, and tertiary carnivorous species, as well as on herbivores. In some cases its trophic level may be removed from the producer level by as many as five or six links in the food chain (plant—herbaceous insect—predatory insect—insectivorous bird—small hawk or owl—peregrine), a fact of particular significance in connection with biological concentration of pesticide residues up the Peregrine's food chain. The great

TABLE 3. Summary of pesticide residues in Alaskan prey of Peregrines.

Prey category	No.	Lipid as % of dry wt. Mean	Lipid Range	DDE ppm dry weight Mean	DDE Range	TDE ppm dry weight Mean	TDE Range	DDT ppm dry weight Mean	DDT Range	Dieldrin ppm dry weight Mean	Dieldrin Range	Total ppm dry weight Mean	Total Range	Residues ppm wet weight[e] Mean	Residues Range
Resident boreal birds[a]	8	6.6	2.8 to 10.5	0.32	0.07 to 0.99	0.11	0.07 to 0.15	0.19	0.07 to 0.74	0.00	—	0.61	0.20 to 1.87	0.20	0.06 to 0.60
Migrant seed-eating passerines[b]	7	6.5	3.5 to 14.3	0.47	0.07 to 1.48	0.12	0.06 to 0.28	0.12	0.06 to 0.28	0.00	—	0.71	0.19 to 2.04	0.23	0.06 to 0.66
Migrant insectivorous passerines[c]	17	11.0	1.9 to 27.6	1.05	0.27 to 3.94	0.17	0.05 to 0.32	0.16	0.05 to 0.32	0.01	0.00 to 0.10	1.39	0.37 to 4.68	0.45	0.12 to 1.51
Migrant sandpipers[d]	4	14.1	8.1 to 27.5	6.02	1.94 to 10.5	0.07	0.06 to 0.10	0.09	0.07 to 0.13	0.11	0.04 to 0.27	6.29	2.11 to 11.0	2.03	0.68 to 3.55

[a] Includes: 2 juvenile Ruffed Grouse, 5 Gray Jays, and 1 Pine Grosbeak.
[b] Includes: 2 Slate-colored Juncos, 3 White-crowned Sparrows, and 2 Fox Sparrows.
[c] Includes: 2 Traill's Flycatchers, 2 Bank Swallows, 2 American Robins, 3 Varied Thrushes, 3 Swainson's Thrushes, 2 Gray-cheeked Thrushes, 1 Yellow Warbler, 1 Northern Waterthrush, and 1 Rusty Blackbird.
[d] Includes: 3 Spotted Sandpipers and 1 Lesser Yellowlegs.
[e] Estimated on the assumption of 68% water content.

TABLE 4. Pesticide residues in the tissues of Alaskan Peregrines.

Tissue analyzed	No.	Lipid as % of dry wt.		DDE ppm dry weight		TDE ppm dry weight		DDT ppm dry weight		Dieldrin ppm dry weight		Total ppm dry weight		Residues ppm wet weight[a]	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Eggs	2	16.8	10.9 to 22.7	48.0	44.0 to 52.0	3.35	0.41 to 6.29	3.02	1.02 to 5.02	2.75	1.45 to 3.06	57.1	46.9 to 66.4	15.0	12.3 to 17.5
Downy chicks	2	10.2	7.3 to 13.1	38.4	28.8 to 48.5	3.65	2.74 to 4.56	2.41	2.14 to 2.69	0.86	0.78 to 0.94	47.6	36.4 to 58.7	15.4	11.7 to 18.9
Juvenal fat	4	91.3	90.2 to 92.9	42.4	17.5 to 56.3	1.29	0.24 to 2.33	1.24	0.75 to 1.54	0.15	0.05 to 0.38	46.2	19.6 to 59.8	42.0	17.8 to 54.4
Adult fat	4	85.8	70.0 to 93.2	622.0	176.0 to 914.0	25.4	5.07 to 48.0	25.3	11.2 to 48.0	6.20	1.45 to 15.1	670.0	224.0 to 934.0	617.0	204.0 to 849.0
Juvenal muscle	4	9.3	3.9 to 14.3	6.33	0.84 to 14.6	0.17	0.07 to 0.46	0.16	0.07 to 0.46	0.05	0.00 to 0.13	6.71	0.97 to 15.6	1.77	0.26 to 4.10
Adult muscle	4	18.1	14.0 to 22.6	89.2	51.8 to 106.0	4.04	1.50 to 5.74	1.93	0.27 to 3.36	4.59	0.78 to 10.9	99.8	61.8 to 147.7	26.3	16.3 to 38.8
Juvenal liver	4	4.6	3.5 to 5.9	1.57	1.27 to 1.92	0.09	0.06 to 0.18	0.08	0.06 to 0.16	0.08	0.00 to 0.18	1.83	1.39 to 2.22	0.56	0.42 to 0.67
Adult liver	4	5.4	3.5 to 8.1	20.9	7.33 to 33.4	1.42	0.27 to 2.20	1.03	0.55 to 1.25	0.72	0.31 to 0.99	24.0	10.4 to 37.1	7.27	3.15 to 11.2
Juvenal brain	4	19.2	17.7 to 21.0	1.64	0.51 to 2.99	0.21	0.09 to 0.56	0.19	0.09 to 0.47	0.00	— —	1.77	0.59 to 3.02	0.37	0.12 to 0.63
Adult brain	4	22.4	20.4 to 24.0	22.6	8.32 to 29.0	1.41	0.31 to 2.40	1.10	0.60 to 1.57	0.85	0.32 to 1.60	25.9	11.6 to 33.7	5.39	2.42 to 7.02

[a] Estimated on the following assumptions: 74% water for eggs, 68% for chicks, 10% for fat, 74% for pectoral muscle, 70% for liver, and 79% for brain.

bulk of the summer food of this Yukon population is made up of migrant birds, only 10 to 15 per cent of the total consumed biomass consisting of resident species of prey. About half of the total weight of food consists of species that are primary or secondary carnivores, and about half consists of species that are herbivores or mixed herbivores and carnivores. All these points have a bearing on the pesticide–peregrine food chain hypothesis.

PESTICIDE RESIDUES IN YUKON PEREGRINES AND THEIR PREY

Table 3 summarizes the results obtained from residue analyses on 36 whole specimens of prey from the Yukon. Resident species averaged only a few tenths ppm of DDE, TDE (DDD), and DDT, and contained no measurable amounts of dieldrin or other chlorinated hydrocarbons. Migrant species of seed-eating birds (primary consumers) contained about the same quantities. Migrant insectivorous birds tended to run somewhat higher in DDE, TDE, and DDT than either migrant seed-eaters or residents, and several of them also contained dieldrin. Migrant sandpipers were rather high in DDE but were low in TDE and DDT; however, they all contained measurable amounts of dieldrin. Abdominal fat from two ducks (a Surf Scoter, *Melanitta perspicillata*, and a White-winged Scoter, *Melanitta deglandi*) averaged 1.36 ppm (dry weight) of DDE, 0.478 ppm of TDE, 0.304 ppm of DDT, and no dieldrin; while fat from two Mew Gulls (*Larus canus*) averaged 46.2 ppm of DDE, 2.13 ppm of TDE, 2.12 ppm of DDT, and 0.179 ppm of dieldrin.

All Peregrine materials and tissues contained measurable amounts of DDE, TDE, and DDT, sometimes in rather high concentrations, and most tissues also contained some dieldrin (table 4). No other chlorinated hydrocarbon residue was found. Whole eggs and chicks contained about 15 ppm (wet weight) of total residues, including dieldrin. These residues are about 10 to 100 times more concentrated in these eggs and chicks than they are in the prey species.

Adult tissues, especially fat, contained the highest concentrations of residues. Total residues for adult fat averaged 617 ppm (wet weight), mostly DDE. Pectoral muscle was the next highest, total residues averaging 26.3 ppm; liver and brain were about the same, 5.39 and 7.27 ppm, respectively. Using the muscle values as an approximation for the whole body, it appears that residues in adult Peregrine tissues are at least 100 times more concentrated than in the Alaskan prey of these falcons.

In general, the concentrations in any given tissue are 10 to 20 times higher in adults than in juveniles (4 to 6 weeks old); yet in only a few weeks of life, the juveniles appear to have acquired significantly higher concentrations of residues than commonly occur in their food species.

Holmes, Simmons, and Tatton (1967) have recently shown that another class of organochlorine pollutants—the polychlorobiphenyl compounds—give chromatograms that have peaks corresponding closely to those of TDE and DDT and thus can bias determinations of ppm for these compounds, unless they have been checked by alternate methods. Our samples were not checked for the presence of these compounds. The polychlorobiphenyls, widely used in industry as plasticizers and for other purposes, are themselves rated as highly toxic to man; and they are exhausted to the air in large volumes. One immediately wonders what effects these persistent compounds may have on wildlife and whether or not they act additively or synergistically with the organochlorine pesticides.

DISCUSSION

Our data show that even in so remote a region as interior Alaska, the Peregrine's food chain is contaminated with significant, measurable quantities of persistent residues of the chlorinated hydrocarbons, and they support the hypothesis—first developed in Great Britain (Moore and Ratcliffe 1962; Ratcliffe 1963)—that there is a biological concentration of these residues in the tissues of Peregrines. But how does one explain the association of high residue levels in these Peregrines with an undiminished population and unhampered reproduction? Either the hypothesis that the decline in Peregrine populations elsewhere has resulted from the organochlorine residues is incorrect, or else these Yukon Peregrines must be precariously poised near some threshold level that will prove inimical once reached.

Although there is some evidence suggesting that Peregrines can attain lethal levels of pesticide residues in nature (Ratcliffe 1965a, 1965b; Jefferies and Prestt 1966), most advocates of the pesticide–peregrine hypothesis have felt that the population decline was brought about—at least initially—by sublethal effects associated in some way with reproductive failure. A difficulty of this hypothesis has been that the exact mechanism of these sublethal effects is unknown, nor is there a clear-cut association between a given concentration of organochlorine residues and a particular kind of reproductive failure.

Most investigators have worked on the assumption that the effect on reproduction in birds must be a fairly direct one—causing infertility of eggs or abnormal embryonic development—and consequently quite a number of eggs of birds of prey have now been analyzed for pesticide residues. Even taking into account differences of technique and of methods of expressing results, the emerging picture is far from clear. Ratcliffe (1965a), reporting on a series of 15 British Peregrine eggs, found total residues ranging from 2.9 to 36.1 ppm (wet weight). Most of these eggs came from aeries that experienced some form of reproductive failure. On the other hand, our two eggs taken from a reproductively sound population give a value for total residues of 15 ppm, a figure near the average for the British eggs. Enderson and Berger (1968) found even higher values in eggs from Peregrines nesting in northwestern Canada in 1966. In contrast, Ames (1966), working with the obviously sick and reproductively failing population of Ospreys (*Pandion haliaetus*) along the Connecticut River, obtained much lower values of DDE, TDE, and DDT in eggs, with an average of only 6.5 ppm (wet weight). Even so, this average was about twice as high as the average for Osprey eggs from the Potomac, where reproduction was much better. Keith (1966) found especially high values, averaging 226.8 ppm (wet weight) of DDT and its metabolites, in nine eggs from a colony of Herring Gulls (*Larus argentatus*), which experienced low reproductive success on islands in Green Bay, Lake Michigan. Species differences, or even local population differences, in susceptibility to pesticide effects may be involved in some of these striking variances, although the levels in brain associated with death seem to be rather uniform among a variety of species (Stickel *et al.* 1966).

Ratcliffe's (1958, 1963, 1965a) perceptive observations on egg-eating and frequent abandonment of eggs or young by adult Peregrines during the decline in Great Britain suggest that the pesticide effect may be initially, if not primarily, on the reproductive physiology and behavior of the breeding adult falcons. He thought that because most of the chlorinated hydrocarbons are nerve poisons there might be a primary action on nervous mechanisms involved in reproductive behavior. Recent work by pharmacologists suggests an alternative mechanism that fits very well with these observed behavioral abnormalities.

Several groups of workers have shown that chlorinated hydrocarbons such as chlordane and DDT stimulate the induction of drug-metabolizing enzymes in the livers of laboratory mammals (Hart and Fouts 1965; Conney *et al.* 1967; Peakall 1967). These drug-metabolizing enzymes also hydroxylate steroid hormones such as progesterone, and hydroxylation of a steroid can interfere with its biological function.

Many of the sex steroids are known to be involved in the potentiation and maintenance of various forms of reproductive behavior, and they often have complex sequential and synergistic interactions on a given mode of behavior. Progesterone, for example, is known to act synergistically with prolactin, or alone, to maintain various modes of maternal behavior, such as broodiness (Riddle 1963; Lehrman 1963). Certainly the induction of an enzyme that can alter steroid structure offers the possibility of a powerful mechanism that could introduce abnormalities in behavior and physiology of the reproductive cycle at any point—from the initiation of courtship activities, through copulation, ovulation, incubation, and finally parental care of the young, depending on which hormones were affected.

Ratcliffe's (1967) recent demonstration of a significant decrease in egg-shell weight associated with the period of decline in the peregrine population of Britain adds cogency to this hypothesis. The decrease in shell weight (thickness?) is symptomatic of a disruption in the normal mobilization and metabolism of calcium during the period the shell is being laid down in the oviduct. Estrogen (estradiol), one of the hormones known to be affected by enzymes induced by chlorinated hydrocarbons, is intimately involved with the parathyroid hormone in the whole picture of what happens to calcium during the period of ovulation.

CONCLUSIONS AND SUMMARY

The Peregrine is one of the 50 species of rare and endangered birds currently listed in the "Red Book" of the U.S. Fish and Wildlife Service (Resource Publication 34, July 1966). It has experienced unprecedented reductions in breeding populations on two continents since World War II, and its continued existence in North America appears to be threatened to a greater extent than the more widely publicized case of the Bald Eagle (*Haliaeetus leucocephalus*). While we are much encouraged to be able to report that this Yukon population of Peregrines is still intact and reproducing at a normal rate, the widespread occurrence of pesticide residues at rather high levels in the eggs and tissues of these falcons allows us no sanguine feeling about their future. The sorry spectacle of what has happened to the Peregrines in Finland belies the easy notion that arctic and boreal populations are specially protected by the wilderness nature of their environment. These same falcons winter in regions grossly affected by human habitation.

If other associative evidence is a valid criterion—and we think it is—then these Alaskan falcons may be perilously balanced near the threshold level of organochlorine residues that initiates dysgenic reproductive behavior and eventual population decline. The Alaskan and Canadian falcons constitute the last substantial breeding populations of this species in North America, and as their fate may well depend on how these residues continue to accumulate, these northern Peregrines certainly should be watched closely over the next few years for evidence of reproductive malfunction coincident with continued, or increasingly, high levels of chlorinated hydrocarbons in their tissues.

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LITERATURE CITED

AMES, P. L. 1966. DDT residues in the eggs of the Osprey in the northeastern United States and their relation to nesting success. J. Appl. Ecol. 3 (Suppl.):87–97.

BISHOP, L. B. 1900. Annotated list of birds. *In* W. H. Osgood, Results of a biological reconnaissance of the Yukon River region. North Amer. Fauna no. 19.

BOND, R. M. 1946. The Peregrine population of western North America. Condor 48:101–116.

CADE, T. J. 1960. Ecology of the Peregrine and Gyrfalcon populations in Alaska. Univ. Calif. Publ. Zoöl. 63:151–290.

CONNEY, A. H., R. M. WELCH, R. KUNTZMAN, and J. J. BURNS. 1967. Effects of pesticides on drug and steroid metabolism. Clin. Pharm. Therapeutics 8:2–10.

ENDERSON, J. 1965. A breeding and migration survey of the Peregrine Falcon. Wilson Bull. 77:327–339.

ENDERSON, J., and D. BERGER. 1968. Chlorinated hydrocarbon residues in Peregrines and their prey species from northern Canada. Condor 70:149–153.

FERGUSON-LEES, I. J. 1951. The Peregrine population of Britain. Bird Notes 24:200–208; 309–314.

HAGAR, J. A. Peregrine Falcon population changes in Massachusetts. *In* J. J. Hickey, ed., Peregrine Falcon populations; their biology and decline. Madison, Univ. Wisconsin Press. In press.

HART, L. G., and J. R. FOUTS. 1965. Further studies on the stimulation of hepatic microsomal drug metabolizing enzymes by DDT and its analogs. Arch. Exper. Path. Pharmakol. 248:486–500.

HERBERT, R. A., and K. G. S. HERBERT. 1965. Behavior of Peregrine Falcons in the New York City region. Auk 82:62–94.

HICKEY, J. J. 1942. Eastern population of the Duck Hawk. Auk 59:176–204.

HICKEY, J. J. In press. Peregrine Falcon populations; their biology and decline. Madison, Univ. Wisconsin Press.

HOLMES, D. C., J. H. SIMMONS, and J. O'G. TATTON. 1967. Chlorinated hydrocarbons in British wildlife. Nature 216:227–229.

JEFFERIES, D. J., and I. PRESTT. 1966. Post-mortems of Peregrines and Lanners with particular reference to organochlorine residues. Brit. Birds 59:49-64

KEITH, J. A. 1966. Reproduction in a population of Herring Gulls (*Larus argentatus*) contaminated by DDT. J. Appl. Ecol. 3(Suppl.):57–70.

LEHRMAN, D. S. 1963. On the initiation of incubation behaviour in doves. Anim. Behav. 11:433–438.

MOORE, N. W., and D. A. RATCLIFFE. 1962. Chlorinated hydrocarbon residues in the egg of a Peregrine Falcon (*Falco peregrinus*) from Perthshire. Bird Study 9:242–244.

PEAKALL, D. B. 1967. Progress in experiments on the relation between pesticides and fertility. Atlantic Nat. 22(2):109–111.

RATCLIFFE, D. A. 1958. Broken eggs in Peregrine eyries. Brit. Birds 14:158.

RATCLIFFE, D. A. 1962. Breeding density in the Peregrine *Falco peregrinus* and Raven *Corvus corax*. Ibis 104:13–39.

RATCLIFFE, D. A. 1963. The status of the Peregrine in Great Britain. Bird Study 10:56–90.

RATCLIFFE, D. A. 1965a. The Peregrine situation in Great Britain 1963–64. Bird Study 12:66–82.

RATCLIFFE, D. A. 1965b. Organo-chlorine residues in some raptor and corvid eggs from northern Britain. Brit. Birds 58:65–81.

RATCLIFFE, D. A. 1967. Decrease in eggshell weight in certain birds of prey. Nature 215:208–210.

RIDDLE, O. 1963. Prolactin or progesterone as key to parental behavior: a review. Anim. Behav. 11: 419–432.

STICKEL, L. F., W. H. STICKEL, and R. CHRISTENSEN. 1966. Residues of DDT in brains and bodies of birds that died on dosage and in survivors. Science 151:1549–1551.

WHITE, C. M. In press. Breeding Alaskan and Arctic migrant populations of the Peregrine. *In* J. J. Hickey, ed., Peregrine Falcon populations; their biology and decline. Madison, Univ. Wisconsin Press.

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