CHLORINATED HYDROCARBON POLLUTANTS IN ALASKAN GYRFALCONS AND THEIR PREY

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ABSTRACT.—Analyses of biopsy fat samples and addled eggs of Gyrfalcons (*Falco rusticolus*) and selected prey items collected during 1970 and 1971 from the Seward Peninsula, Alaska show that all samples contained both industrial and agricultural contaminants. A pathway of aerial transport to this remote arctic ecosystem is indicated. Geometric mean levels of DDE, the principal insecticide derivative in both the eggs and fat of Gyrfalcons, are 20 ppm, lipid basis. PCB concentrations are 2–3 times higher, and are significantly correlated with DDE levels in both eggs and fat; the mean ratio of PCB/DDE is 3.0. A similar ratio was found in ptarmigan (*Lagopus* sp.), the principal prey species, indicating similar movement of these pollutants within this arctic food web. Resident arctic species utilized as prey contain low whole body residue levels, less than 0.5 ppm DDE, lipid basis. The calculated body content of pollutant residues in several Gyrfalcons indicates burdens could not result from resident prey alone but are attributed to the higher residue levels in migratory prey species. Whole body DDE residues were 5.0 ppm in Long-tailed Jaegers (*Stercorarias longicaudus*) and 50.0 ppm in Golden Plovers (*Pluvialis dominica*) and Whimbrels (*Numenius phaeopus*), lipid basis. No significant thinning of Gyrfalcon eggshells was found. Unlike some populations of other species of the genus *Falco* in North America, this population of Alaskan Gyrfalcons does not appear to be endangered by organochlorine contamination.—*Department of Biological Sciences, University of Alaska, Fairbanks, Alaska 99701. Present address: University of California, Bodega Marine Laboratory, Bodega Bay, California 94923.* Accepted 26 June 1975.

THE Gyrfalcon (*Falco rusticolus*) is a terminal avian carnivore inhabiting the tundra of the Northern Hemisphere. In North America populations of three closely related species, the Peregrine Falcon (*F. peregrinus*), Prairie Falcon (*F. mexicanus*), and Merlin (*F. columbarius*), have experienced reproductive failures (Fyfe et al. 1969, Enderson and Berger 1970, Cade et al. 1971, Fyfe et al. MS), and the Peregrine has disappeared from large continental areas (Hickey 1969). High levels of several industrial and agricultural contaminants, particularly the DDT metabolite p,p′-DDE, are associated with these reproductive failures (Cade et al. 1968, Enderson and Berger 1968, Fyfe et al. MS). The eggshells of populations of these three species and of another falcon, the American Kestrel (*F. sparverius*), have become thinner, and concentrations of DDE are significantly correlated with shell thickness in all four species (Enderson and Berger 1970, Ratcliffe 1970, Cade et al. 1971, Anderson and Hickey 1972, Lincer 1972). Large numbers of Prairie Falcon and Merlin eggs have become available; regression of shell thickness on DDE has shown that DDE accounts for most, if not all, of the increased variability of recent shell thickness (Fyfe et al. MS). These conclusions are supported by laboratory studies showing that dietary DDE produces thinner shells of kestrel eggs (Porter and Wiemeyer 1969, Wiemeyer and Porter 1970). In the present paper, a population of Gyrfalcons was examined for burdens of chlorinated contaminants including DDE, and for the shell thinning associated with lowered reproduction in other falcon populations.

MATERIALS AND METHODS

Biopsied fat was obtained from 10 adult breeding Gyrfalcons using the method described by Enderson and Berger (1968). The biopsy technique has the advantage of minimizing adverse effects upon the falcons, which resume normal behavior, including nest defense, immediately upon release. Biopsied fat was stored in clean glass jars until analysis. Addled or deserted eggs from seven nesting attempts provided

TABLE 1

DDE AND PCB IN GYRFALCON TISSUES AND PREY ITEMS[1]

	N	DDE means Arith.	DDE means Geom.	PCB means Arith.	PCB means Geom.	% water Mean (range)	% lipid Mean (range)
		(range)		(range)			
Gyrfalcon eggs	14	23	20	70	40	Not	3.96
		(3.9–53)		(6.6–200)		determined	(2.02–6.87)
Gyrfalcon biopsies							
Adult females	8	51	18	71	35	17.0	68.2
		(0.72–210)		(5.7–210)		(6.6–45.8)	(37.7–84.4)
Adult males	2	(5.6, 290)		(18, 48)		(23.8, 39.4)	(48.4, 44.5)
Subadult female	1	170		260		5.8	52.0
Immature male	1	36		7.1		10.0	80.6
Gyrfalcon prey							
Resident arctic							
Lagopus lagopus	6	0.47		0.84		68.2	1.85
L. mutus	6	0.08		0.24		70.5	2.04
Spermophilus undulatus	6	0.01		0.01		66.1	9.51
Migrant							
Stercorarius longicaudus	6	6.1		5.0		63.2	8.65
Pluvialis dominica	8	62		1.6		62.5	10.40
Asio flammeus	2	6.3		5.2		65.5	3.83
Numenius phaeopus	6	39		1.7		66.3	4.58
Turdus migratorius	5	4.8		4.2		67.2	4.80

[1] All values parts per million, lipid basis.

a sample of eleven 1970 and five 1971 eggs for analysis. Weight, length, and breadth measurements were taken on intact eggs; contents were stored frozen in clean glass jars, and shells were rinsed and left at room temperature for several months before eggshell weights were taken.

Gyrfalcon prey species were shot and frozen whole. Birds were completely plucked and feet and bills removed. Each individual was ground to form a whole-body homogenate in a blender. From several of these homogenates, equal wet weights were combined and rehomogenized to create a pooled sample for each species. Residues reported for prey species therefore represent arithmetic mean levels. Gyrfalcon eggs and fat samples were analyzed individually.

Details of procedures followed in extraction, cleanup, and chromatographic analyses have been reported elsewhere (Walker 1973). Polychlorinated biphenyl (PCB) residues found contained between 54% and 60% chlorine by weight. For uniformity, all PCBs were quantified by comparing the total areas of the first six peaks eluting after DDE on a QF-1 column to the corresponding peaks of a standard of Aroclor 1254 (Risebrough et al. 1970). In the majority of samples, DDT analogs were removed by saponification before PCB quantification (Anderson et al. 1969, Risebrough et al. 1969).

RESULTS AND DISCUSSION

Results of chlorinated hydrocarbon analyses are presented in Table 1. Both arithmetic and geometric means are given when samples were individually analyzed. Pollutant distributions among large samples of Prairie Falcon and Merlin eggs are right-skewed and often log-normal (Fyfe et al. MS); in distributions of this sort, the geometric mean more adequately describes central tendency. Gyrfalcon eggs were found to contain geometric means of 20 ppm DDE and 40 ppm PCB in the lipid. Fat from eight adult females contained geometric mean levels of 18 ppm DDE and 35 ppm PCB. These mean DDE levels are lower than levels reported for other North American falcons (Enderson and Berger 1968, Fyfe et al. MS). Comparable low DDE burdens in another sample of Gyrfalcon eggs from the Seward Peninsula have been reported (Cade et al. 1971). Two biopsy samples contained more than 200 ppm DDE, which is within the range of DDE contamination reported by Cade et al.

(1971) for Peregrines breeding in the Arctic. In some fat samples with high DDE levels, p,p′-DDD and p,p′-DDT were also present, but these were not seen above the limits of detection in eggs. DDE levels in fat were more variable (coefficient of variation = 130) than in eggs (coefficient of variation = 58). PCB and DDE levels were significantly correlated in both eggs (Spearman's rank correlation coefficient, $r_s = 0.70, P < 0.01, n = 14$) and fat ($r_s = 0.66, P < 0.05, n = 12$). The mean ratio of PCB to DDE was 3.0 in eggs, 3.0 for female fat, and 2.5 for all fat biopsies taken. A comparable PCB/DDE ratio was found by Risebrough et al. (1970) in biopsy fat from 10 immature peregrines migrating through Wisconsin. Trapped on their first flight south, these peregrines might reflect an arctic pattern of pollutant distribution.

Ptarmigan (*Lagopus* sp.) and arctic ground squirrels (*Spermophilus undulatus*) were found to contain levels of DDE and PCB less than 0.5 ppm lipid, and the ratio PCB:DDE in these resident arctic Gyrfalcon prey items was between 1.0 and 3.0. Rock Ptarmigan (*L. mutus*) analyzed from Amchitka Island, Alaska, also contained low burdens of PCB and DDE. Carcass homogenates had an average of 0.18 ppm PCB and 0.03 ppm DDE, lipid basis; these residue levels and the PCB:DDE ratio are similar to those of Rock Ptarmigan sampled from the Seward Peninsula in this study (White and Risebrough 1976). Considerable evidence indicates DDE and PCB are transported through the atmosphere (Risebrough et al. 1968, Risebrough and Berger 1971, Harvey et al. 1973, Bidleman and Olney 1974). The presence of these pollutants in ptarmigan and ground squirrels further supports this hypothesis; both species are arctic animals inhabiting a terrestrial ecosystem away from ocean currents and point sources of contamination; atmospheric fallout is the only plausible input source.

Migratory bird prey items contained much higher levels of both PCB and DDE than arctic residents, with lower PCB:DDE ratios ranging between 0.03 and 0.86 for five species examined. American Golden Plovers (*Pluvialis dominica*) were the most contaminated species observed, with an arithmetic mean DDE concentration of 62 ppm lipid basis. Cade et al. (1968) also found that among prey items of peregrines nesting along the Yukon River, Alaska, migrants were more highly contaminated with DDE than resident species.

On the Seward Peninsula Roseneau (1972) investigated the summer diet of Gyrfalcons and recorded 31 avian and 8 mammalian species in it. In the total of 1,483 kills identified in 1968–70, over 70% by weight were ptarmigan and 82% were arctic residents. The Peregrine, in contrast, consumes a greater variety of prey species (Cade 1960, White and Cade 1971). During the winter the number of species available as prey is strikingly reduced. Christmas bird counts made in the vicinity of Nome, Alaska yielded only three species in 1970: Willow Ptarmigan (*Lagopus lagopus*), Common Raven (*Corvus corax*), and McKay's Bunting (*Plectrophenax hyperboreus*) (1971, Amer. Birds 25: 160). Of the mammals identified as prey species, the most important is the arctic ground squirrel, but this species hibernates from October to early May. Lemmings (*Dicrostonyx groenlandicus*) might rarely be available during winter. The red-backed vole (*Clethrionomys rutilus*) and other microtine rodents stay beneath the snow cover in winter (Bee and Hall 1956). The population of Gyrfalcons on the Seward Peninsula is therefore limited essentially to preying upon ptarmigan for most of the year.

It may be assumed that residues found in Gyrfalcons result in part from trophic concentration within arctic food webs of pollutants entering the arctic ecosystem via fallout, after aerial transport from the sources of contamination. In addition, migrant birds are a direct pathway for contaminants to enter the Arctic from more polluted areas and, to the extent they are preyed upon, constitute a source of contamination for Gyrfalcons.

The pollutant burdens found in some Gyrfalcons are surprisingly high. If it is assumed that Gyrfalcons contain 5% fat and weigh 1500 g, whole body burdens corresponding to contaminant levels of 1.0 ppm, 20 ppm, and 200 ppm lipid would be 75, 1500, and 15000 μg respectively. If prey species also contain 5% fat and a Gyrfalcon consumes 200 g of food daily, a daily ration of ptarmigan with 0.20 ppm DDE contamination contains only 2 μg DDE. At an input rate of 2 μg DDE per day, a Gyrfalcon would acquire 700 μg in a year, assuming total assimilation and no loss. The lowest observed levels of DDE in Gyrfalcons, therefore, can be accounted for from a diet of ptarmigan alone, while the observed mean level DDE could be reached in about 2 years. To reach the highest observed levels at this input rate would take 20 years. Clearly there must be another dietary source. Long-tailed Jaegers (*Stercorarius longicaudus*) weigh about 150 g and contain about 45 μg DDE each. Six jaegers eaten during the summer would account for 270 μg of DDE. Golden Plovers weigh about 100 g and contain 300 μg of DDE each, about 300 times more DDE than an equivalent weight of ptarmigan. Eating only 3 plovers during the summer, therefore, would expose a Gyrfalcon to more DDE than a year's feeding upon ptarmigan. A year's diet containing 30 plovers would result in an exposure to 9000 μg DDE; assuming total assimilation, less than 2 years would be required to reach the highest levels observed in Gyrfalcon fat, while 50 plovers would contain approximately the estimated body burden of the most contaminated Gyrfalcon observed. It is not unreasonable to expect that some Gyrfalcons consume 50 plovers during a single summer. The accumulation of high levels of DDE by some Gyrfalcons is probably only explained by the consumption of highly contaminated migratory birds.

Measurements of pre-1945 Gyrfalcon eggshells in the museum of the Western Foundation of Vertebrate Zoology provide a base with which recent shells may be compared (Swartz MS). These museum shells have an arithmetic mean thickness index (Ratcliffe 1967) of 2.27 (n = 183, variance = 0.02887). Eggshells collected during 1970 and 1971 in the course of this study had an arithmetic mean of 2.18 (n = 14, variance = 0.05116) that did not differ significantly (Student's t-test, $P > 0.05$) from the pre-1945 mean. Cade et al. (1971) reported on 12 Gyrfalcon eggshells collected from the same area during 1968 and 1969. Combining all data, the recent eggshell sample has an arithmetic mean thickness index of 2.21 (n = 26, variance = 0.03992), which also does not differ significantly (t-test, $P > 0.1$) from the pre-1945 sample.

In northern Alaska, the Gyrfalcons along the Colville River system have been studied since the 1950's and have shown no decrease in numbers, in contrast to declining numbers of Peregrines in the same area (White and Cade 1971). Data on Gyrfalcon numbers and productivity from the Seward Peninsula during the 5 years 1968–72 show yearly changes, but no downward trends or decreased production has been observed (Swartz et al. 1973). This Gyrfalcon population is not presently endangered by the events that seriously threaten other North American falcon species.

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