PEREGRINES AND PESTICIDES IN ALASKA*

by

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INTRODUCTION

The peregrine falcon (Falco peregrinus) is a wide-ranging predator, formerly of nearly cosmopolitan distribution. Breeding populations still occur on every continent and on most of the larger islands of the world. The species is most common as a breeding bird in the Northern Hemisphere and reaches maximum densities in the north temperate maritime, subarctic, and low arctic latitudes.

Peregrines are well-known 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 (Hickey, 1942; Ferguson-Lees, 1951; Cade, 1960; Ratcliffe, 1962)--even in the face of extensive human modification and disruption of the environment. In Great Britain, where the species has been most intensively studied, until recently the breeding population of some 600 pairs appears 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.

Moreover, peregrine populations have shown remarkable recuperative powers in the face of deliberate decimation by man. During the period 1939 to 1944, peregrines nesting along the southern shores of England were systematically shot off their cliffs or trapped, and their eggs and young were destroyed in the nest, because these falcons reputedly interfered significantly with carrier pigeons in use by the military across the channel. Once the war was over, the peregrines very quickly began reoccupying their former nesting cliffs along these shores (Ferguson-Lees, 1951; Ratcliffe, 1962). In many parts of its worldwide range, observers have noted that adult falcons which are removed from their breeding sites are rapidly replaced by other adults, apparently from a "reservoir" of unmated individuals in the population. Thus, historically, peregrine populations have demonstrated a notable capacity to maintain stability of breeding pairs within a wide range of

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environments, over long periods of time, and under varying degrees of mortality, including systematic destruction by man.

Quite suddenly in recent years many of these once vigorous breeding populations, particularly in north temperate regions of intensive human occupance, began to show peculiar reproductive failures, followed after a time by disappearance of the adults from their nesting sites. This turn of events was so unexpected and so subtle in its initial manifestation that there was little chance to document the details of this unprecedented population decline as it was happening. Fortunately, a few people in widely scattered places had their eyes open, and at the Peregrine Conference held at the University of Wisconsin in 1965, the full extent of this 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 the Peregrine Conference show that the species has experienced simultaneous, catastrophic population declines over much of North America and Europe. The peregrine is now extinct as a breeding bird in the eastern United States from the Mississippi Valley right to the Atlantic Coast and from Alabama north at least to Nova Scotia, a region that used to contain about 300 nesting sites known to be more or less continually occupied by breeding peregrines. Herbert and Herbert (1965) have presented some details about one local population in this region, and other examples will be found in the published version of the Peregrine Conference. Peregrines have also virtually disappeared from an extensive breeding range in Ontario. Reductions have been reported in all regions west of the Mississippi River where any kind of recent study has been carried out (see, for example, 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. 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 strongly 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 quite clearly at the Peregrine Conference. These are: (1) reproductive malfunctions and population decline show a close temporal correspondence with the beginning of intensive 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, with some local exceptions that can probably be explained by heavy contamination of the falcons on their wintering grounds (the Finnish population, for example); (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 finally 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, inordinately high residue levels of chlorinated hydrocarbons have been found (Ratcliffe, 1965a and b; Jefferies and Prestt, 1966).

Alaska is the only state in the union where breeding peregrines are still common and apparently unaffected as yet by the widespread 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 biological concentration of persistent residues of chlorinated hydrocarbons in the peregrine's food-chain is the factor responsible for the population decline. If the Alaskan peregrines are just 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

White and Haugh used a 28-foot, flat-bottomed river boat, powered by a 50 hp outboard motor, for transportation during the field work. Four complete 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 by a "Tacro" tacrometer on U.S.G.S. maps with a scale of 1:63360. These trips were made between 10 June and 31 July 1966. The two earlier trips allowed the investigators to gather information at a time when there were downy young and/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 climbed to, 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 simply killed by collapsing their lungs.

Specimens were preserved in a 10% formalin solution made up from well water obtained at Eagle, Alaska. 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 into 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.

Several mammals were taken in snap traps and preserved in the same way as the birds. Fresh, intact items of food found in the aeries were also preserved.

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.

Appendix A presents all pertinent data obtained on the specimens in the field.

The pesticide residue analyses were carried out by the Wisconsin Alumni Research Foundation. Appendix B presents details of the procedures used, as well as the complete findings on each sample analyzed. Eighty-four separate analyses were performed.

RESULTS AND DISCUSSION

Distribution and density of breeding pairs. In 1966, 17 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 that there was about one pair every 10 miles, 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 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 (one outside the present area of consideration) 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 than they are at present.

It is instructive to compare the distribution of occupied cliffs listed in Table 1 with the total number of "suitable" nesting cliffs on this stretch of the Yukon. From our knowledge of the kinds of sites chosen for nesting by these peregrines, we judge there are at least 35 cliffs potentially available for nesting on this stretch of river. 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 probable that territorial aggression also is not a limiting factor, as suggested by Ratcliffe (1962) for the much denser British population prior to its decline.

The sector of river between cliffs numbered 17 and 27 was especially sparsely occupied, only three pairs in each year spread among 11 cliffs. It is unlikely that density of food species *per se* 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 3 eggs, and the number of young chicks ranges around 2.3 to 2.7 per aerie, indicating that about 1 or 2 eggs out of 10 are lost even among successful pairs (Cade, 1960). In 1966, the mean number of downy chicks and/or eggs 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 figure is based on an assessment made at a somewhat later stage of the breeding period than was the case in 1966.) The mean number of fledged or nearly fledged young per occupied cliff (includes successful and unsuccessful pairs) was 1.80, as compared with 1.05 in 1951, and 1.4 for 25 aeries along the Colville 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 over-all average figure of about 1 young fledged per occupied site. (See Table 2.)

The Yukon figure 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. Herbert and Herbert (1965) found an average of about 2.0 young per aerie along the Hudson River during the years 1941-1945; and Beebe (1960) judged that the population of F. p. pealei on Langara Island produces about 2 young per pair, although his observed average of 2.7 young per productive pair is no greater than for more northern populations and his surveys were carried out at a time when it was impossible to determine the number of unsuccessful pairs in the starting population. The reproductivity of the Yukon peregrines in 1966 also exceeds the two best years reported for 14 Massachusetts aeries between 1935 and 1942 (Hagar, in press).

Food of the Yukon peregrines. Three hundred and twenty-nine items of prey were found around the aeries in 1966, and these are compared in Table 3 with the 226 items found in 1951 (Cade, 1960). The data for the two years are quite similar in general outline and show that these peregrines sampled widely from the available avifauna, although certain types of birds were more prone to capture than others. A few mammals were also taken. Waterfowl constituted about 50 per cent of the diet by weight; pintails (Anas acuta), green-winged teal (Anas carolinensis), and shovelers (Spatula clypeata) were among the most frequently taken species. Shorebirds constituted 10 to 12 per cent of the food by weight; the common snipe (Capella gallinago), spotted sandpiper (Actitis macularia), and lesser yellowlegs (Totanus flaviceps) were most often caught. Small gulls made up about 10 to 15 per cent. Small land birds (Piciformes and Passeriformes) constituted 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 were hardest hit. Small mammals made up 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 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, of species that are herbivores or mixed herbivores and carnivores. All these points have an important bearing on the pesticide-peregrine food-chain hypothesis.

Pesticide residues in Yukon peregrines and their prey. Table 4 summarizes the results obtained from residue analyses on 36 whole specimens of prey from the Yukon. In general these results conform to expectation, although we were surprised to find measurable amounts of residues in resident species. Resident species averaged only a few tenths ppm (dry weight) of DDE, 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 sandpipers were rather high in DDE (several ppm dry weight) but were low in DDD and DDT; but they all contained measurable amounts of dieldrin. Migrant insectivorous birds tended to run somewhat higher in DDE, DDD, and DDT than either migrant seed-eaters or residents, and several of them also contained 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 DDD, 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 DDD, 2.12 ppm of DDT, and 0.179 ppm of dieldrin.

All peregrine materials and tissues contained measurable amounts of DDE, DDD, and DDT, sometimes in rather high concentrations, and most tissues also contained some dieldrin (Table 5). No other chlorinated hydrocarbon residue was found. Whole eggs and chicks contained tens of ppm (dry weight) of DDE, and several ppm each of DDD, DDT, and dieldrin. These residues were about 10 to 100 times more concentrated in these eggs and chicks than they were in the prey species.

Adult tissues, especially fat, contained the highest concentrations of residues. Total residues for adult fat averaged 679 ppm (dry weight), of which 622 ppm was DDE. Pectoral muscle was the next highest, total residues averaging 99.8 ppm dry weight (89.2 ppm DDE). Brain was third, 26.0 ppm total residues (22.6 ppm DDE); and liver was a close fourth, 24.1 ppm total residues (20.9 ppm DDE). It appears that residues in adult peregrine tissues run around 100 to 1000 times more concentrated than in the Alaskan prey of these falcons.

It is interesting to compare levels in the tissues of juveniles (4 to 6 weeks old) with levels in the same tissues of adults. In general, the levels for any given tissue were 10 to 20 times higher in adults than in juveniles; yet in only a few weeks of life, the juveniles appear to have achieved significantly higher levels of residues than commonly occur in their food species.

These 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 effects of pesticides 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 to suggest that peregrines can attain lethal levels of pesticide residues in nature (Ratcliffe, 1965; Jefferies and Prestt, 1966; see also, Stickel et al., 1966, for a comparison with experimentally induced lethal levels in several species), most advocates of the pesticide-peregrine hypothesis have felt that the population decline was brought about--at least initially--by sub-lethal effects associated in some way with reproductive failure. A difficulty of this hypothesis has been that the exact mechanism of these sub-lethal effects is unknown, nor is there a clear-cut association between a given level of pesticide 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 methods of expressing results, the emerging picture is far from clear. Ratcliffe (1965), reporting on a series of 15 British peregrine eggs, found total residues ranging from 5.5 ppm (wet weight) to 36.1 ppm. 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, when expressed on a comparable basis, give a value for total residues of about 14.3 ppm (wet weight) and fall near the average value of the British eggs. Enderson and Berger (unpublished manuscript) 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, DDD, 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) got really high values, averaging 226.8 ppm (wet weight) total residues, in 9 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; 1965) 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 suggested 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 workers have shown that chlorinated hydrocarbons such as chlordane and DDT stimulate the induction of drug-metabolizing enzymes in the livers of rats, mice, rabbits, guinea pigs, and squirrel monkeys (Hart *et al.*, 1963; Hart and Fouts, 1963; 1965; Fouts and Hart, 1965; Cram *et al.*, 1965; Kuntzman and Jacobsen, 1965; Conney *et al.*, 1966; Conney *et al.*, 1967). These drug-metabolizing enzymes also hydroxylate steroid hormones such as progesterone, and hydroxylation of a steroid can interfere with its biological function. (We are indebted to Dr. David Peakall for drawing our attention to this literature.)

Many of the steroid hormones (sex hormones) are known to be involved in the potentiation and maintenance of various forms of reproductive behavior, and they often have complex sequential and synergistic co-actions 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. The high DDE levels so characteristic of residues in peregrines and other top avian predators may indicate that the induced drug-metabolizing enzymes have been at work for a long time; if so, they may also be indicative of a high percentage of altered steroid hormone molecules. How many molecular abnormalities does it take to produce abnormal behavior? Work along these lines should be initiated on birds as soon as possible.

In conclusion, 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. If other associative evidence is a valid criterion--and we think it is--then these falcons must be perilously balanced near the threshold level of pesticide residues that initiates dysgenic reproductive behavior and eventual population decline. As their fate may well depend on how these residues continue to accumulate, these Yukon peregrines certainly should be watched closely over the next few years for evidence of reproductive malfunction coincident with continued, or increasingly, high levels of residues of the chlorinated hydrocarbons in their tissues.

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Table 2. Reproductivity of peregrines nesting along the Yukon River.

Number at aerie	Down chicks and/or eggs, 1966 only	Fledged or nearly fledged young 1951[+]	Fledged or nearly fledged young 1966[++]
0	2	7[+++]	3
1	1	6	3
2	3	4	4
3	1	2	4
4	6	0	1
Total	34	20	27
Mean of productive pairs	3.09	1.67	2.25
Mean per occupied cliff	2.72	1.05	1.80

[+] Revised from Cade (1960). [++] Figures include predation by investigators on eggs and young. [+++] Figure includes 3 cliffs where only single adults were found in 1951 but where pairs are known to have nested in other years.

Table 3. The prey of peregrines in the taiga zone of Alaska.

Species	Weight class in grams	1951+ No.	& Total	% Weight	1966 No.	% Total	% 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++	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++	-	-	-	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++	-	-	-	4	1.21	2.20
Hawk Owl	350	1	0.44	1.00	-	-	-
Boreal Owl	80	-	-	-	1	0.30	0.18
Yellow-shafted Flicker 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	-	-	-

Table 3. Continued.

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++	-	-	-	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
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

+Based on table 7 of Cade (1960).

Table 4. Summary of pesticide residues in Alaskan prey of peregrines.

Pesticide	Prey category	No.	ppm dry weight Mean	Range	ppm lipid weight Mean	Range
DDE	A	17	1.05	(0.269-3.94)	12.2	(2.48-41.8)
DDE	B	7	0.473	(0.069-1.48)	5.41	(0.677-14.3)
DDE	C	4	6.02	(1.94-10.5)	48.1	(7.71-129.0)
DDE	D	8	0.316	(0.066-0.987)	7.71	(0.825-35.1)
DDD	A	17	0.170	(0.051-0.323)	2.21	(0.480-5.33)
DDD	B	7	0.121	(0.062-0.281)	1.61	(0.308-3.67)
DDD	C	4	0.073	(0.059-0.095)	0.582	(0.210-0.900)
DDD	D	8	0.105	(0.066-0.147)	1.98	(0.770-4.01)
DDT	A	17	0.157	(0.051-0.323)	2.11	(0.357-6.15)
DDT	B	7	0.120	(0.062-0.281)	1.58	(0.332-3.67)
DDT	C	4	0.087	(0.070-0.130)	0.412	(0.136-0.972)
DDT	D	8	0.191	(0.066-0.740)	1.77	(0.408-4.18)
Dieldrin	A	17	0.010	(0.000-0.099)	0.067	(0.000-0.675)
Dieldrin	B	7	0.000	-	0.000	-
Dieldrin	C	4	0.112	(0.044-0.274)	0.965	(0.173-2.59)
Dieldrin	D	8	0.000	-	0.000	-

A - Migrant insectivorous passerines: 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.

B - Migrant seed-eating passerines: 2 slate-colored Juncos, 3 white-crowned sparrows, and 2 fox sparrows.

C - Migrant sandpipers: 3 spotted sandpipers and 1 lesser yellowlegs.

D - Resident boreal birds: 2 juvenile ruffed grouse, 5 gray jays, and 1 pine growbeak.

Table 5. Pesticide residue in the tissues of Alaskan peregrines.

Pesticide	Tissue analyzed	No.	ppm dry weight		ppm lipid weight	
			Mean	Range	Mean	Range
DDE	Eggs	2	48.0	(44.0-52.0)	330.0	(190.0-469.0)
DDE	Downy chicks	2	38.4	(28.8-48.5)	381.0	(372.0-391.0)
DDE	Juvenal fat	4	42.4	(17.5-56.3)	46.2	(19.6-59.8)
DDE	Adult fat	4	622.0	(176.0-914.0)	778.0	(186.0-1335.0)
DDE	Juvenal muscle	4	6.33	(0.836-14.6)	61.8	(11.5-125.0)
DDE	Adult muscle	4	89.2	(51.8-135.0)	513.0	(236.0-950.0)
DDE	Juvenal liver	4	1.57	(1.27-1.92)	33.6	(23.6-43.2)
DDE	Adult liver	4	20.9	(7.33-33.4)	415.0	(117.0-790.0)
DDE	Juvenal brain	4	1.64	(0.512-2.99)	8.52	(2.69-14.4)
DDE	Adult brain	4	22.6	(8.32-29.0)	103.0	(35.2-128.0)
DDD	Eggs	2	3.35	(0.408-6.29)	15.4	(3.68-27.2)
DDD	Downy chicks	2	3.65	(2.74-4.56)	41.5	(21.1-61.9)
DDD	Juvenal fat	4	1.29	(0.239-2.33)	1.45	(0.254-2.67)
DDD	Adult fat	4	25.4	(5.07-48.0)	28.5	(7.41-53.4)
DDD	Juvenal muscle	4	0.167	(0.066-0.464)	1.77	(0.465-3.95)
DDD	Adult muscle	4	4.04	(1.50-5.74)	20.5	(10.6-25.2)
DDD	Juvenal liver	4	0.090	(0.060-0.177)	2.15	(1.04-5.08)
DDD	Adult liver	4	1.42	(0.273-2.20)	26.4	(7.63-51.5)
DDD	Juvenal brain	4	0.212	(0.092-0.564)	1.07	(0.480-2.72)
DDD	Adult brain	4	1.41	(0.310-2.40)	6.36	(1.36-10.8)
DDT	Eggs	2	3.02	(1.02-5.02)	10.5	(9.20-11.7)
DDT	Downy chicks	2	2.41	(2.14-2.69)	24.8	(20.6-29.1)
DDT	Juvenal fat	4	1.24	(0.754-1.54)	1.36	(0.845-1.69)
DDT	Adult fat	4	25.3	(11.2-48.0)	29.1	(16.3-53.4)
DDT	Juvenal muscle	4	0.157	(0.066-0.397)	1.63	(0.465-3.38)
DDT	Adult muscle	4	1.93	(0.272-3.63)	4.85	(1.92-13.7)
DDT	Juvenal liver	4	0.085	(0.060-0.156)	1.99	(1.04-4.43)
DDT	Adult liver	4	1.03	(0.546-1.25)	20.0	(17.4-31.7)
DDT	Juvenal brain	4	0.189	(0.092-0.473)	0.956	(0.480-2.28)
DDT	Adult brain	4	1.10	(0.600-1.57)	4.88	(2.64-7.04)
Dieldrin	Eggs	2	2.75	(1.45-3.06)	16.9	(6.27-27.6)
Dieldrin	Downy chicks	2	0.861	(0.784-0.938)	9.36	(6.02-12.7)
Dieldrin	Juvenal fat	4	0.149	(0.046-0.385)	0.164	(0.048-0.423)
Dieldrin	Adult fat	4	6.20	(1.45-15.1)	7.37	(1.52-17.4)
Dieldrin	Juvenal muscle	4	0.051	(0.000-0.134)	0.525	(0.000-1.14)
Dieldrin	Adult muscle	4	4.59	(0.781-10.9)	28.1	(4.05-77.3)
Dieldrin	Juvenal liver	4	0.083	(0.000-0.184)	1.87	(0.000-4.14)
Dieldrin	Adult liver	4	0.720	(0.312-0.988)	13.5	(8.72-20.8)
Dieldrin	Juvenal brain	4	0.000	-	0.000	-
Dieldrin	Adult brain	4	0.850	(0.322-1.60)	5.49	(1.36-7.82)