

DDE DECREASES IN PLASMA OF SPRING MIGRANT PEREGRINE FALCONS, 1978-94

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Abstract: Mean *p,p'*-DDE (DDE) residues in plasma of combined adult and subadult female peregrine falcons (*Falco peregrinus*) decreased significantly in spring migrants captured at Padre Island, Texas, between 1978 and 1979 (1.00 µg/g wet wt), 1980 (0.57), 1984 (0.50), and 1994 (0.34). No other organochlorine pesticides were detected (detection limit, 0.02 µg/g) in 1994. Mirex, oxychlorodane, dieldrin, heptachlor epoxide, and the parent material DDT were routinely found in plasma samples in earlier years. Polychlorinated biphenyls (PCBs) were found in 75% of the adult females in 1994, but PCB data collected in 1984 were not comparable. The decrease in organochlorine pesticide residues was associated with peregrine population increases in the Arctic and elsewhere in North America. The arctic peregrine (*F. p. tundrius*) was removed from the list of Threatened and Endangered Species by the U.S. Fish and Wildlife Service in 1994. Satellite telemetry and plasma sampling provide new insight into continuing sources of DDE and PCBs. Chemicals that replaced organochlorine pesticides require additional investigation in North and South America.

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Key words: DDE, endangered species, *Falco peregrinus*, PCBs, peregrine falcon, satellite telemetry, Texas, toxicology.

Peregrine falcons have suffered population declines in much of the northern hemisphere (Hickey 1969, Ratcliffe 1980). These declines coincided with the use of DDT and resultant decreases in eggshell thickness. In North America the status of the highly migrant northern breeding populations was the least understood. We first captured fall-migrant peregrines and collected blood samples in 1976 (Henny et al. 1982). The blood plasma was analyzed for organochlorine pesticides. Earlier work with humans and birds showed that DDE residues in blood plasma were correlated with exposure and body burden (Henny and Meeker 1981). The blood-sampling approach seemed especially suitable for endangered species research because it is nondestructive. Furthermore, blood sampling in Texas is relatively inexpensive compared to investigations in remote arctic regions where nesting birds are at low density. Our approach complements the few detailed arctic investigations (e.g. Burnham and Mattox 1984, Ambrose et al. 1988, Court et al. 1989). While studies from small nesting areas may not be representative, migrants captured at Padre Island represent broad geographical regions (breeding birds from Alaska to Greenland and wintering birds from throughout Latin America) (Yates et al. 1988).

We include here residue concentrations from spring migrant peregrines captured and sampled along coastal Texas in 1978-79, 1980, 1984, and 1994. Long-term residue trends are discussed and evaluated. Also, we placed satellite transmitters on 7 adult female peregrines in the spring of 1994 to determine nesting locations and subsequently wintering localities. Thus, contaminant burdens (from blood plasma) may be evaluated in relation to where individuals nest and winter. This phase of our program is in early development.

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STUDY AREA AND METHODS

A spring concentration of migrating peregrines was first discovered at Padre Island, Texas, in April 1978 by F.P. Ward (Hunt and Ward 1988, Henny et al. 1988). Padre Island peregrine habitat was described by Hunt and Ward (1988). Only 4 birds were captured in 1978, but techniques were improved, and 25 were captured in 1979 and 82 in 1980.

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In 1994 we collected blood from the brachial vein as described by Henny et al. (1982). The plasma samples were homogenized with anhydrous sodium sulfate and extracted with hexane in a soxhlet apparatus for 7 hours. To minimize background interferences, we ignited the sodium sulfate at 675 C for 3 hours and rinsed all glassware with 15% ethyl ether in hexane. For each set of 20 samples, a procedural blank of sodium sulfate was run through the entire analytical process. The extracts of all samples were cleaned up on a partially deactivated Florisil column (Cromartie et al. 1975). Pesticides and PCBs were separated on a silica gel column into 4 fractions (Kaiser et al. 1980). We quantified residues using a gas chromatograph equipped with an electron capture detector and a DB-1701 capillary column. Ten percent of all samples with identifiable residues were confirmed by GC/MS.

PCBs were estimated and DDE, *p,p'*-DDD (DDD), *p,p'*-DDT (DDT), dieldrin, heptachlor epoxide, oxychlorane, *trans*-chlordane, *cis*-chlordane, *trans*-nonachlor, *cis*-nonachlor, endrin, toxaphene, hexachlorobenzene, mirex, hexachlorocyclohexane (alpha, beta, and gamma isomers), *o,p'*-DDE, *o,p'*-DDD and *o,p'*-DDT concentrations were determined in 1994. The latter 4 were not evaluated in 1984 or earlier, and PCBs were not quantified before 1984. Henny et al. (1982, 1988) present all organochlorines detected in earlier years, but only those occurring in at least 10% of the samples for any age/year are summarized here. The lower limit for reportable residues for pesticides was 0.01 for pesticides and 0.05 $\mu\text{g/g}$ for PCBs in 1994; however, for data analysis (comparing yrs) we used 0.02 and 0.10 $\mu\text{g/g}$, respectively, to be comparable to the earlier datasets. The few sample nondetections were assigned 1/2 of the detection limit for DDE.

Seven peregrine falcons captured for the study were tracked by satellites via the Argos/Tyros system (Taillade 1992, Fancy et al. 1988). Each peregrine was equipped with a Platform Transmitter Terminal (PTT, Microwave Telemetry Inc., Columbia, Md.). The PTT, model 100, weighed 28 g and was designed for 12 months of operation. The PTTs were attached in a backpack configuration using 1/4 inch teflon ribbon. The PTT was centrally located on the peregrines back and held in place by a breast loop and a body loop (behind the wings, around the abdomen) (Fuller et al. 1995). The PTTs were

Table 1. DDE residues ($\mu\text{g/g}$, wet wt) in blood plasma of female peregrine falcons captured in the spring at Padre Island, Texas, 1978-94.

Age ^a	Year	n	Geometric mean DDE ($\mu\text{g/g}$)	High DDE ($\mu\text{g/g}$)
SY	1978-79	8	1.43	6.3
SY	1980	19	0.42	3.0
SY	1984	16	0.43	2.9
SY	1994	25	0.25	1.4
ASY	1978-79	21	0.88	3.8
ASY	1980	63	0.62	3.1
ASY	1984	27	0.55	4.3
ASY	1994	45	0.41	2.4

^a SY = second year; ASY = after second year.

individually fitted to allow for all natural movement. In addition to the PTT each peregrine received a U.S. Fish and Wildlife Service band attached to the tarsus. The processing of each falcon required about 1 hour and the birds were released in the exact location they were captured.

Statistical analyses were limited to females, since few males were captured. We used 2-factor Analysis of Variance (ANOVA) with age (ASY and SY) and year (1978-79, 1980, 1984, 1994) as factors to evaluate the log-values of DDE residues. Differences found in the ANOVA were quantified with the Tukey comparison procedure (SAS 1994). If a contaminant did not occur above the detection limit in at least 75% of the samples for an age class, Fisher's Exact test was used to compare occurrence during the years 1978-79, 1980, 1984 and 1994. We used the significance level of $P \leq 0.05$ for rejection of the null hypothesis.

RESULTS AND DISCUSSION

Trends in DDE Contamination in Spring Migrants

Based on residues in blood samples from 433 peregrines captured in fall and spring (1976-80), Henny et al. (1982) concluded that much of the pesticide burden, primarily DDE, in the strongly migratory population sampled was accumulated on wintering grounds in Latin America. Also, DDE declined significantly from 1978-79 to 1980 in first-time migrants returning from Latin America. In 1976-79, hatch-year peregrines were the dominant age class (about 85% captured and bled during fall migration. They were only a few months old and contained low

Table 2. Organochlorine pesticides (excluding DDE) and polychlorinated biphenyls (PCBs) in blood plasma of female peregrine falcons captured in the spring at Padre Island, Texas, 1978-94.

Age ^b /Year	n	No. with detectable residues (% occurrence) ^a						PCBs
		DDT ^c	DDD	Heptachlor epoxide	Dieldrin	Oxychlorthane	Mirex	
SY 1978-79	8	2 (25%)	0	4 (50%)	4 (50%)	0	0	NA ^d
SY 1980	19	0	0	12 (63%)	9 (47%)	0	1 (5%)	NA ^d
SY 1984	16	0	0	7 (44%)	9 (56%)	1 (6%)	1 (6%)	NA ^d
SY 1994	25	0	0	0	0	0	0	12 (48%)
Fisher's test (P)		0.012	no test	<0.0001	<0.0001	NS ^f	NS ^f	no test
ASY 1978-79	21	4 (19%)	2 (10%)	6 (29%)	9 (43%)	2 (10%)	4 (19%)	NA ^d
ASY 1980	63	1 (2%)	0	28 (44%)	37 (59%)	11 (17%)	18 (29%)	NA ^d
ASY 1984	27	1 (4%)	1 (4%)	9 (33%)	15 (56%)	4 (15%)	7 (26%)	NA ^d
ASY 1994	45	0	0	0	0	0	0	34 (76%)
Fisher's test (P)		0.003	0.016	<0.0001	<0.0001	0.008	0.0001	no test

^a Number of samples with ≥ 0.02 $\mu\text{g/g}$ wet wt, except PCBs (see methods). Fisher's Exact test used to determine whether differences in occurrence among year (test made for each age class separately).

^b SY = second year; ASY = after second year.

^c High value each contaminant ($\mu\text{g/g}$): DDT 0.44, DDD 0.28, Heptachlor Epoxide 1.40, Dieldrin 0.65, Oxychlorthane 0.13, Mirex 0.17, PCB 4.52.

^d NA = not analyzed.

^e Data not directly comparable to 1994 (see text).

^f NS = not significant.

organochlorine residues. Therefore, to evaluate trends in residue concentrations during the 1980s and 1990s, we concentrated our effort in the spring when all birds captured (second yr [SY], known to have hatched in the calendar year preceding the year of capture, and after second yr [ASY]) would contain residues of interest. Caution is required when interpreting plasma residues, which may be inflated for birds with severe weight loss. However, poor body condition was not encountered with spring migrants.

DDE is the primary metabolite of DDT and was detected (≥ 0.02 $\mu\text{g/g}$, wet wt) in plasma from 67 of 68 SY females and 154 of 156 ASY females between 1978 and 1994 (Table 1). The 2-factor ANOVA showed that geometric mean DDE values varied among years ($F = 9.18$, $P = 0.0001$), but showed no difference between age classes ($F = 0.93$, $P = 0.34$), and no interaction ($F = 1.39$, $P = 0.25$). Tukey comparisons among years indicated that mean DDE concentrations in $\mu\text{g/g}$ wet weight (SYs and ASYs combined) decreased significantly (1978-79, 1.00 A; 1980, 0.57 B; 1984, 0.50 BC; 1994, 0.34 C). Years sharing a letter are not significantly different.

The highest DDE concentration in 1984 (4.3 $\mu\text{g/g}$) in an ASY female was accompanied by the only occurrence of parent DDT plus DDD (14% of DDTr [DDT and metabolites] was DDT and DDD). This residue profile suggests that some birds in 1984 were exposed to recently-applied DDT despite the general downward trend in DDE. No DDT or DDD were detected in samples collected in 1994. The decrease in DDE concentrations for ASY females, the largest dataset, was 25% between 1984 and 1994. DDE in SY females, returning north from Latin America for their first time, decreased 42% between 1984 and 1994.

Other Pesticides

In addition to DDT and its metabolites, the 1994 plasma samples were tested for 13 other organochlorine pesticides or metabolites. None of these pesticides or metabolites was detected in 1994. Those contaminants with comparable data throughout the study are shown in Table 2. DDT, DDD, heptachlor epoxide, dieldrin, oxychlorthane, and mirex, which were frequently encountered in the late 1970s and early 1980s, generally decreased over time and were no longer detected in 1994.

This information implies a change in pesticide use from persistent organochlorines to less

Therefore, to evaluate conditions during the 1980s, we conducted our effort in the captured (second yr [SY], first yr in the calendar year) birds, and after second year, residues of interest. In interpreting plasma concentrations inflated for birds with poor, poor body condition with spring migrants. The metabolite of DDT and DDE ($\mu\text{g/g}$, wet wt) in plasma samples and 154 of 156 ASYs and 1994 (Table 1). The mean that geometric mean values for years ($F = 9.18$, $P < 0.05$) no difference between years ($F = 0.34$), and no interaction ($F = 0.5$). Tukey comparisons showed no difference at mean DDE concentration (SYs and ASYs combined) (1978-79, 1.00 $\mu\text{g/g}$; 1984, 0.34 $\mu\text{g/g}$; 1994, 0.34 $\mu\text{g/g}$). Years were significantly different ($F = 4.3$). The concentration in 1984 (4.3 $\mu\text{g/g}$) was accompanied by parent DDT plus DDD metabolites] was DDT. The profile suggests that birds were exposed to recently-arrived general downward trend or DDD were detected in 1994. The decrease in DDE in ASY females, the largest decrease between 1984 and 1994. Migrating north from Latin America, decreased 42% be-

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Table 3. Nesting and wintering localities and contaminant concentrations ($\mu\text{g/g}$ wet wt) for adult female peregrine falcons captured in April-May 1994 at Padre Island, Texas.

PTT number	Date captured	Blood plasma		Nesting area	Wintering area
		DDE	PCBs		
5696	21 Apr	0.79	0.76	SW Greenland	^a
5695	22 Apr	0.55	<0.05	Upper Yukon River, AK	No. Argentina
5699	24 Apr	0.35	0.72	NWT, Canada	^a
5697	30 Apr	0.97	1.79	300 km N. Rankin Inlet, NWT, Canada	Cuba
5738	03 May	0.42	<0.05	W. Greenland	^a
5709	04 May	0.99	2.39	King William Is., NWT, Canada	Yucatan, Mexico
5707	05 May	0.13	<0.05	W. Baffin Island, Canada	Panama

^a Signal stopped during summer 1994.

persistent, but in some cases more toxic, organophosphorus and carbamate insecticides (Basili et al. 1994). These less persistent chemical groups of pesticides have killed raptors in the United States, Canada, and elsewhere (e.g., Henny et al. 1985, 1987; Wiemeyer 1991; Mineau 1993; Franson et al. 1995, Woodbridge et al. 1995, Dietrich et al. 1995, Franson et al. 1996). Studies by Franson and colleagues documented 139 bald eagles (*Haliaeetus leucocephalus*) and golden eagles (*Aquila chrysaetos*) killed by organophosphorus and carbamate pesticides in 25 states plus 19 red-tailed hawks (*Buteo jamaicensis*). The procedures used in this migration study do not detect these non-persistent pesticides, which could affect raptor populations by direct mortality soon after pesticide application. Peregrines capture live birds in flight and may not be especially vulnerable to these pesticides, but insectivorous (especially flocking species) and other raptors associated with agricultural lands may become vulnerable by feeding on exposed sick and dead insects and vertebrates. A meaningful evaluation of these chemicals cannot be accomplished during migration, but requires studies at spray sites at the time of pesticide application and necropsies of birds found dead, including assays of brain cholinesterase. Field evaluations of the alternative pesticides now used in Latin America, where much of the DDE accumulated in the late 1970s and early 1980s (Henny et al. 1982), seem prudent. We also need additional investigations of raptor exposure to anticholinesterase compounds in North America.

Polychlorinated Biphenyls

PCBs were not quantified before the 1984 collections, therefore, only 1984 could be compared with 1994 (Table 2). The occurrence of PCBs appeared to increase for both SYs and ASYs from 1984 to 1994. Also, PCB detections in 1994 showed generally higher concentrations than reported in 1984. In an attempt to determine if changes in analytical procedures (both estimated on the basis of Aroclor 1260) were responsible for the reported increase, we analyzed 23 plasma samples in 1995 that were collected from ASY female peregrines in the spring of 1985. These plasma samples were stored frozen for almost 10 years. Fifteen of the 23 (65%) from 1985 contained PCBs ($\geq 0.10 \mu\text{g/g}$), which does not differ ($P = 0.402$) from the 76% positive for PCBs in 1994. Thus, we believe analytical problems with our 1984 PCB analyses precludes direct comparisons with the 1994 data. The distribution of PCBs in plasma differs from DDE. Almost all peregrine samples collected in 1994 contained DDE residues, but PCBs were found in only 76% of the ASYs and 48% of the SYs. The occurrence of PCBs undoubtedly reflects the diet of individual peregrines (e.g., waterbirds vs. no waterbirds) and perhaps association with industrial regions or prey from industrial regions.

Nesting and Wintering Localities of Satellite-equipped Peregrines

The 7 ASY females captured and equipped with satellite transmitters on Padre Island be-

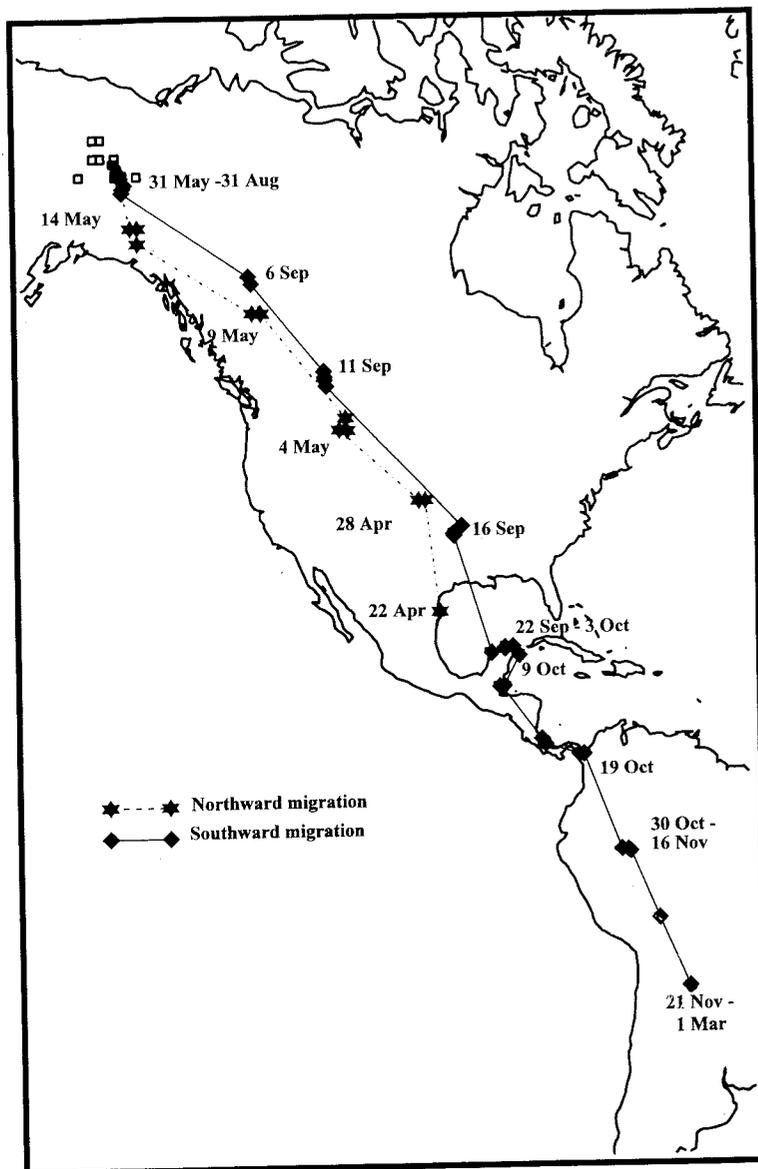


Fig. 1. The northward and southward migration of ASY female peregrine falcon (PTT 5695) captured 22 April 1994 at Padre Island, Texas. The open squares are locations during the summer.

tween 21 April and 5 May 1994 had geometric mean DDE concentrations in their plasma similar to that for all ASY females captured in 1994 (0.50 vs. 0.41 $\mu\text{g/g}$). As expected, this sample of peregrines nested across the Arctic from Alaska to Greenland (Table 3). The movements of 2 ASY females are shown in Figures 1 and 2. The sample size remains quite small to discern patterns, but the 2 birds wintering in the Caribbean

Basin (Cuba and Yucatan, Mexico) had the highest DDE and PCB concentrations. Additional information is needed for a complete evaluation. Residue concentrations in individuals were quite variable, and in spite of the general decrease in concentrations, some individuals continue to remain contaminated. We believe satellite telemetry can help us understand sources of the DDE and PCBs that continue to persist

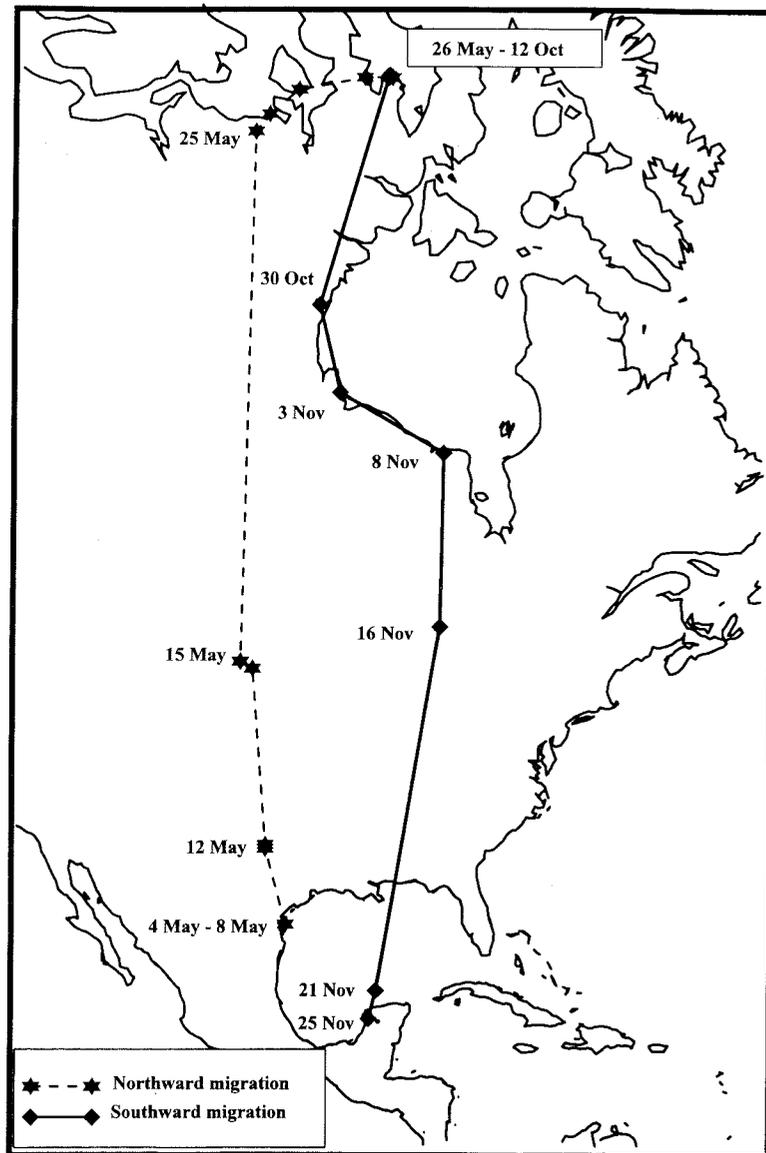


Fig. 2. The northward and southward migration of ASY female peregrine falcon (PTT 5709) captured 4 May 1994 at Padre Island, Texas.

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in segments of the peregrine population. Howey (1992) provides details for tracking birds by satellite. We are in the early stage of developing a procedure to rapidly analyze plasma for organochlorine pesticides and PCBs in the field while the peregrine remains in captivity. Then, individuals can be selected for satellite transmitters based on plasma contaminant burdens. This approach provides a cost effective use of

satellite transmitters for determining contaminant sources in the future.

Status of Peregrine Populations in the Arctic

Arctic peregrine populations increased dramatically during the last decade based on both localized counts of breeding pairs at study areas and systematic counts at migration sites farther

south (e.g., Ambrose et al. 1988, Ward et al. 1988). We recognized that DDE concentrations in 1984 were below levels known to adversely affect the arctic population's productivity, although a few individuals probably had reproductive problems (Henny et al. 1988). Certainly, fewer birds are affected now.

The decrease of organochlorine pesticides is encouraging because burdens in this long-distance migrant reflect the condition of the environment in both North and South America. The relative contribution of Latin America versus North America to the overall reduced accumulation of DDE in the peregrines studied cannot be easily estimated from adult females sampled because: (1) adult females lose a portion of their total body burden of DDE during summer egg laying (Bogan and Newton 1977), and (2) many summer avian prey species of peregrines in the Arctic, winter in Latin America. These migrant prey may accumulate DDE in Latin America during the winter, which would contribute to peregrine DDE accumulation in North America during summer months confounding analyses of relative contribution. Residue data from SY females in spring is less confounded. DDE decreased over the years in plasma of SY female peregrines sampled near the Mexico border in the spring (when 9–10 months old) (Table 1). These peregrines arrived in Latin America (mostly from the Arctic) the previous fall (when 3–4 months old) with extremely low (0.03 to 0.05 $\mu\text{g/g}$) DDE concentrations (Henny et al. 1982). The above pattern provided evidence that DDE accumulation in Latin America during winter was reduced between 1978 and 1994.

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